PO-PSO-CO & SYLLABUS of VARIOUS PROGRAMS

17	**INTEGRATED Ph.D. (DOUBLE DEGREE) - LIFE SCIENCES**	
18	**INTEGRATED Ph.D. (DOUBLE DEGREE) - MATHEMATICAL SCIENCES**	
19	**INTEGRATED Ph.D. (DOUBLE DEGREE) – PHYSICAL SCIENCES**	
20	**DMRIT**	
21	**M.Sc. (PHYSICAL SCIENCES)**	
22	**M.D.**	
23	**D.M.**	
24	**M.Ch.**	
25	**Dip. R. P.**	
26	**INTEGRATED M.Sc. (CHEMICAL SCIENCES)**	
27	**INTEGRATED M.Sc. (LIFE SCIENCES)**	
28	**INTEGRATED M.Sc. (MATHEMATICAL SCIENCES)**	
29	**INTEGRATED M.Sc. (PHYSICAL SCIENCES)**	
30	**M.Sc. (NURSING)**	
31	**PGDFIT**	
32	**M.Sc. (CLINICAL RESEARCH)**	
33	**INTEGRATED Ph.D. (SINGLE DEGREE) - ENGINEERING SCIENCES**	

BACK TO MAIN

PGD IN CHEMICAL SCIENCE (PROGRAM CODE: CHEM00)

Program Code : CHEM00	Programme Outcome	Building strong foundation in areas of chemical and nuclear sciences
		Prepare young chemists for pursuing research in frontier areas of chemical and nuclear sciences
		Train the manpower for DAE in chemical aspects in nuclear science and technology
		Prepare the manpower for societal and strategic areas of DAE

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**
2. **IGCAR**
    - **SYLLABUS**
    - **PSO-CO**

PGD IN ENGINEERING SCIENCE (PROGRAM CODE: ENGG00)

Program Code : ENGG00	Programme Outcome	To provide DAE with a manpower trained in the nuances of Nuclear Science & Technology
		Building strong foundation in the area of engineering and nuclear sciences
		Expose the young students to state-of-the art experimental techniques and development of experimental facilities
		Teach fundamental aspects pertaining to latest developments in the field of engineering and nuclear sciences
		Understanding the role of engineering sciences in DAE programmes
		Understating the role of engineering sciences in societal and strategic programmes

1. **BARC**
   - **SYLLABUS**
   - **PSO-CO**
2. **BARC - AMD GEOLOGY & GEOPHYSICS**
   - **SYLLABUS**
   - **PSO-CO**
3. **BARC - NFC**
   - **SYLLABUS**
   - **PSO-CO**
4. **IGCAR**
   - **SYLLABUS**
   - **PSO-CO**
5. **RRCAT**
   - **SYLLABUS**
   - **PSO-CO**

PGD IN LIFE SCIENCE (PROGRAM CODE: LIFE00)

Program Code : LIFE00	Programme Outcome	To provide DAE with a manpower trained in the nuances of Nuclear Science & Technology in Life Sciences
		Building strong foundation in the area of Life and nuclear sciences
		Expose the young students to state-of-the art experimental techniques
		Teach fundamental aspects pertaining to latest developments in the field of Life and nuclear sciences
		Understanding the role of Life Science in DAE programmes
		Understanding the role of biology in societal and strategic programmes

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

PGD IN PHYSICAL SCIENCE (PROGRAM CODE: PHYS00)

Program Code : PHYS00	Programme Outcome	To provide DAE with a manpower trained in the nuances of Nuclear Science & Technology in Physical Sciences
		Building strong foundation in the area of physical and nuclear sciences
		Expose the young students to state-of-the art experimental techniques
		Teach fundamental aspects pertaining to latest developments in the field of physical and nuclear sciences
		Understanding the role of physics in DAE programmes
		Understanding the role of physics in societal and strategic programmes

BACK TO MAIN

M.Tech.
(PROGRAM CODE: ENGG01)

Program Code : ENGG01	Programme Outcome	Advanced knowledge in engineering science with required knowledge in Physics and mathematics for understanding complex engineering problems
		Training in working with various equipment, computational tools and familiarizing with simulation and modeling

1. **BARC**
   - **SYLLABUS**
   - **PSO-CO**
2. **BARC - AMD GEOLOGY & GEOPHYSICS**
   - **SYLLABUS**
   - **PSO-CO**
3. **BARC - NFC**
   - **SYLLABUS**
   - **PSO-CO**
4. **IGCAR**
   - **SYLLABUS**
   - **PSO-CO**
5. **RRCAT**
   - **SYLLABUS**
   - **PSO-CO**
6. **IPR**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

M.Phil. in CHEMICAL SCIENCE (PROGRAM CODE: CHEM02)

Program Code : CHEM02	Programme Outcome	Building strong foundation in fundamentals of core subjects in chemical sciences including Inorganic, Nuclear, Physical and Analytical Chemistry
		Development of skills in applying the basic knowledge in chemical sciences to applications in DAE programme
		Skill developments in effective communication of scientific results
		Development of skill set necessary for starting a research career in chemical sciences and allied areas
		Appreciate the central role of chemistry in DAE programmes and apply these to take up research in key issues such energy, health and medicine.

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**
2. **IGCAR**
    - **SYLLABUS**
    - **PSO-CO**

M.Phil. in PHYSICAL SCIENCE (PROGRAM CODE: PHYS02)

Program Code : PHYS02	Programme Outcome	Manpower development with the ability to apply basic concepts and methods in physics to research problems.
		Training in working with interdisciplinary subjects with physics as one of the disciplines
		Developing an understanding of modern mathematical methods and using them in the research environment.

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**
2. **IGCAR**
    - **SYLLABUS**
    - **PSO-CO**
3. **RRCAT**
    - **SYLLABUS**
    - **PSO-CO**

M.Sc. in ENGINEERING SCIENCE (PROGRAM CODE: ENGG03)

Program Code : ENGG03	Programme Outcome	Apply the knowledge of Natural sciences, mathematics and engineering sciences to the solution of complex engineering problems in the field of specialisation
		Ability to Identify new research problem, formulate the problem, to find the appropriate best solution to the complex engineering problem with relevant input from research literature, performing the requisite experiments and computational calculation

1. **BARC**
   - **SYLLABUS**
   - **PSO-CO**
2. **IGCAR**
   - **SYLLABUS**
   - **PSO-CO**
3. **IPR**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

Ph.D. in APPLIED SYSTEMS ANALYSIS (Program Code: APSA04)

Program Code : APSA04	Programme Outcome	To conduct policy-oriented research into problems involving multi-disciplinary approach

1. **NISER**

    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

Ph.D. IN CHEMICAL SCIENCE
(PROGRAM CODE: CHEM04)

Program Code : CHEM04	Programme Outcome	Foundation in the fundamentals of core chemical sciences fields including those in Analytical, Inorganic, Nuclear and Physical Chemistry.
		Skill development in critical thinking and problem solving applied to scientific problems.
		Development of skills to clearly communicate the results of scientific work in oral, written and electronic formats to both scientists and the public at large.
		Development of skill set necessary for starting a research career in chemical sciences and allied areas
		Appreciate the central role of chemistry in DAE programmes and apply these to take up research in key issues such energy, health and medicine.

1. **BARC**
   - **SYLLABUS / PSO-CO**
2. **IGCAR**
   - **SYLLABUS**
   - **PSO-CO**
3. **NISER**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

Ph.D. IN ENGINEERING SCIENCE (PROGRAM CODE: ENGG04)

Program Code : ENGG04	Programme Outcome	Manpower development with the ability to apply basic concepts and methods in physics, mathematics and engineering to the complex engineering problems.
		A thorough understanding of knowledge within their research area in engineering sciences and basic understanding in allied areas
		Skill development in critical thinking and problem solving applied to complex engineering problems.
		Development of skills to clearly communicate the results of engineering research work in oral, written and electronic formats to both technocrats and the public at large.
		Development of skill set necessary for starting a research career in engineering sciences and allied areas
		Appreciate the central role of engineering sciences in DAE programmes and apply these to take up research in key issues like advanced reactor design, reactor safety, material development etc.

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**
2. **IGCAR**
    - **SYLLABUS**
    - **PSO-CO**
3. **VECC**
    - **SYLLABUS**
    - **PSO-CO**
4. **IPR**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

Ph.D. IN LIFE SCIENCE (PROGRAM CODE: LIFE04)

Program Code : LIFE04	Programme Outcome	A thorough understanding of knowledge within their research area in life sciences and basic understanding in allied areas
		Skill development in critical thinking and problem solving applied to scientific problems.
		Development of skills to clearly communicate the results of scientific work in oral, written and electronic formats to both scientists and the public at large.
		Development of skill set necessary for starting a research career in Life sciences and allied areas
		Appreciate the central role of life sciences in DAE programmes and apply these to take up research in key issues such food, agriculture, health and medicine.

1. **BARC**
   - **SYLLABUS / PSO-CO**
2. **SINP**
   - **SYLLABUS**
   - **PSO-CO**
3. **TMC**
   - **SYLLABUS**
   - **PSO-CO**
4. **IMSc**
   - **SYLLABUS**
   - **PSO-CO**
5. **NISER**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

Ph.D. in MATHEMATICAL SCIENCES (PROGRAM CODE: MATH04)

Program Code : MATH04	Programme Outcome	At the end of the program, the student should be knowing the basic concepts and tools in the core subjects of pure mathematics to undertake research for thesis work.

1. **HRI**
   - **SYLLABUS**
   - **PSO-CO**
2. **IMSc**
   - **SYLLABUS**
   - **PSO-CO**
3. **NISER**
   - **SYLLABUS**
   - **PSO-CO**

Ph.D. in COMPUTER SCIENCES (PROGRAM CODE: MATH04)

Program Code : MATH04	Programme Outcome	A deep understanding of foundational and theoretical aspects of Computer Science
		Development of critical analytic skills applicable across sub-areas
		Development of self-direction and originality in problem-solving

1. **IMSC**
   - **SYLLABUS**
   - **PSO-CO**
2. **NISER**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

Ph.D. IN PHYSICAL SCIENCE (PROGRAM CODE: PHYS04)

Program Code : PHYS04	Programme Outcome	Manpower development with the ability to apply basic concepts and methods in physics to research problems.
		Training of manpower to take up research in frontier areas of physics
		Building human resource in carrying out R&D in physical and nuclear sciences
		Training of manpower in working in interdisciplinary subjects with physics as one of the subjects

Ph.D. IN MEDICAL & HEALTH SCIENCES (PROGRAM CODE: HLTH04)

Program Code: HLTH04	**Program Outcomes**	Knowledge and scientific competencies: research methods, information literacy, scientific writing, professional conduct, ethics and integrity, and awareness of interdisciplinary contexts.
		Organization and management competencies: project management, self-management, and teaching.
		Training in application of Nuclear Medicine in diagnosis and therapy of diseases.

1. **TMC**
    - **SYLLABUS**
    - **PSO-CO**

INTEGRATED Ph.D. in ENGINEERING SCIENCE

(DOUBLE DEGREE)

(Program Code: ENGG05)

Program Code : ENGG05	Programme Outcome	Manpower development with ability to apply basic concepts and methods in physics to engineering problems
		Skill development in working in interdisciplinary research problems
		Developing understanding of modern mathematical methods and using them in research environments
		Ability to apply the basic knowledge in engineering science to DAE programme

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**
2. **IGCAR**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

INTEGRATED Ph.D. LIFE SCIENCES

(DOUBLE DEGREE)
(Program Code: LIFE05)

Program Code : LIFE05	Programme Outcome	To provide DAE with manpower trained in the nuances of Nuclear Science & Technology in Life Sciences
		Building strong foundation in the area of Life and nuclear sciences
		Expose the young students to state-of-the art experimental techniques
		Teach fundamental aspects pertaining to latest developments in the field of Life and nuclear sciences
		Understanding the role of Life Science in DAE programmes
		Understanding the role of biology in societal and strategic programmes

1. IMSc

- **SYLLABUS**
- **PSO-CO**

BACK TO MAIN

INTEGRATED Ph.D. MATHEMATICAL SCIENCES

(DOUBLE DEGREE)

(Program Code: MATH05)

Program Code : MATH05	Programme Outcome	Original research in chosen specialized area
		Knowledge of literature in chosen area and related areas
		Ability to apply concepts and techniques in problem solving
		Ability to communicate clearly both orally and in writing
		Ability to critically evaluate current research

1. IMSc

- **SYLLABUS**
- **PSO-CO**

BACK TO MAIN

INTEGRATED Ph.D. in PHYSICAL SCIENCE

(DOUBLE DEGREE)

(Program Code: PHYS05)

Program Code : PHYS05	Programme Outcome	Manpower development with the ability to apply basic concepts and methods in physics to research problems.
		Training of manpower with the ability to work in interdisciplinary subjects, particularly those in the interface of different disciplines in physics.
		Developing an understanding of modern mathematical methods and using them in the research environment.
		Training of manpower which has the ability to work in diverse areas and adapt to change in professional and national requirements.

1. **HRI**
   - **SYLLABUS**
   - **PSO-CO**
2. **IMSC**
   - **SYLLABUS**
   - **PSO-CO**
3. **NISER**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

DIPLOMA in MEDICAL RADIOISOTOPE TECHNIQUES (DMRIT) (Program Code: HLTH07)

Program Code :HLTH07	Programme Outcome	To develop human resource, in the form of Nuclear Medicine Technologist, for nuclear medicine departments of various hospitals in the country, possessing specialized knowledge in theoretical & experimental nuclear medicine techniques.
		Understand techniques in Scintigraphy and PET-CT for application of radioisotopes in nuclear medicine -diagnosis & -treatment.
		To develop theoretical and practical knowledge and the required competencies to function in a nuclear medicine setup.
		To be able to adopt and apply, both established and evolving techniques & technologies, in radiopharmaceutical formulations, for both SPECT & PET agents, nuclear medicine imaging techniques and laboratory applications like radioimmunoassay (RIA), Immunoradiometric assay (IRMA) and other related methods.

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**

M.Sc. in PHYSICAL SCIENCES (Program Code: PHYS08)

Program Code : PHYS08	Programme Outcome	Develop manpower with the ability to apply basic concepts and methods in physics to understand diverse phenomena.
		Develop manpower with the ability to work in interdisciplinary subjects, particularly those in the interface of physics and engineering
		Develop manpower with the understanding of modern mathematical methods and the ability to apply them in any quantitative analysis.

1. **HRI**

- **SYLLABUS**
- **PSO-CO**

M.D.
(PROGRAM CODE: HLTH09A)

Program Code : HLTH09	Programme Outcome	Ability to provide evidence-based treatment to the patient.
		Well informed about the established and evolving biomedical and Clinical sciences and ability to apply the knowledge for patient's care in the area of specialisation.
		Ability to communicate with the patient effectively about health care advice and treatment.
		Ability to carry out professional work by maintaining high ethical standards.

I. M.D. (PATHOLOGY)

1. **TMC**
   - **SYLLABUS**
   - **PSO-CO**

II. M.D. (RADIO – DIAGNOSIS)

1. **TMC**
   - **SYLLABUS**
   - **PSO-CO**

III. M.D. (RADIATION ONCOLOGY)

1. **TMC**
   - **SYLLABUS**
   - **PSO-CO**

IV. M.D. (MICROBIOLOGY)

1. **TMC**
   - **SYLLABUS**
   - **PSO-CO**

BACK TO MAIN

V. M.D. (NUCLEAR MEDICINE)

1. BARC
   - SYLLABUS
   - PSO-CO
2. TMC
   - SYLLABUS
   - PSO-CO

VI. M.D. (PALLIATIVE MEDICINE)

1. TMC
   - SYLLABUS
   - PSO-CO

VII. M.D. (IMMUNO – HEMATOLOGY & TRANSFUSION MEDICINE)

1. TMC
   - SYLLABUS
   - PSO-CO

VIII. M.D. (ANESTHESIA)

1. TMC
   - SYLLABUS
   - PSO-CO

BACK TO MAIN

D.M.
(PROGRAM CODE: HLTH10A)

Program Code : HLTH10A	Programme Outcome	Ability to diagnose health issues and provide comprehensive care to the patient in the area of super specialization.
		Ability to carry out all necessary diagnostic and therapeutic procedures as required in the area of super specialization.
		Extensive knowledge in the area of super specialization and the ability to apply the knowledge for optimal treatment of the patient.
		Ability to counsel parents and relatives of the patient with empathy and compassion
		Ability to design and execute research projects and interact with medical colleagues in multiple disciplines
		Ability to conduct teaching sessions, bedside seminars and lectures

I. D.M. (MEDICAL ONCOLOGY)

1. **TMC**
   - **SYLLABUS**
   - **PSO-CO**

II. D.M. (PAEDIATRIC ONCOLOGY)

1. **TMC**
   - **SYLLABUS**
   - **PSO-CO**

III. **D.M. (GASTROENTEROLOGY)**

1. **TMC**
    - **SYLLABUS**
    - **PSO-CO**

IV. **D.M. (CRITICAL CARE MEDICINE)**

1. **TMC**
    - **SYLLABUS**
    - **PSO-CO**

V. **D.M. (ONCOPATHOLOGY)**

1. **TMC**
    - **SYLLABUS**
    - **PSO-CO**

VI. **D.M. (INTERVENTIONAL RADIOLOGY)**

1. **TMC**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

M.Ch

(PROGRAM CODE: HLTH10B)

Program Code : HLTH10B	Programme outcome	Development of trained man power in Oncology.
		Building strong foundation in clinical research and surgery.

1. **M.Ch (SURGICAL ONCOLOGY)**
   - **SYLLABUS**
   - **PSO-CO**
2. **M.Ch (GYNECOLOGICAL ONCOLOGY)**
   - **SYLLABUS**
   - **PSO-CO**
3. **M.Ch (PLASTIC SURGERY & RECONSTRUCTIVE SURGERY)**
   - **SYLLABUS**
   - **PSO-CO**
4. **M.Ch (HEAD & NECK ONCOLOGY)**
   - **SYLLABUS**
   - **PSO-CO**

Post M. Sc. Diploma in Radiological Physics (Dip. R. P.) (Program Code: HLTH11)

Program Code : HLTH11	**Programme Outcome**	Apply principles of basic science concepts in understanding, analysis and predication
		To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application of Medical Physics and ionising radiation safety concepts.
		To introduce advanced ideas and techniques required in emergent area of Medical Physics and radiation safety in cancer care.
		To develop human resources with specialization in theoretical and experimental technique as well as radiation safety required for medical, industrial and research applications of ionizing radiation.

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

INTERGRATED M.Sc. in CHEMICAL SCIENCES (Program Code: CHEM13)

Program Code : CHEM13	Programme Outcome	Ability to learn and engage in emerging areas of chemical science
		Ability to collaborate and work in interdisciplinary areas of science where chemistry knowledge is required
		Ability to pursue a career in chemical research
		Human resource with knowledge base in theoretical and experimental chemistry
		Ability to work on societal problems involving chemistry
		Ability to apply the basic concepts and principles of chemistry in solving real life problems

1. **NISER**
    - **SYLLABUS**
    - **PSO-CO**

INTEGRATED M.Sc. in LIFE SCIENCES (Program Code: LIFE13)

Program Code : LIFE13	Programme Outcome	Ability to learn and engage in emerging areas of bioscience
		Ability to collaborate and work in interdisciplinary areas of science where bioscience knowledge is required
		Ability to pursue a career in bioscience research
		Human resource with knowledge base in theoretical and experimental bioscience
		Ability to work on societal problems involving bioscience
		Ability to apply the basic concepts and principles of bioscience in solving real life problems

1. **NISER**

- **SYLLABUS**
- **PSO-CO**

INTEGRATED M.Sc. in MATHEMATICAL SCIENCES
(Program Code: MATH13)

Program Code : MATH13	Programme Outcome	The Integrated M.Sc. Program in Mathematics aims to provide comprehensive training to the students so that they will be able to build a carrier in Mathematics for themselves
		The program aims to train people who are oriented towards research and teaching in both basic and advanced areas of Mathematical sciences.
		After successful completion of this program students will be able to apply knowledge of Mathematics in different fields of science and technology.

1. **NISER**

- **SYLLABUS**
- **PSO-CO**

INTEGRATED M.Sc. IN PHYSICAL SCIENCE (PROGRAM CODE: PHYS13)

Program Code : PHYS13	Programme Outcome	Building the manpower with ability to apply basic concepts and methods in physics to understand diverse phenomena.
		Building of manpower with the ability to work in interdisciplinary subjects, particularly those in the interface of physics and engineering
		Understanding of modern mathematical methods and ability to apply them in any quantitative analysis.

1. **NISER**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

M.Sc. NURSING

(PROGRAM CODE: HLTH15)

Program code: HLTH15	**Program Outcome**	Developing skilled man power with knowledge of patient care.
		Building trained man power for patient care, assisting the docter, effective oral communication and ethical practises.

1. TMC

- **SYLLABUS**
- **PSO-CO**

BACK TO MAIN

PGDFIT
(PROGRAM CODE: HLTH16)

Program Code : HLTH16	Programme Outcome	To develop highly skilled human resource in nuclear medicine technology.

1. TMC

- **SYLLABUS**
- **PSO-CO**

M. Sc. in CLINICAL RESEARCH (Program Code: HLTH17)

Program Code : HLTH17	Programme Outcome	To train the students in various aspects of clinical research – Ethics, Guidelines and Rules; and roles and responsibilities of a clinical research professional.
		This will also enable the individual to be a good trained knowledgeable clinical research person while supporting new drug development and clinical trials.
		To be able to participate in clinical trials management, including planning and execution of the trial and be a part of the multidisciplinary team delivering ethical clinical trials meeting all national and international norms and guidelines.

1. TMC

- **SYLLABUS**
- **PSO-CO**

BACK TO MAIN

INTEGRATED Ph.D. ENGINEERING SCIENCE

(SINGLE DEGREE)

(PROGRAM CODE: ENGG18)

Program Code : ENGG18	Programme Outcome	To provide DAE with a manpower trained in the nuances of Nuclear Science & Technology
		Building strong foundation in the area of engineering and nuclear sciences
		Expose the young students to state-of-the art experimental techniques and development of experimental facilities
		Teach fundamental aspects pertaining to latest developments in the field of engineering and nuclear sciences
		Understanding the role of engineering sciences in DAE programmes
		Understanding the role of engineering sciences in societal and strategic programmes

1. **BARC**
    - **SYLLABUS**
    - **PSO-CO**
2. **IGCAR**
    - **SYLLABUS**
    - **PSO-CO**

BACK TO MAIN

Revised Syllabi after approval of:

BARC Training School Chemistry Committee
(Date of meeting: 28-05-2018)

HBNI BoS (Chemical Sciences)
(Date of meeting: 1-06-2018)

HBNI Academic Council
(Date of meeting: 30-06-2018)

Submitted to BARC Training School on 3-07-2018

SYLLABUS FOR

PGD in Chemical Sciences
under BARC
(Program Code: CHEM00)

SYLLABUS - 2018

CHEMICAL SCIENCES

COURSE STRUCTURE-CHEMISTRY

FOUNDATION COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Mathematics, Quantum Chemistry & Computational Methods	CY501	40+10	4	150
2	Analytical Chemistry	CY502	40+8	4	150
3	Material Science	CY503	20+5	2	75
4	Radiation Detection and Measurements	CY504	20	2	75
5	Nuclear and Radiochemistry	CY505	40+8	4	150
6	Thermodynamics	CY506	20+4	2	75
	FOUNDATION TOTAL		**180+35**	**18**	**675**

CORE COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Lasers	CY601	10	1	50
2	Electronics & Chemical Instrumentation	CY602	20+4	2	75
3	Production and Applications of Radioisotopes	CY603	20+4	2	75
4	Reactor Physics and Reactor Chemistry	CY604	20	2	75
5	Molecular Structure & Spectroscopy	CY605	30+6	3	125
6	Radiation and Photochemistry	CY606	30+8	3	125
7	Chemistry in Nuclear Fuel Cycles	CY607	40	4	150
8	Advanced Chemical Kinetics & Dynamics	CY608	20+4	2	75
9	Health Physics and Radiation Biology	CY609	20	2	75
10	Research Methodology	CY610	20	3	100
11	Safety in Chemical and Radiochemical labs	CY 611	10	1	50
	CORE TOTAL		**240+26**	**25**	**975**

***Tutorials**

ELECTIVES (Any Two) 4 Credits

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Nanomaterials, Chemical Sensors	CY701	20	2	75
2	Soft Condensed Matters	CY702	20	2	75
3	Nuclear Probes for Material Characterization	CY703	20	2	75
4	Molecular Bioorganics	CY704	20	2	75
5	Laser Spectroscopy	CY705	20	2	75
6	Actinide Chemistry	CY706	20	2	75
7	Computational Chemistry	CY707	20	2	75
8	Advanced NMR Spectroscopy	CY708	20	2	75
9	Atmospheric Chemistry	CY709	20	2	75
10	Statistical Analysis	CY710	20	2	75
	ELECTIVES TOTAL		**40**	**4**	**150**

	THEORY TOTAL	**460+61**	**47**	**1800**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code		Credits	Marks
1	Viva Voce	CY591	-	6	200
2	Mini Project	CY592	-	9	300
3	Seminar	CY593	-	2	100
		TOTAL		**17**	**600**

Total Contact Hrs: 460+61 (Tutorials); Total Credits: 64; Total Marks: 2400

Note: Credit Requirement for PhD: 60

Marks are calculated using the formula (As per BOS decision)

2*Hours+20*Credits (Nearest multiple of 25)

Summary Table and Index- Chemical Sciences

S.No.	Course Code	Course Title		Lectures	Marks	Credits	Sem	Page No.
FOUNDATION COURSES								
1	**CY501**	Mathematics, Quantum Chemistry & Computational Methods		40	150	4	1	
2	**CY502**	Analytical Chemistry		40	150	4	1	
3	**CY503**	Material Science		20	75	2	1	
4	**CY504**	Radiation Detection and Measurements		20	75	2	1	
5	**CY505**	Nuclear and Radiochemistry		40	150	4	1	
6	**CY506**	Thermodynamics		20	75	2	1	
CORE COURSES								
11	**CY601**	Lasers		10	50	1	2	
12	**CY602**	Electronics & Chemical Instrumentation		20	75	2	1	
13	**CY603**	Production and Applications of Radioisotopes		20	75	2	2	
14	**CY604**	Reactor Physics and Reactor Chemistry		20	75	2	2	
15	**CY605**	Molecular Structure & Spectroscopy		30	125	3	2	
16	**CY606**	Radiation and Photochemistry		30	125	3	2	
17	**CY607**	Chemistry in Nuclear Fuel Cycles		40	150	4	2	
18	**CY608**	Advanced Chemical Kinetics & Dynamics		20	75	2	2	
19	**CY609**	Health Physics and Radiation Biology		20	75	2	2	
21	**CY 610**	Research Methodology		20	100	3	2	
20	**CY 611**	Safety in Chemical and Radiochemical labs		10	50	1	2	

ELECTIVE COURSES								
S.No.	**Course Code**	**Course Title**	**Course Coordinator**	**Lectures**	**Marks**	**Credits**	**Sem**	**Page No.**
20	**CY701**	Nanomaterials and Chemical Sensors		20	75	75	SS	
21	**CY 702**	Soft Condensed Matters		20	75	75	SS	
22	**CY703**	Nuclear Probes for Material Characterization		20	75	75	SS	
23	**CY704**	Molecular Bioorganics		20	75	75	SS	
24	**CY705**	Laser Spectroscopy		20	75	75	SS	
25	**CY706**	Actinide Chemistry		20	75	2	SS	
26	**CY707**	Computational Chemistry		20	75	2	SS	
27	**CY708**	Advanced NMR Spectroscopy		20	75	2	SS	
28	**CY709**	Atmospheric Chemistry		20	75	2	SS	
29	**CY710**	Statistical Analysis		20	75	2	SS	
NON-SUBJECTASSIGNMENTS								
22	**CY591**	Viva Voce		NA	200	6	SS	
23	**CY592**	Mini Project		11 Weeks	300	9	SS	
24	**CY593**	Seminar		NA	100	2	SS	

FOUNDATION COURSES

CY 501: Mathematics, Quantum Chemistry and Computational Methods (40/10/10)

Differential Equations & Integral Transforms

Introduction to differential equations: order and degree; Different methods of solution; Overview of Legendre, Lagurre and Hermite differential equations;
Introduction to Fourier series, Fourier transform and Laplace transform.

Vector Calculus

Vector differentiation and integration: Concepts of gradient, divergence and curl; Laplacian operator.

Matrix Algebra
Elementary operations and elementary matrices. Solution of linear equations; Similarity transformations; Eigenvalues and eigenvectors; Diagonalization and inversion of matrices.

Group Theory and Symmetry in Chemistry
Concepts of groups, sub groups and classes; Symmetry elements, and symmetry operations; Point groups and matrix representations; Great orthogonality theorem and its importance in chemistry, Reducible and irreducible representations; Character Tables and their applications to spectroscopy, molecular geometry and chemical reactions.

Quantum Chemistry

Postulates of quantum mechanics, Classes of operator: Linear and Hermitian, Physical significance of eigen value in quantum mechanics; Boundary value problem in quantum mechanics; Exactly solvable problems: Particle in a box and ring; simple harmonic oscillator; rigid rotor and hydrogen atom; Approximation methods: Variation method; perturbation theory for time-independent and time dependent systems; Many-electron systems: Hartree-Fock theory and beyond; Chemical binding in simple molecular systems: Valence bond and molecular orbital theories; Concept of LCAO and introduction to ab-initio and semi-empirical molecular orbital calculations of molecules; Extended systems: From bonds to bands; Applications to few simple molecules.

Computer Programing and Numerical Methods
Computers and modeling in chemistry; Basics of computer programming: Variables, constants, input/output and control statements, arrays, functions, and subroutines. Computer oriented numerical methods: Newton-Raphson method for finding roots, differentiation, integrations by quadrature techniques, solutions of differential equations, diagonalisation and inversion of matrices. Curve fitting. Basics of computer simulation: Monte Carlo and molecular dynamics simulations.

References
[1] M.R. Spiegel. Advanced Mathematics for Engineers and Scientists, Schaum's Outline Series (1983).
[2] K.F. Riley, M.P. Hobson and S.J. Bence. Mathematical Methods for Physics Engineering, Cambridge University Press (1998).
[3] M.R. Spiegel. Theory and Problems of Vector Analysis, Schaum's Outline Series (1981).
[4] F.A. Cotton. Chemical Applications of Group Theory, Wiley (1971).
[5] S.F.A. Kettle. Symmetry and Structure: Readable Group theory for Chemists, John Wiley (1995).
[6] A. K. Mukherjee and B. C. Ghosh. Group Theory and Chemistry: Bonding and Molecular Spectroscopy, University Press, 2017.
[7] I.N. Levine. Quantum Chemistry, Prentice-Hall (1994).
[8] A.K. Chandra. Introductory Quantum Chemistry, Tata McGraw Hill (1979).
[9] V. RajaRaman. Computer Oriented Numerical Analysis, Prentice Halls India, 3rd ed. (1999)
[10] William E. Mayo. Programming with Fortran 77, Schaum Outlines Series, McGraw Hill, International ed. (1995).

CY 502: Analytical Chemistry (40/8/5)

Introduction
Relevance of Analytical Chemistry in Atomic Energy Programme, Terminologies in Analytical Chemistry, Quality Assurance in Analytical Chemistry, Accreditation and its importance

Separation Technique
Solvent extraction: Principles and Applications, Conventional solvent extraction, Liquid membranes, Bulk membranes, Supported and Emulsified liquid membrane, Super critical fluid extraction (SFE).
Ion Exchange: Principles and Applications, Conventional ion exchange, Solid Phase Extraction (SPE)
Chromatography: Principles and Applications, Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion chromatography (IC), Supercritical fluid Chromatography(SFC),Capillary electrophoresis.

Electrochemical Techniques
Introduction to the oxidation and reduction process, equilibrium electrochemistry, Activity, Nernst equation, Butler-Volmer equation, Tafel treatment. Potentiometry/potentiometric titration and ion Selective Electrodes (ISE), Modified electrodes.
Electrochemical double layer, Mass transfer processes, Fick's law of diffusion, Polarisation, Voltammetry & Polarography, working electrode, reference electrode and counter electrodes, Votammetric techniques like; Linear sweep voltammetry, Cyclic voltammetry, Pulse and Stripping Voltammetry, Coulometry and Amperometry, Hydrodynamic voltammetry.
Electrochemical Impedance spectroscopy and modelling of the electrochemical interface. Electrochemistry at ultramicro electrode, Scanning Electrochemical Microscopy, electrochemistry at confined geometry and detection at single molecule level, Hyphenated in-situ spectro-electrochemical techniques.

Spectrochemical Techniques
An introduction to spectrometric methods, Performance Characteristics of instruments, Calibration of instrumental methods, Quantitative aspects of spectrochemical measurements.
Atomic Absorption spectrometry(AAS), Sources of radiation(Hollow Cathode lamp, Continuum Source), Atom cell, Flame Atomic Absorption Spectrometry (FAAS), Electrothermal Atomic Absorption Spectrometry (ETAAS), Cold vapor Atomic Absorption Spectrometry (CVAAS), Hydride generation Atomic Absorption Spectrometry (HGAAS), Types of Interferences in AAS and Background correction methods.
Optical Emission Spectrometry, Emission sources: Flame, Inductively Coupled plasma, Glow Discharge, DC-Arc, Inductively Coupled Plasma Optical Emission Spectrometry(ICP-OES), Types of interference in ICP-OES and background correction methods, Laser Induced Fluorescence(LIF).

Mass Spectrometry
Basic principle, Ion sources: Thermal Ionisation (TI), Electron Impact(EI), Inductively Coupled Plasma(ICP), Glow Discharge(GD), Laser Ablation (LA), Secondary Ionisation (SI), Resonance Ionisation (RI), Matrix Assisted Laser Desorption and Ionisation (MALDI), mass analysers: Magnetic Sector, Quadrupole, Time of Flight (TOF), Ion Cyclotron Resonance(ICR),detectors: Faraday Cup, Channeltron and Daly detector, resolution, abundance sensitivity, Laser Induced Breakdown Spectroscopy (LIBS), Resonance Ionization Mass Spectroscopy (RIMS) Hyphenated Technique - IC-MS, HPLC-MS, GC-MS.

Thermal Methods
Principle and applications, Thermogravimetric Analysis (TGA), Derivative Thermogravimetric Analysis (DTG), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Evolved Gas Analysis (EGA)

Nuclear Methods
Principle of Activation Analysis – Neutron Activation Analysis (NAA), Charged Particle Activation Analysis (CPAA), X-ray fluorescence (XRF) spectrometry: Principles, methodology and matrix effect.

Statistics in Chemical Analysis
Accuracy, Precision, Errors in quantitative analysis, Classification of errors, Propagation of errors, treatment of errors, Normal distribution, Tests of Significance and Confidence Limits, Reporting of analytical results

Laboratory Experiments (Any Five)
1. Determination of trace impurities in high purity materials by AAS.
2. Application of electroanalytical methods to trace analysis.
3. Anion analysis by ion selective electrode.
4. TGA and DTA study of inorganic compounds
5. Neutron Activation Analysis of trace constituents in a complex matrix
6. Analysis of an alloy sample by EDXRF
7. Chromatographic separation and measurement of the components in a mixture
8. Isotopic Analysis by Mass Spectrometry

References
[1]. Encyclopaedia of Analytical Chemistry: Applications, Theory and Instrumentation, Editor R. A. Meyers, John Wiley & Sons Ltd. (2000).
[2]. Fundamentals of Analytical Chemistry, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
[3] Principles of Instrumental Analysis, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
[4]. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).
[5] Solvent Extraction of Metals, A. K. De, S. M. Khopkar and R. A. Chalmers, Van Nostrand, Reinhold (1970).
[6] Ion Exchangers, F. Helfferich, McGraw Hill (1962).
[7] Introduction to Modern Liquid Chromatography, L. R. Snyder and J. J. Kirkland, 2nd Edition, Wiley (1979).
[8] High Performance Liquid Chromatography : Principles and Methods in Biotechnology, Editor E. D. Katz, John Wiley and Sons, Chichester (1996)
[9] Atomic Absorption and Emission Spectroscopy, A. Metcalfe, Wiley (1987).
[10] Introduction to Mass Spectrometry: Instrumentation and Techniques, John Roboz, Interscience (1968).
[11] Inductively Coupled Plasma Spectrometry and its Application, Editor Steve J. Hill, Sheffield Academic Press (1998).
[12] Thermal Analysis, T. Daniels, Kogan Page (1973).
[13] Electrochemical Methods, A. J. Bard and L. R. Faulkner, 2nd Edition, Wiley (2001).
[14] Principles of Activation Analysis, P. Kruger, Wiley Interscience (1971).
[15] Principles and Practices of X-Ray Spectrometric Analysis, E. P. Bertin, Plenum Press New York, Fourth Edition (1984).
[16] Statistics and Chemometrics for Analytical Chemistry, J. N. Miller and J. C. Miller, Sixth Edition, Pearson Education Limited (2010).

CY 503: Material Science (20/5/2)

Crystal Structure
Different types of unit cells, Space lattices, Miller indices, atomic packings, radius ratio, structures of NaCl, CsCl. ZnS, diamond, CaF_2, perovskite, double pervoskites, pyrochlores, spinels, garnet structure and framework solids, aperiodic systems, symmetry, relevance of crystal structures to nuclear materials (glass, ceramics, intermetallics and alloys).

Powder X-ray Diffraction Technique for Phase Identification
Concept of X-ray diffraction, reciprocal space, Ewald construction, structural and scattering factors, grain/particle size effects, different techniques of recording diffraction patterns, indexing of diffraction patterns, Diffraction data files and their utility, Neutron diffraction, electron diffraction.

Types of Bonding in Solids
Van der Waals interactions, Lennard-Jones potential, crystals of inert gases, ionic bonding, Madelung energy and its calculation in the case of NaCl/CsCl, covalent bonding, hydrogen bonding.

Defects in Solids
Defects and defect concentration, dependence on temperature, 0- D, 1- D, 2-D defects, Experimental methods for their characterisation, color centres, phase transitions, classification with examples, dependence of phase transition on T and P, thermodynamic classification of phase transitions, order- disorder phase transitions, austenite- martensite phase transitions in alloys. Solid solutions, their significance, simple and complex solid solutions, methods to characterize solid solutions.

Transport Properties of Solids
Ionic conductivity, electronic conductivity, dielectric, ferro, piezo and pyro electric materials. structural basis and applications, superconductivity, thermal conductivity with examples.

Basic techniques for characterization
Concept of various characterization techniques based on X-rays and electrons: XRF, EPMA, XPS, AES, EELS and their application with examples

Methods of material preparation and processing
Solid state reactions and soft chemical routes, concepts of annealing, sintering and calcination, processing techniques like spin coating, powder coating, screen printing etc.

Laboratory Experiments: (Any two)
1. XRD characterization, indexing and cell parameter determination
2. Micro structure of metal/alloy by metallography and SEM
3. Electrical resistivity and its temperature dependence

References
[1]. Introduction to solid state physics – Charles Kittle
[2] Solid-state chemistry and physics, Vol. 1 & 2 – (Ed) P. F. Weller
[3] A first course in materials science – V. Raghavan
[4] Modern aspects of solid-state chemistry – C.N.R. Rao
[5] New Directions in solid-state chemistry – C.N.R. Rao and J. Gopalakrishnan
[6] Solid-state chemistry and its applications – Anthony R. West
[7] The powder method in X-ray crystallography – Leonid V. Azaroff and M. J. Buerger
[8] Solid-state chemistry techniques (Ed) – A. K. Cheetam and Peter Da
[9] Advanced Techniques for Materials Characterization" Eds. A. K. Tyagi, M. Roy, S. K. Kulshreshtha, S. Banerjee, Trans Tech Publications Ltd, Switzerland (2009)
[10] Functional Materials: Preparation, Processing and Applications, Eds. S. Banerjee and A. K. Tyagi, Elsevier Publishers (2011)
[11] Solid State Chemistry: An Introduction, by Lesley E. Smart, Elaine A. Moore
[12] Principles of the Solid State by H. V. Keer

CY 504: Radiation Detection and Measurement (20)

Interaction of Radiation with Matter
Interaction of Heavy Charged Particle with matter
Ionization in gaseous medium, Bragg's curve, stopping power, Bethe Equation for stopping power, Range of heavy charged particle and straggling, Range energy relationship.

Interaction of Fast Electrons with Matter
Comparison with heavy charged particle, LET for electron, Bremsstrahlung radiation, Cerenkov radiation, Bethe Equation, path length and range of electrons, Attenuation and absorption of β particles, Backscattering of β- and Positron annihilation.

Interaction of Electromagnetic Radiations (γ, X-Rays) with Matter
Photoelectric Effect, Compton Scattering, Pair Production, .Variation of cross section for different process with γ energy and Z of the medium, Attenuation and Absorption of gamma rays

Interaction of neutrons with matter
Elastic and Inelastic Scattering of neutrons and slowing down, nuclear reactions

Radiation Detectors
Principle of Radiation Detectors: Pulse height spectrum, Counting Characteristics, plateaus, Detection efficiency, Energy resolution, Dead time, Counting Statistics
Gas filled Detectors
Ionization Chamber, Proportional counter, GM counter

Scintillation Detectors
Organic and Inorganic scintillators, Liquid scintillation counter, Pulse shape discriminator, Solid state scintillation detectors: NaI(TI), CsI and $LaBr_3$ detectors

Semiconductor Detectors
p-n junction, HPGe detector for gamma ray spectroscopy, Clover detectors, Si(Li) for x-ray spectroscopy, Silicon detectors for charged particle spectroscopy

Neutron Detectors
BF3, 3He gas filled counters.

Solid State Nuclear Track Detectors (SSNTD)
Basic principle and applications

Application of Radiation Detectors in Nuclear Probes

References
[1] Radiation detection and measurement, G.F. Knoll, John Wiley & Sons

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CY 505: Nuclear and Radiochemistry (40/8/5)

Radioactivity
Radioactivity, Radioactive decay laws, Half-life and radioactive equilibria.

Nuclear Stability
Concept of nucleus, Nuclear mass and Binding energy, Nuclear force.

Nuclear Models
Liquid drop model, Shell model, Concept of spin, Parity electric and magnetic moments, Isomerism.

Modes of Decay
α decay, β decay, Electron captures, γ de-excitation, Internal conversion.

Nuclear reaction and fission

Q value equation, Reaction threshold, Centre of mass system, Cross-section for neutron and charged particle induced reactions , Nuclear Temperature, Compound nucleus mechanism, Nuclear fission: observables and models, Synthesis and separation of heavy and trans-actinides, Accelerators, Application of accelerators in ion beam analysis

Techniques in Nuclear Chemistry
Target preparation and target chemistry, Radiochemical separations, Concept of tracer and carrier, Chemical yield, Radiochemical purity, Application of radiotracers in chemical sciences, Determination of half-life.

Laboratory Experiments (Any Five)
1. GM Counter: plateau, statistics and dead time
2. Gamma-ray spectrometry using NaI(Tl) and HPGe detector: Energy Calibration, Resolution, Efficiency
3. Separation of actinides using solvent extraction technique
4. Alpha spectrometry

5. Determination of half-life of a radioisotope
6. Solid State Nuclear Track Detector
7. Separation of fission products / Transient equilibrium

References

[1] Nuclear and Radiochemistry (1981) – G. Friedlander, J. Kennedy, J. M. Miller and J. W. Macias
[2] Atomic Nucleus (1955) - R. D. Evans
[3] Source book of Atomic Energy (1969) - S. Glasstone
[4] Man made elements (1963) - G. T. Seaborg
[5] Essentials of Nuclear Chemistry (1982) - H. J. Arnikar
[6] The Chemistry of Transuranium Elements (1971) - C. Keller
[7] Fundamentals of Radiochemistry, IANCAS Publication, 2007

CY 506: Thermodynamics (20/4)

Introduction to Chemical and Statistical Thermodynamics
Laws of thermodynamics, Fundamental equations and thermodynamic potentials, Introduction to statistical thermodynamics, Einstein and Debye theories of specific heats of solids, Phase transitions, Thermodynamics of solutions, ideal and regular solution models.

Chemical Equilibrium
Solid-gas equilibrium, Ellingham diagram.

Relation between Thermodynamics and Phase Diagrams
Binary and ternary phase diagrams, CALPHAD definition of phases, Degree of freedom rule and lever-rule, Calculation of simple binary phase diagrams from thermodynamic properties, Chemical potential variations across phase diagrams

Phase Diagram and Thermodynamics of Nuclear Fuels
Relevant phases for nuclear fuel applications, Change in chemical potentials with compositions of virgin fuels, Change in chemical potentials with burn-up, Thermodynamics of Fuel-Clad and Coolant-Clad interactions, Thermodynamics of molten fluorides, Concepts of metastable materials.

Experimental Thermodynamics
Calorimetric measurements, Vapor pressure measurements, Estimation of thermodynamic quantities

References

[1] Introduction to Thermodynamics of Materials (Fourth Edition) by D. R. Gaskell (2003) Taylor & Francis Books, Inc., New York
[2] The Principles of Chemical Equilibrium by K. Denbigh (Fourth Edition) (1981) Cambridge University Press, Cambridge
[3] Materials Thermodynamics by Y.A. Chang and W.A. Oates (2010), John Wiley & Sons, Hoboken, New Jersey.
[4] Fundamentals of Classical and Statistical Thermodynamics by B.N. Roy (2002) John Wiley & Sons, Hoboken, New Jersey, England
[5] Comprehensive Nuclear Materials, R.J.M. Konings, T.R. Allen, R.E. Stoller, S. Yamanaka, Elsevier 2012.

CORE COURSES

CY 601: Lasers (10/0/1)

Basic principles - Spontaneous & stimulated emission, population inversion, laser components, Einstein coefficients, optical amplification, optical & electrical pumping, rate equations (two, three and four level laser systems)

Properties of laser beams - coherence (spatial and temporal), monochromaticity, intensity, polarization

Optical resonators – Types, properties, spatial field distribution in resonators, stable & unstable resonators, gain and losses in the cavity, Q-factor, threshold condition, laser modes (longitudinal and transverse),
Types & some laser systems - Solid state lasers, gas lasers, dye lasers, diode lasers, fiber lasers, free electron laser and quantum cascade lasers, tunable lasers

Generation of short and ultrashort pulses - Q-switching and mode locking, chirp pulse amplification

Non-linear optical techniques – Phase matching, harmonic generation, optical parametric oscillator & amplifier

Modulation in laser pulses-amplitude, wavelength, temporal

Characterization of laser pulses - Measurement of the pulse temporal profile (electronic & optical), spectral measurements (interferometric), amplitude - phase measurements (FROG)

Laser applications & laser safety.

References

[1] Laser Spectroscopy: Basic Concepts and Instrumentation- W. Demtroder
[2] Laser Fundamentals-William Silfvast
[3] Laser and Non-linear Optics- B. B. Laud
[4] Principles of Lasers- O. Svelto and D. C. Hanna
[5] Laser Safety- Roy Henderson and Karl Schulmeister

Laboratory experiment: Time-frequency bandwidth relationship for laser pulses-Checking the Heisenberg uncertainty principle

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CY 602: Electronics and Chemical Instrumentation (20/4/5)

Electronics
DC & AC Fundamentals: Concept of charge, current, voltage, power, Ohms law, AC –Sinusoidal, Peak & RMS values, Frequency.
Electronic components: Resistors, capacitors, diodes, transformer
Power Supply, Rectification, Filter, Line/Load Regulation, Regulator Chips, Low Voltage & High Voltage power supplies, SMPS.

Analogue Electronics
Operational Amplifiers, Ideal Characteristics, Inverting, Non-invertingAmplifier, Integrator, Comparator, Summer, Pulse Amplifier and Instrumentation Amplifier.

Digital Electronics
Number system and Logic gates - Decimal, Binary and Hexadecimal number systems, Logic gates, Flip Flop, Counter, Decoder, Display Device.
Analog to Digital Converters and Digital to Analog Converters

Instrumentation
Concept of Instrumentation, Order of instruments, concept of broad specifications (accuracy, precision etc), Voltmeter and Current meter, concept of Multimeter & concept of loading.
Signal & Noise: Concept of Noise & Signal, dB, S/N ratio and improvement techniques.
Transducers: Transducers and their applications (temperature sensors, PMT, photo diode and vacuum gauges)
Signal analysis & Processing: Selective signal amplification, filter, Lock-in-amplification, Boxcar Averager, Fast Fourier Transform.

Computer in Labs
PCs & interfacing concepts, RS232, USB ports, Embedded systems, Lab View programming.

References:

[1] Basic electronics for Scientists- McGraw Hill International (1977) - J. J. Brophy
[2] Basic Electronics - Bernard Grob McGraw Hill Book Co.
[3] Electronic Principles – Tata McGraw Hill Pub. Malvino
[4] Operational Amplifiers and linear integrated circuits –Prentice Hall of India Ltd.-Robert Conghlin, Fredrick Driscoll
[5] Art of Electronics, Cambridge University Press, London - Paul Horonitz and Winfield Hill
[6] Digital Principles and applications Tata McGraw Hill - Malvino& Leach
[7] Instrumental methods of chemical analysis, McGraw Hill - Ewing
[8] Introduction to instrumental analysis, McGraw Hill Book Co. - Robert D. Bramn.
[9] Principles of instrumental analysis by Skoog , Holler and Neiman (Fifth Edition)
[10] Electronic Instrumentation & Measurement technique - W D Cooper & A. D. Helfrick
[11] Optimisation of Electronic Measurement - Enke, Croach, &Florlicks
[12] Myer. Kuts, Temperature Control- Wiley (1968)
[13] S. Dushman and J.M. Lafferty- Scientific foundations of vacuum techniques, Wiley (1962)

CY 603: Production and Applications of Radioisotopes (20/4)

Introduction to the course
Relevance and contribution of the isotope program in DAE.

Production of Radioisotopes
Need for radioisotope production, Basic principles and different routes of radioisotope production using nuclear reactors and charged particle accelerators. Szilard-Chalmers effect and its utility in radioisotope production. Derivation of equation to calculate production yields in nuclear reactors and charged particle accelerators, Calculations of production yields; Bateman's equation and its utility in production yield calculations.

Production of some important radioisotopes in nuclear reactor and in cyclotron, Selection of target material, Methods of target preparation, Methods of processing of irradiated targets, Methods of production of some important radioisotopes (such as, $^{32/33}P$, ^{60}Co, ^{82}Br, ^{99}Mo, ^{99m}Tc, ^{125}I, ^{131}I, ^{137}Cs, ^{153}Sm, ^{166}Ho, ^{177}Lu, $^{186/188}Re$, ^{192}Ir, and ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{44}Sc, ^{64}Cu, ^{67}Ga, ^{68}Ge, ^{89}Zr, $^{123/124}I$, ^{201}Tl etc.).

Concept of radionuclide generators; Growth and decay of activity in a radionuclide generator; Different types radionuclide generators with special emphasis to ^{99}Mo-^{99m}Tc generators along with their relative advantages and disadvantages; Few other important generator systems such as, ^{68}Ge-^{68}Ga, ^{90}Sr-^{90}Y, ^{188}W-^{188}Re etc.

Applications of Radioisotopes in Medicine
Concept of nuclear medicine and radiopharmaceuticals, Classification of radiopharmaceuticals, Characteristics of diagnostic (SPECT and PET) and therapeutic radiopharmaceuticals. Basis of designing radiopharmaceuticals, Preparation of radiopharmaceuticals and Methods of radiolabeling.

New approaches in radiopharmaceuticals chemistry - ^{99m}Tc-tricarbonyl method, ^{99m}Tc-nitrido method, ^{99m}Tc-HYNIC method etc., Advantages of new approaches.

Some important organ-specific diagnostic radiopharmaceuticals (myocardial imaging, brain imaging, renal imaging, tumor and inflammation imaging, receptor-specific imaging agents etc.). Radioimmunoscintigraphy (RIS), PET radiopharmaceuticals - Principle and applications.

Concepts of brachytherapy and teletherapy.

Therapeutic radiopharmaceuticals for some specific applications [Metastatic Bone Pain Palliation (MBPP), Radiation Synovectomy (RSV), Peptide Receptor Radionuclide Therapy (PRRT), Radioimmunotherapy (RIT) etc.]

Quality control of radiopharmaceuticals - physicochemical and biological quality control tests.

Industrial Applications of Radiation Technology
Fundamental aspects of radiation processing and radiation technology, Radiation sources and effects of ionizing radiation on materials, Comparison of different radiation sources for different applications, Radiation dosimetry for industrial radiation sources.

Radiation polymerization vis-à-vis conventional polymerization, Polymerization kinetics and polymer characterization, Radiation effects on Polymers under different conditions, Theories of radiation crosslinking.

Radiation induced modification of polymers for industrial and environmental applications, wire and cable crosslinking, surface curing and grafting, heat-shrinkable materials, radiation cured polymer coatings and radiation grafted functional polymers for various applications, radiation degradation of polymers and applications, etc..

Radiation processed polymers for healthcare applications, Introduction to radiation sterilization of medical products (process, D_{10} value, SAL, inactivation factor and safety factor), hydrogels and their property standardization using radiation for wound dressings, radiation processed drug delivery devices.

Radiation processing of food, Objectives and dose limits for different food items

Radiation chemistry aspects of radiation hygienization of sewage sludge process and process control

Radiation processing of flue gases and radiolysis of flue gas components

Radiation induced enhancement in the functional attribute of blends and composites, Introduction to rheology of polymers, crosslinking and degradation behavior of multi-phase system, microscopic and mechanical characterization of blends and composites.

Application of radioisotopes as tracers in process optimization, trouble shooting in industries and sediment transport in harbours.

Application of Radioisotopes as Tracers
Principle and industrial applications of radiotracers, Process optimization and trouble shooting in industries-blockage location in buried pipelines, Leak detection in buried pipelines & industrial systems, Wear rate of anti-fungal paints, Flow rate determination in industrial processes.
Environmental isotopes and artificial radioisotopes in hydrology. Application of environmental isotopes in studying ground water salinity, pollution, recharge etc., Artificial radioisotopes in studying dam seepage, effluent dispersion etc.

References
[1] Manual for Reactor Produced Isotopes. IAEA-TECDOC-1340, IAEA, 1999.
[2] Fundamentals of Radiochemistry. D.D. Sood, A.V.R. Reddy, N. Ramamoorthy. Indian Association of Nuclear Chemists and Allied Scientists, 2004.
[3] Radiopharmaceuticals: Chemistry and Pharmacology, Adrian D. Nunn. Marcel Dekker, 1992.
[4] Fundamentals of Nuclear Pharmacy, G.B. Saha, Springer-Verlag, 1984.
[5] Radionuclides in Therapy, R.P. Spencer, R.H. Sievers, A.M. Friedman. CRC Press, Boca Raton, 1987.
[6] PET in Oncology: Basics and Clinical Applications, J. Ruhlmann, P. Oehr, H.J. Biersack. Springer-Verlag, 1998.
[7] ICRU Report (1980) Radiation Quantities and Units, ICRU Publications, 33
[8] An Introduction to Radiation Chemistry. J.W.T. Spinks and R.J. Woods, John-Wiley, New York-London-

Sydney, 1990.
[9] Radiation Processing of Polymer Materials and its Industrial Applications K. Makuuchi, S. Cheng, Wiley, 2012.
[10] Dynamic Mechanical Analysis: A Practical Introduction. K.P. Menars, CRC Press, Boca Raton, 1999.
[11] Industrial application of radioisotopes. G. Foldiak.
[12] Guide Book on Radioisotope Tracers in Industry - Tech. Rep. Series 316, IAEA, Vienna, 1990.
[13] Environmental Isotopes in Hydrogeology. Ian Clarke and Peter Fritz, Lewis Publishers, NY, 1997.

CY 604: Reactor Physics and Reactor Chemistry (20)

Fission, Energy from fission, Burn-up, Spontaneous and induced fission, Chain reaction, Fissile-Fissionable-fertile materials, Prompt and delayed neutrons, Four factor formula, Neutron interaction with matter, Fission products, Critical mass, Neutron Diffusion Theory, Multiplication factor, Reactor kinetics and control.

Different types of homogeneous and heterogeneous reactors, Components of reactors.

Introduction to the types of water cooled power reactors & their process systems. Schemes of preparation of dimineralized water, Variation in properties of water and heavy water as a function of temperature and pressure. An overview of types of corrosion, methods of evaluation of corrosion and its prevention. An overview of materials of construction for the different components of reactor systems. Hot Conditioning of PHT circuit in PHWR. An overview of water chemistry regimes in BWR, PWR & PHWR.

Principles and processes relevant to chemistry control in primary heat transport systems. Radioactivities in reactor waters & their control. CRUD generation and activity transport in the primary heat transport system of reactors its control. Radiolysis of water, related hazard, and its control, Reactivity control through chemistry: Use of soluble neutron poisons- for chemical shim and for emergency shutdown. Purification of reactor cover gas by Catalytic recombination and adsorption techniques.

Chemistry control in secondary heat transport system, pH control methodologies of secondary system, Scaling and methodology of its control in secondary system.

Chemistry control in the tertiary heat transport system, Bio-fouling and its control methodologies.

References
[1] R.A. Knief: Nuclear Energy Technology (1981).
[2] S. Glasstone and M.C. Edlund: The elements of Nuclear Reactor Theory (1952).
[3] P. Cohen: Water Coolant Technology in Power Reactors, American Nuclear Society, U.S.A (1980).
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[5] H. H. Uhlig: Corrosion and Corrosion Control, John-Wiley & Sons, N.Y., (1985)
[6] International Atomic Energy Agency, Coolant Technology of Water Cooled Reactors, IAEA-TECDOC-667, Vols. 1-4,Vienna
[7] M. Benedict, T.H. Pigford and Levi: Nuclear Chemical Engineering.
[8] S. Glasstone & A. Sesonske: Nuclear Reactor Engineering, Vol I & II, CBS Publications, Delhi (1977)

CY 605: Molecular Structure and Spectroscopy (30/6/4)

Coordination Chemistry
Werner's Coordination theory, Valence Bond Theory, Crystal Field Theory, splitting of "d" orbital in different geometry, Jahn Teller effect, Thermodynamic effects of crystal field, Coordination chemistry of lanthanide and actinide ions, Brief introduction to group theory, Application of group theory for d-d transition, Racah parameters, electronic spectra of complex ions, Tanabe Sugano diagram, nephelauxetic effect, ligand metal orbital overlaps, magnetic properties and susceptibility measurements of complex ions, drawbacks of CFT, f-f transitions in lanthanides.

Molecular orbital theory and construction of molecular orbital diagram from concepts of group theory, MO's for Sigma bonding in AB_6 molecules, tetrahedral AB_4 case, MO's for pi bonding in AB_6 molecules, Metal organic framework materials. Dissociative & associative reaction mechanism of ligand replacement in octahedral and square planar complexes, trans effect and its implications.

Characterization Techniques of Complexes
NMR: Basic Principles of NMR Spectroscopy, Chemical Shift, Spin-Spin Coupling, Decoupling Experiments, Pulse NMR, Relaxation Effects, Two-Pulse Experiment, T1-Measurment, T-2 measurement, solid state NMR, ESR: Basic Principles of ESR Spectroscopy, The g-value, Hyperfine Coupling, Electron Nuclear Double Resonance (ENDOR), Mossbauer spectroscopy

Electronic, Vibrational and Rotational Spectroscopy
Classification of molecules, their characteristic spectral features and selection rules, pure microwave, Rotational Raman, Vibrational and rotational vibrational spectroscopy, IR and Raman spectroscopy.
Basic principles of Fourier transform spectroscopy (FTIR, FT-RAMAN).
Surface enhanced Raman spectroscopy (SERS), Terahertz spectroscopy, Nonlinear optical methods, sum & difference frequency generation (SFG & DFG).
Synchrotron radiation and its application in spectroscopy, X ray absorption based techniques (XANES, EXAFS)
X ray Photoelectron Spectroscopy.
Doppler-free high-resolution spectroscopy

Laboratory Experiments
[1] Electronic spectra of a transition metal complex .d-d transitions.
[2] NMR
[3] FT-IR
[4] Raman

References

[1] Advance Inorganic Chemistry - F.A.Cotton and G.Wilkinson
[2] Physical Methods in Inorganic Chemistry - R.S. Drago
[3] Modern Coordination Chemistry – Lewis and Wilkins
[4] Introduction to ligand fields - B.N. Figgis
[5] Ligand field theory - C.J. Ballhausen
[6] Comprehensive Inorganic Chemistry - Huchey
[7] Molecular Spectroscopy - C.N. Banwell
[8] Infra red spectra of Inorganic and coordination compounds - K. Nakamoto
[9] Laser spectroscopy: Basic concepts and instrumentation - W. Demtroder

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CY 606: Radiation and PhotoChemistry (30/6/4)

Radiation Chemistry
Interaction of High-energy Radiation with Matter
Chemical consequences, absorption coefficients, G-values, track entities and LET effects, radiation sources.
Diffusion kinetics and homogeneous reaction stages, time scales of events in radiation chemistry, ion-pairs, ion-molecule reactions

Radiation Chemistry of Water and Nonpolar Liquids
Radiolysis of water & heavy water, radical and molecular yields, material balance, chemical dosimetry
Radiolysis of non-polar solvents, geminate recombination, electron salvation
Radiation chemistry of micro heterogeneous systems and ionic liquids
Comparative aspects of radiolysis of liquids, solids and gases

Experimental Techniques
Detection of primary species and free radicals using pulse radiolysis coupled with optical absorption

spectroscopy, ESR, conductivity, resonance Raman spectroscopy
Evaluation of absolute rate constants, pK values of transient species, one-electron redox potentials, picoseconds pulse radiolysis

Application
Radiolytic synthesis of nanoparticles
Radiation chemistry of water at high temperature and high pressure
Radiation chemistry of antioxidants and radioprotectors.

Photochemistry
Photophysical Processes
Electronic transitions, oscillator strength, selection rules
Franck-Condon principle, absorption, emission and fluorescence excitation spectra, charge-transfer spectra.
Deexcitation processes - fluorescence, phosphorescence, delayed emission, triplet-triplet annihilation, heavy atom effect, kinetics of excited state processes, quantum yields of photo-processes
Fluorescence anisotropy
Photophysical processes in semiconductors, multiphoton processes
Environment effect- polarity, viscosity (anisotropy), temperature

Photochemical Processes
Excited state acid-base properties, redox potentials, geometry, dipole moments
Kinetics and mechanism of processes like photo-dissociation, photo-ionization, electron transfer, energy transfer, proton transfer, supra-molecular interactions

Experimental Techniques
Steady-state absorption and fluorescence techniques
Time-resolved absorption and fluorescence techniques like time-correlated single photon counting, fluorescence up-conversion, nanosecond laser flash photolysis and ultrafast pump-probe spectroscopy; single molecule spectroscopy, fluorescence correlation spectroscopy

Applications
Photosynthesis, vision, solar energy conversion, photocatalysis, fluorescence sensors.

Laboratory Experiments
Radiation Chemistry
[1] Fricke dosimetry and estimation of G-values.
[2] Study of free radical reactions using pulse radiolysis technique.
Photochemistry
[1] Fluorescence quenching studies: determination of quenching rate constant.
[2] Excited state properties: determination of acid dissociation constant using absorption & fluorescence techniques.

References
Radiation Chemistry
[1] An introduction to Radiation Chemistry. J. W. T. Spinks and R. J. Woods; Wiley Interscience, New York, 1990.
[2] Radiation Chemistry: An Introduction. A. J. Swallow; Longman, London, 1973.
[3] Radiation Chemistry. Belloni
[4] Charged particle. A. Mozumdar &Y. Hatano .
[5] Radiation Chemistry: Principles and Applications. Editors: Farhataziz and Michael A. J. Rodgers, VCH, New York, 1987.
[6] The Study of Fast Proccesses and Transient Species by Electron Pulse Radiolysis. Editors: J. H. Baxendale and F. Busi; Reidel, Dordrecht, Holland, 1982.
[7] A. J. Swallow, Reaction of free radicals produced from organic compounds in aqueous solution by means of radiolysis. Prog. React. Kin. 9, 1978, 195.
Photochemistry
[1] K. K. Rohatgi-Mukherjee, Fundamentals of Photochemistry; Wiley Eastern: New Delhi, 1978.
[2] J. B. Birks, Photophysics of Aromatic Molecules. Wiley Interscience, New York, 1970.
[3] J. R. Lakowicz, Principle of fluorescence spectroscopy, 3rd ed.; Springer: New York, 2006.
[4] J. Turro, Modern Molecular Photochemistry, Benzamin, Menlo Park, CA, 1978.

[5] R. P. Wynes, Principles and Applications of Photochemistry. Oxford Science Publications, 1988.
[6] A. Gilbert, J. Baggott, and P. J. Wagner, Essentials of molecular photochemistry, Blackwell Science Inc. Cambridge, USA, 1991.
[7] D. V. O'Connor and D. Phillips, Time Correlated Single Photon Counting. Academic Press, New York (1984).
[8] J. N. Demas, Excited State Life Time Measurements. Academic Press, New York, 1983.

CY 607: Chemistry in Nuclear Fuel Cycle (40)

Separation and purification of uranium and thorium from their ores, Principles of isotope separation, enrichment of uranium, systematics and processes.

Conversion processes for preparation of UO_2, $(U,Pu)O_2$, UC, (U,Pu)C, UN (U,Pu)N, metals and alloys.

Separation and purification of zirconium from its ore, Principle and process for heavy water production.

Fuel fabrication processes and chemical quality control

Behavior of nuclear fuels (thermal/fast) during irradiation

Post irradiation studies, fuel clad chemical interaction, Burn-up etc.

Thermo-physical and themo-chemical aspects of fuel, Properties of oxide, carbide, nitride and metallic fuel materials, Coated particle based fuels.

Cladding, moderator, coolant materials and their properties, Liquid metal coolants like sodium and lead-bismuth, Chemical aspects of corrosion, Monitoring and maintenance of the purity of coolant.

Reprocessing of thermal and fast reactor fuels, chemistry of various process PUREX, THOREX etc., Systematic and process of pilot plant CORAL, Challenges in reprocessing of fast reactor fuel.

Waste processing and management, classification of waste and treatment practices of gaseous, liquid and solid waste.

Vitrification of high level liquid waste, Partitioning of actinides from high level liquids waste, Decontamination process.

Nuclear safety, Management of H_2, Xe, Kr, I_2 and tritium in operating nuclear power plants

References
[1] D. R. Olander: Fundamental Aspects of Nuclear Reactor Fuel Elements: USERDA Report TID-26711 (1976)
[2] D. Wilson: The Nuclear Fuel Cycle, From Ore to Waste, Oxford University Press Inc. New York (1996)
[3] E. Glueckauf, Atomic Energy Waste: Its Nature, Treatment and Disposal, Interscience Publishers Inc. New York (9161)
[4] R. L. Murray and J. A. Powell: Understanding Radioactive Waste, 4th Edition, Columbus: Battelle Press (1994)

CY 608: Advanced Chemical Kinetics and Dynamics (20/4)

Intermolecular interaction potential, Collision theory, Potential energy surfaces, Activated complex theory, adiabatic and non-adiabatic reactions, Landau-Zener crossing, Lindemann's theory of unimolecular reactions, energy transfer, fall-off region and its limitations, Hinshelwood's Treatment. Rice-Ramsperger and Kassel (RRK) model, and Marcus refinement of RRK model (RRKM) for the calculation of rate constants of simple unimolecular reactions.

Molecular beam experiments, types & characteristics of molecular beams, scattering as a probe; differential cross-section; quantum mechanical approach to elastic scattering; conservation of angular momentum – Newton diagram, lab–to-centre of mass transformation, reaction cross section - reaction probability; opacity function – steric factor; reactive asymmetry – angular distribution in reactive collisions – direct reaction versus collision complex; forward, backward, and forward–backward scattering; potential energy contour diagram, reactions with early & late barrier. Different molecular energy transfer processes. Laser based spectroscopic techniques- LIF, REMPI, CRDS, detection and measurement of trace constituents and free radicals, rate coefficient measurement, chemical kinetics and dynamics studies, atmospheric chemistry.

IR laser chemistry, laser isotope separation, mode and bond selective chemistry, intramolecular vibrational energy redistribution (IVR), coherent control of chemical reaction,

References

[1] Chemical Kinetics - K. J. Laidler, Third Edition, Pearson Education, Singapore (2004).
[2] Molecular reaction dynamics and chemical reactivity - R. D. Levine and R. B. Bernstein, Oxford University Press, New York (1987).
[3] Chemical dynamics via molecular beam and laser techniques - R. B. Bernstein, Clarendon Press, Oxford (1982)
[4] Unimolecular reactions - P. J. Robinson, S.H. Robertson and K. A. Holbrook, Wiley, London (1996)
[5] Introduction to molecular dynamics and kinetics - G.D.Billing and K.V. Mikkelsen, Wiley, NY (1996)
[6] Chemical Kinetics and Dynamics - J F. Steinfeld, J.S. Francisco and W. L. Hase, Prentice Hall International, Inc. III, New Jersey (1999).
[7] Chemical Kinetics and Reaction Dynamics – P.L. Houston, McGraw-Hill Higher Education, (2001).
[8] Laser Spectroscopy: Basic Concepts and Instrumentation- W. DemtrÖder, Springer International (2004)

CY 609: Health Physics and Radiation Biology (20)

Health Physics
Fundamentals of Radiation Protection
Radioactivity, Ionizing radiation, Radiation quantities and units**,** Basis and structure of the system for radiation protection, System of radiological protection for human, natural radiation.

Basic Radiation Physics and Radiation Dosimetry Aspects
Interaction of radiation with matter, External and internal radiation hazards in nuclear and radiation facilities, Radiation dosimetery: basics, concepts and definitions, External radiation dosimetry and dosimetry of internally deposited radio nuclides, Radiation detection principles, Monitoring instruments and Personnel monitoring devices

Operational Monitoring and Safety Aspects of Facility Design
Exposure situations as per ICRP-103 recommendations, Control of external and internal radiation hazards, Radiation dose limits and its basis, General principles and techniques of radiation monitoring, air activity and area contamination, Assessment and control of radiation hazards in nuclear fuel cycle facilities with special reference to metallurgical, radiochemical and radioisotope facilities and fuel reprocessing plants, Criticality safety aspects, Environmental safety aspects during operation of nuclear and radiation facilities, Industrial hygiene and safety aspects during operation of nuclear and radiation facilities.

Radiological Safety Aspects in Design of Radio-Chemical Laboratories
Safety aspects of design of radiochemical laboratory, its types and operational aspects, Partial containment/confinement systems and ventilation system in a laboratory.

Emergency Preparedness and Response System at Nuclear and Radiation Facilities
Classification of radiation emergency, Emergency preparedness and response system, Reference levels and guidance values for emergency workers.

Basic Radiation Radiobiology
Water radiolysis, Free radicals and its reactions with biological systems, Oxygen effect.

Radiation damage at bio-molecular level, Damage to DNA and chromosomes (single and double structural breaks, chromosomal aberrations) and its biological consequences, Radiation damage to membrane and its biological consequences, Major health effects of radiation exposure.

Mode of interaction of different types of radiation with biological systems, Track structure, Concept of LET, Radiobiological effectiveness (RBE), Radiation dose units with reference to radiobiology, Direct and indirect effect of radiation.

Molecular and Cellular Effects of Radiation
Assay for radiation damage in human cells (survival curve), Physical and biological factors affecting the cellular radio-sensitivity, Dose and dose rate effect, Dose fractionation, Inverse dose rate effect, Oxygen enhancement ratio and Optimum LET, Radio-protectors and radio-sensitizers.
Cell cycle arrest and radiation damage repair, Cancer and its induction by radiation, Radiobiology of cancer radiotherapy approaches

References
[1] Introduction to Health Physics by Herman Camber
[2] International Commission on Radiological Protection (ICRP) Publication-103, 2007
[3] IAEA- BSS- GSR Part-7, 2015
[4] AERB Safety Guidelines NO. AERB/NRF/SG/EP-5 (Rev. 1), 2015
[5] Biological Effects of Radiation by J. E. Coggle
[6] Radiobiology for Radiologist by Eris J. Hall

CY 610: Research Methodology (20)

Objectives and types of research: Motivation and objectives - Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem - Literature review – Primary and secondary sources - reviews, treatise, monographs-patents - web as a source - searching the web - Critical literature review - Identifying gap areas from literature review - Development of working hypothesis.

Research design and methods - Research design – Basic Principles - Need of research design - Features of good design – Important concepts relating to research design - Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Value of Statistics; Errors and Statistics - Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results - students's t test; F-test; Chi Square test; propagation of errors.

Reporting and thesis writing – Structure and components of scientific reports - Types of report - Technical reports and thesis - Significance - Different steps in the preparation – Layout, structure and Language of typical reports - Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation - Planning - Preparation - Practice - Making presentation - Use of visual aids - Importance of effective communication - Computers in Chemistry, Usage of packages such as, Excel, AIM2000, ChemCraft, etc. Manuscript drafting based on 'Experimental data and Literature Survey'.

Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialisation - Copy right - Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights - Reproduction of published material - Plagiarism - Citation and acknowledgement - Reproducibility and accountability.

References
[1] Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction to Research Methodology, RBSA Publishers.
[2] Kothari, C.R., 2000, Research Methodology: Methods and Techniques. New Age International.
[3] Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Publications (2 volumes)
[4] R. Paneer Selvam - Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
[5] Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
[6] Day, R.A., 1992.How to Write and Publish a Scientific Paper, Cambridge University Press.
[7] Vogel's Text Book of Quantitative Inorganic Analysis, ELBS.

CY 611 Safety in Chemical and Radiochemical labs (10)

Chemical labs

Definition of chemical safety and its assessment, general chemical safety awareness, Classification of chemicals: Corrosive, Flammables, explosives, toxics, pyrophoric, carcinogen. Chemical which create lachrymation and smoke, Entry of such chemicals into human/biological system and its consequences, precautionary and safe methods for handling such chemicals, Compatibility issues with chemicals, Understanding the Safety Data Sheets (Material Safety Data Sheets) for different chemicals. Storing different chemicals, incompatible chemicals, making inventory of chemicals, labelling chemicals depending upon its nature, safe disposal of chemicals, precautions and safe operating procedures (SOP) to be taken into consideration for chemical spills, chemical protective clothing, chemical accidents and their classification and consequences, Emergency Procedures during chemical accidents, Personal Protective equipment from chemical exposure, precautions to be taken with chemical which need to be refrigerated. Safe practices while using vacuum lines and laser. Fire safety and different types of fire extinguishers.

Radiochemical labs

Classification of laboratories, classification of radioactive zones in the laboratory, ventilation, Shielding and dosimetry requirements for handling different types of radioactivity, Radioactivity handling in fume-hoods and glove boxes, Movement of radioactivity within the lab, Washing of radioactive glass wares, Disposal of radioactive aqueous and organic waste, Disposal of compressible and non-compressible radioactive waste, fire safety in radioactive labs, Personnel radiation monitors, Managing personnel and laboratory contamination, Precautions in a radioactive lab and emergency procedures.

ELECTIVE COURSES

CY 701: Nanomaterials and Chemical Sensors (20)

An overview of the course

Physics of nanomaterials
Finite size systems, cluster science, bulk versus nanomaterials, quantum confinement effects in nano-regime, evolution of electronic structure from atoms to bulk, density of states, dimensionality and its effect on electronic structure, surface effects, calculation of surface-to-volume ratio for different structural arrangements, size dependent physico-chemical properties, carbon based materials (0D, 1D, 2D and 3D).

Chemistry of nanomaterials
Top down and bottom up approaches for synthesis of nanomaterials, such as laser ablation, ball-milling, sputtering, combustion, metathesis, sol-gel etc.

Common characterization techniques for nanomaterials
Characterization techniques at different length scales, application of XRD, TEM, SEM, AFM and DLS for characterization of nanomaterials.

Properties of nanomaterials
Fundamentals of Semiconductors, direct and indirect band gaps, semicounductor in nano-dimesnions (quantum dots, core-shell nano-particles of semiconductors), metallic nanoparticles and surface plasmon, an overview of magnetic, optical and catalytic properties of nanomaterials.

Applications of nanomaterials
Nanomaterials in energy conversion (solar cell, rechargable batteries, supercapacitors and materials for hydrogen energy), nanomaterials for bio-applications (drug delivery), environmental applications (sorbents) and DAE application.

Chemical sensors and their applications
Threshold limit values (TLV) of common toxic species, selection of sensor materials mechanism of sensing action, features of sensors (selectivity, response time, reproducibility and regeneration), typical examples of nanomaterials based sensors for H_2S, NH_3, SO_2, and heavy metal ions, common bio-sensors, sensors for DAE applications.

References
[1] Advanced Techniques for Materials Characterization Eds. A. K. Tyagi, M. Roy, S. K. Kulshreshta, S. Banerjee, Trans Tech Publications Ltd, Switzerland (2009)
[2] Fundamental properties of Nanostructured Materials, Eds. D. Fiorani (World Scientific, Singapore, 1994)
[3] Nanostructured Magnetic Materials and their Applications, Eds. D. Shi et al. (Springer, Berlin, 2002)
[4] Mechanical Properties and Deformation Behavior of Materials having Ultrafine Microstructures, Eds. M. Nastasi et al. (Kluwer, Amsterdam, 2002)
[5] Functional Materials: Preparation, Processing and Applications, Eds. S. Banerjee and A. K. Tyagi, Elsevier Publishers (2012)

CY 702: Soft Condensed Matter (20)

Introduction to Soft Matter
Forces, energies, length and time scales in soft matter. Soft matter systems (colloids, surfactant / micellar systems, gels, polymer solutions, polymers, polyelectrolytes, microemulsions, membrances, biological macromolecules), Interactions (electrostatic, van der Walls, hydrophilic and hydrophobic interactions, depletion interaction). Viscous, elastic and viscoelastic behavior, Liquids and Glasses, Soft matter in nature:

Experimental techniques to investigate structure and dynamics in soft matter
Scattering techniques (Small-angle X-ray scattering (SAXS), Ultra-small-angle-X-ray scattering (USAXS), Small-angle (SANS) Static and Dynamic light scattering (SLS & DLS)
Colloids
Introduction, Brownian motion of colloidal particles. Sterically stabilized and Charge stabilized colloids, Colloidal interactions, Liquid phase synthesis of colloidal particles, Structural ordering, Dynamics, Phase Transitions [Gas-liquid, Melting /freezing, Glass Transition, Crystal-amorphous]

Surfactants
Types of surfactants, Micellization, Langmuir- Blodgett films, Monolayer, Bilayers and Vesicles, Lyotropic liquid crystalline phases, Micro emulsions.

Polymers and Polyelectrolytes
A single ideal chain, mean-squared end to-end distance, radius of gyration. Gaussian chain, Freely joined chain. Excluded volume, solvent quality, theta-temperature. Polymer solutions : Flory-Huggins theory, osmotic pressure, scaling laws for good solvents, Size of a polymer in semi-dilute solutions : osmotic pressure, light scattering, intrinsic viscosity, Classes of gels : physical gels, chemical gels and photo-polymerized gels, Sol-Gel transition, Swelling and shrinking of gels, theory of gelation. Polyelectrolytes : Debye-Huckle theory, Donnan equilibrium, manning condensation. Dynamics of polymeric liquids : Maxwell model. Rouse theory, Zimm theory, Reptation theory : tube model, reptation dynamics, self –assembly and order-disorder transitions of diblock copolymers

Applications of Soft Matter
Nanoparticle suspensions as heat transfer fluids. Colloidal assemblies in liquid-liquid extraction systems. Ionic liquids as extractants. Foams and Gels for decontamination. Foamability of surfactants. Dynamic interfacial tension and foamability. Defoamers, Soft matter in drug delivery and diagnostics.

References
[1] Soft Condensed Matter. R. A. L .Jones, Oxford university (2003)
[2] Soft Matter: Complex Materials on Mesoscopic scales. J.K.G Dhont, G. Gompper and D. Richter (Eds) (Forschungzentrum Jülich GmbH, Jülich-2002)
[3] Ordering and Phase Transitions in Charged Colloids. A.K. Arora and B.V.R. Tata (Eds) (VCH-1996)
[4] Colloidal Dispersions. W.B. Russel, D.A. Saville and W.R. Schowalter (Cambridge university press, Cambridge, 1989)
[5] Intermolecular and Surface Forces. (J.N. Israelachvili) (Academic press, London, 1992)
[6] Micelles. Membranes, Microemulsions and Monolayers. Edited by W.M. Gilbet, A. Ben-Shaul and D. Roux (Springer-Verlag, Berlin,1994)
[7] Principles of Condensed Matter Physics. P.M. Chaikin and T.C. Lubensky, (Cambridge university press, Cambridge, 1995)
[8] Polymer Solutions: An introduction to Physical Properties. Iwao Toraoka, (John Wiley & Sons, 2002)
[9] Polymer Physics. M. Rubinstein and R.C. Colby (Oxford University Press ,2003)
[10] Physical properties of polymeric gels. J.P.C. Added (John Wiley & Sons, 1996).
[11] Neutrons, X-rays and Light: Scattering Methods Applied to Soft condensed matter" P. Linder, T. Zebu Eds. (North Holland-Elsevier, 2002)
[12] Dynamic light scattering: Applications of Photon Correlation Spectroscopy. R. Pecora (Plenum, 1985).
[13] The colloidal domain: where physics, chemistry, biology and technology meet. D. F. Evans and H. Wennerstrom (Wiley-VCH)

CY 703: Nuclear Probes for Material Characterization (20)

Positron Annihilation Spectroscopy
Introduction to positron, positronium, formation and its systematic, Experimental techniques, applications in molecular solids, defect studies in metals, alloys and semiconductors, Slow positron accelerators and associated developments in materials characterization.

Ion beam analysis

Introduction to ion beam analysis, Rutherford backscattering spectrometry, elastic recoil detection analysis, nuclear reactions analysis, particle induced gamma ray emission, particle induced X-ray emission-Theory and applications.

Neutron Scattering Techniques
Neutron Sources, Properties of Neutron, Neutron Scattering Lengths and Cross-sections, Coherent and Incoherent Neutron Scattering

Small-Angle Neutron Scattering
Scattering from General Two Phase Systems, Scattering from Fractal Aggregates, Nuclear vs. Magnetic Scattering

Small-Angle Neutron Scattering Instrumentation
Experimental Aspects, Data Treatment

Analysis of Small-Angle Neutron Scattering Data
Model Independent Analysis, Model Dependent Analysis, Contrast Variation

Applications
Nanomaterials, Colloids, Biological Systems, Porous and Fractal Structures)

X-ray absorption Spectroscopy
Introduction of X-ray absorption spectroscopy including different processes of absorption of X-rays in materials, Theoretical formalism of EXAFS, Derivation of the EXAFS equation with physical interpretation, Experimental techniques with some introduction to Synchrotron radiation, Data analysis (EXAFS & XANES), Usefulness of the EXAFS technique in material characterization- with few case studies.

References
[1] Structure Analysis by Small-Angle X-Ray and Neutron Scattering, L.A. Feigin and D.I. Svergun (Plenum Press, New York, 1987)
[2] Neutron, X-Ray and Light Scattering, P. Lindner and T. Zemb (North-Holland, Amsterdam, 1991)
[3] Neutron Scattering from Polymers, J.S. Higgins and H. Benoit (Clarendon, Oxford, 1994)
[4] Analysis of Small-angle Scattering Data from Polymeric and Colloidal Systems: Modelling and Least-squares Fitting, J. S. Pedersen, Advances in Colloid and Interface Science **70**, 171-201 (1997).
[5] Small-angle Scattering Studies of Biological Macromolecules in Solution, D.I. Svergun and M.H.J. Koch, Reports on Progress in Physics 66, 1735–1782 (2003).
[6] Introduction to XAFS: A Practical Guide to X-ray Absorption Fine Structure Spectroscopy, G. Bunker, Cambridge University Press, 2010.
[7] X-ray Absorption: principles, applications and techniques of EXAFS, SEXAFS and XANES, D.C. Koeningsberger and R. Prins, Wiley (NY) 1988.
[8] Treatise on Heavy Ion Sciences, W.A. Landford, Edited by Allan Bromley, vol. 6, (1986), p363.

CY 704: Molecular Bioorganics (20)

New paradigm in synthesis
Rational synthetic design, convergent and divergent strategies, multi-component and domino reactions, sequential reactions, high-throughput synthesis, organocatalysis, substrate and reagent controlled asymmetric synthesis
New paradigm in synthetic approaches
Green strategies, atom economy, bio-catalysis and solvent engineering, microwave and sono-chemistry, non-conventional reaction media (room temperature ionic liquids, super critical fluids, florous phase, super-heated steam), template-driven synthesis.

New paradigm in functional targets
Design and synthesis of functional molecules/ molecular assemblies, non-covalent interactions, electro-magnetic radiation active organics, organic-inorganic hybrids, organics in nuclear fuel cycles.

References

[1] J. Zhu and H. Bienayme, Multicomponent Reactions, Wiley-VCHVerlaggmbH& Co. 2005.
[2] G. Jung, Combinatorial Chemistry: Synthesis, Analysis, Screening, Wiley, 1999.
[3] W. Bannworth and E. Felder, Combinatorial Chemistry: A Practical Approach, Wiley, 2000.
[4] G. R. Stephenson, Advanced Asymmetric Synthesis, Chapman & Hall, 1996.
[5] P. T. Anastas and T. C. Williamson, Green Chemistry, Oxford Univ. Press, 1998.
[6] C. H. Wong and G. M. Whiteside, Enzymes in Synthetic Organic Chemistry, Pergamon Press 1994.
[7] G. W. Gokel, Advances in Supramolecular Chemistry, 2000.
[8] J. W. Steed and J. L. Altwood, Supramolecular Chemistry, Wiley, 2004.

CY 705: Laser Spectroscopy (20)

Coherence properties of radiation fields
Temporal and spatial coherence, coherence volume, degree of coherence, coherence of atomic systems.

Widths and profiles of spectral lines
Natural line width, Doppler width, collisional broadening of spectral lines, transit time broadening, homogeneous and inhomogeneous line broadening, spectral line profiles in liquids and solids.

Nonlinear optical mixing techniques
Phase matching, second harmonic generation, sum frequency and higher harmonic generation, difference frequency generation, optical parametric oscillator and amplifier, tunable Raman laser, Gaussian beams.

Spectrometers, interferometers, wavemeters and detectors
Basic concepts of spectrometers and interferometers, different kinds of interferometers - Michelson interferometer, Mac-Zhender interferometer, Fabry - Perot interferometer, multilayer dielectric coatings, interference filters, tunable interferometers. Webmeters - Michelson, Sigmameter, Fabry - perot and Feazeu. Detectors – photoconductive and photovoltaic detectors, fast and avalanche photodiodes, photodiode arrays, photomultipliers, multichannel platesand image intensifiers.

Absorption and emission spectroscopic techniques
High sensitivity methods of absorption spectroscopy - cavity ring down spectroscopy. Laser induced fluorescence spectroscopy, photoacoustic spectroscopy, optothermal spectroscopy, ionization spectroscopy, optogalvanic spectroscopy.

Nonlinear spectroscopy
Nonlinear absorption, saturation of inhomogeneous line profiles, hole burning spectroscopy, lamb dip spectroscopy, saturation spectroscopy, polarization spectroscopy, multiphoton spectroscopy, Doppler free two photon spectroscopy, saturated interference spectroscopy.

Laser Raman spectroscopy
Stimulated Raman, coherent anti-Stokes Raman spectroscopy (CARS), Resonance Raman and surface enhanced Raman scattering.

Applications of laser spectroscopic techniques in physics, chemistry and biology

CY 706: Actinide Chemistry (20)

Position in Periodic Table: Electronic configuration, The Actinide Concept, Transuranium elements.

Actinide Spectroscopy: Electronic states, Atomic properties, UV-visible absorption and emission spectroscopy. Time resolved fluorescence spectroscopy (TRFS).
Electronic structure and bonding: Introduction to *'f'* orbitals and their splitting in the ligand field. Relativistic effect and its consequences. Modern techniques for understanding the bonding in actinide compounds.

Co-ordination Chemistry: Ionic radii, Coordination number, Hydration Energy.

Redox Behavior: Redox potentials, Eh-pH diagrams, Variable oxidation states, Ionic species, unusual oxidation states in actinides and their stabilization, Thermodynamic/ kinetics of redox reactions, Disproportionation.

Hydrolysis of Actinides: Hydrolysis, Polymerization / Depolymerization.

Auto-radiolysis: Auto-radiolytic effects in aqueous solutions, Auto-radiolysis effects in solid compounds of actinides.

Complexation behaviour with inorganic/organic ligands: Ion-exchange, Solvent extraction methods for actinides (inter and intra-group separations), Complexation reactions relevant in CQC of nuclear fuels, Analytical chemistry of transplutonium elements, Lanthanides-actinide separation, SANEX process.
Actinides in the Environment: Natural abundance of actinides, Oklo phenomenon, Actinide speciation in aquatic environment, Complexation with naturally occurring organics such as humic acid and fulvic acid, Sorption and Migration, Interaction with rock, clay, mica etc. Formation and migration of radiocolloids.

Biochemistry of Actinides: Actinide-microbe interaction, Actinide migration in the food chain, Fixation in human, Pu in blood, Intra-cellular uptake of Pu, Sequestering using chelation therapy, Bioremediation of nuclear wastes.

Transactinides: Production, Rapid separation techniques, Atom-at-a-time chemistry. Aqueous chemistry of elements 104, 105 and 106

References
[1] J.J. Kratz, G.T. Seaborg and L.R. Morss; The Chemistry of Actinide Elements, 2nd Edition, Vol. 1&2, Chapman & Hall, New York (1986).
[2] J.J. Katz, L.R. Morss, J.Fuger, and N.M. Edelstein; Chemistry of Actinide and Transactinide Elements, 3rd edition, Springer, Berlin Volume 1-5, (2006).
[3] J.C. Bailar, H.J. Emelius, R. Nyholm and A.F. Trotman-Dickenson; Comprehensive Inorganic Chemistry, Vol. 5, Pergamon Press, Oxford (1973).
[4] A.J. Freeman and C. Keller (Eds.); Handbook of Chemistry and Physics of the Actinides, Vol. 1-6, North Holland Publishers, Amsterdam (1986).
[5] G.R. Choppin and M.K. Khankhasayev; Chemical Separation Technologies and Related Methods of Nuclear Waste Management, Kluwer Academic Publishers, Netherlands (1999).
[6] G.R. Choppin and J. Rydberg; Nuclear Chemistry, Theory and Application, Pergamon Press, Great Britain (1980).

CY 707: Computational Chemistry (20)

Introduction: Revision to Classical Mechanics, Revision to Quantum Mechanics
Force Field Methods: Force Field Energy , Stretching, Bending, Out-of-plane bending, Torsion, van der Waals, Electrostatic, cross terms, Validation of Force Fields, Advantage & Limitations.
Optimization Techniques: Finding Minima-Steepest descent, Conjugate gradient methods, Newton–Raphson methods; Finding Saddle Points-linear and quadratic synchronous transit, gradient norm minimization, Newton–Raphson; Conformational Sampling and the Global Minimum Problem; Stochastic and Monte Carlo methods; Simulated annealing.
Electronic Structure Methods: Self Consistent Field Theory, Restricted & unrestricted HF, Semi-empirical Methods.
Electron Correlation Methods: Configuration Interaction Methods, Multi Configuration Self-Consistent Field, Many Body Perturbation Theory, Couple Cluster Method.
Basis Sets: Slater and Gaussian Type Orbitals, Pople style basis sets, Dunning–Huzinaga basis sets, Correlation consistent basis sets, Plane Wave Basis Functions, Basis Set Superposition Errors.
Density Functional Methods: Kohn–Sham Theory, Reduced Density Matrix Methods, Exchange–Correlation Functionals-Local Density Approximation, Hybrid or hyper-GGA methods, DFT Problems.
Wave Functional analysis: Population Analysis Based on Basis Functions, Population Analysis Based on the

Electrostatic Potential, Population Analysis Based on the Electron Density, Localized Orbitals, Natural Atomic Orbital and Natural Bond Orbital Analysis.
Molecular Properties: Perturbation Methods, Derivative Techniques, Electric Field Perturbation, Magnetic Field Perturbation.
Simulation Techniques: Monte Carlo Methods, Molecular dynamics methods.
Computer Laboratory Work: Ab initio electronic structure calculation of small systems-designing of input using a visualization program, running an electronic staructure calculation applying GAMESS program, analyzing output manually and using visualization program.

References

[1]. An Introduction to Computational Chemistry by Frank Jensen (Wiley)
[2]. Essentials of Computational Chemistry: Theories and Models by Christopher J. Cramer (Wiley)
[3]. Electronic Structure: Basic Theory and Practical Methods by Richard M. Martin. (Cambridge University Press)
[4]. Molecular Quantum mechanics by Atkins & Friedman
[5]. Computer Simulation of Liquids by Allen & Tildesley

CY 708: Advanced NMR Spectroscopy (20)

The basics of NMR experiment
Basics of NMR spectroscopy, Pulse NMR, The mechanisms of relaxation, The components of a modern NMR instrument, Basic data acquisition and processing

The NMR of Important Nuclei
Chemical shifts for ^{1}H, ^{13}C and ^{31}P nuclei, Homolnuclear and heteronuclear couplings (J), Factors that influence the sign and magnitude of J

Double Resonance Techniques and Complex pulse sequences
Decoupling experiments (homonuclear and heteronuclear), Nuclear Overhauser Effect (NOE), Distortionless Enhancement by Polarization Transfer (DEPT) Experiments

The study of dynamic processes by NMR
Reversible and irreversible dynamic processes, Reversible complexation and chemical shift reagents, Variable temperature NMR, Determination of activation parameters

Two-Dimensional NMR Spectroscopy
Basics of 2D NMR experiments, ^{1}H-^{1}H Correlation Spectroscopy, ^{1}H-^{13}CCorrelaion Spectroscopy,

Nuclear magnetic resonance in solids
Basic NMR interactions in the solid state and their relative magnitudes, Chemical shift tensors and their orientation, Dipolar and quadrupolar couplings, Electron Paramagnetic effects in solid state NMR, Differences in the solid state NMR spectra from spin ½ and quadruple nuclei, Detection of NMR signals in solids, Wide line and zero field NMR experiments

High resolution Solid State NMR experiments
Magic Angle Spinning (MAS) NMR experiments, Side band manipulations and line shape analysis in MAS NMR experiments, Evaluation of chemical shift anisotropy parameters form side band intensity analysis, Cross Polarization Magic Angle Spinning (CP MAS) NMR experiments with suitable examples, Probing the local environmentaround nuclei and measurement of inter-nuclear distances by different solid state NMR techniques, Variable temperature MAS NMR experiments, Multi Quantum (MQ) MAS NMR experiments, Application of solid state NMR techniquesfor characterization of glasses, porous and amorphous materials, polymers, biomaterials, nano-materials, hybrid-materials, catalysts etc.,

Principle of NMR imaging.

References:

[1] Understanding NMR Spectroscopy, 2nd Edition, James Keeler, Wiley, 2008

[2] Becker Edwin D., High Resolution NMR: Theory and Chemical Applications, 3rd Edition, Academic Press 1999.
[3] A complete introduction to modern NMR spectroscopy, R. S. Macomber, Wiley Interscience, 1998.
[4] Sanders, Jeremy K. M. and Brian K. Hunter. Modern NMR spectroscopy: a guide for chemists, Oxford; New York : Oxford University Press, 1987.
[5] Solid state NMR in Materials Science: Principles and Applications By Vladimir I. Bakhmutov, CRC Press, Boca Raton (2012)
[6] C. A. Fyfe, Solid State NMR for Chemists, CFC press, Guelph (1983)

CY 709: Atmospheric Chemistry (20)

Structure of Atmosphere
Physical characteristics, Chemical Composition, Carbon, Hydrogen and oxygen cycle.

Atmospheric Radiation
Terrestrial and solar radiation, Energy balance for Earth and Atmosphere, Radiative flux, Actinic flux; Spectroscopy, Absorption of radiation by atmospheric gases and aerosols, Absorption by O_2 and O_3, Radiative forcing, Photolysis rate as a function of altitude.

Chemistry of Troposphere and Stratosphere
Stratosphere - Chapman mechanism - HO_x, NOx cycle
Troposphere - Hydroxyl radicals and other tropospheric oxidants, Photochemical cycles of NO_2, NO and O_3 , Chemistry of NO_x, carbon monoxide, Methane, Definition of tropospheric lifetimes, Importance of gas phase kinetics.

Atmosphere Pollutants
Oxides of nitrogen, Volatile Organic Compounds (VOCs), Halogenated compounds, Sulfur compounds and particulate matter.

Effects of pollution
Photochemical smog - production of ozone and NOx; trends in trophospheric ozone concentration, relationship of VOCs and NOx to O_3, atmospheric chemistry of ozone and its precursors, chemistry of sulfur and nitrogen compounds, Acid Deposition.

Global effects of pollutio
Green House Effect, Global Warming Potential, Stratospheric Ozone Depletion, Ozone depletion Potential, Montreal / Kyoto protocol.

Laboratory and field measurements
Techniques for species identification and quantification, Aerosoles - formation, sampling and characterization. Experimental methods to study reactions of importance in the atmosphere (Laser Induced Fluorescence, Chemiluminescence, Cavity Ring Down Spectroscopy).

References
[1] Introduction to Atmospheric Chemistry, D.J. Jacob, Princeton University Press, 1999.
[2] Atmospheric Chemistry and Physics, from Air Pollution to Climate Change, J.H. Seinfeld and S.N. Pandis, Wiley-Interscience.
[3] Introduction to Atmospheric Chemistry, P.V. Hobbs, Cambridge University Press, 2000.
[4] Chemistry of the Upper and Lower Atmosphere, Finlayson-Pitts and Pitts, Academic Press.
[5] Atmospheric Chemistry, A.M.Holloway and R.P.Wayne, RSC Publishing.
[6] Chemistry of Atmospheres, R. P.Wayne, Oxford University Press, 1991.

CY 710: Statistical Analysis (20)

Population and Sample, Treatment of data, Frequency distribution, Measure of central tendency, Measure of variability, Probability distribution, Probability, Discrete distribution, Continuous distribution, Sampling theory, Sampling distribution, Sampling distribution of means, Statistical inference, Test of hypothesis and significance, One tailed and two tailed tests, Type I and type II errors, Operating characteristic curves and power of a test, Sampling distribution of variance, F distribution, Chi-square distribution, Curve fitting, The method of least squares, Regression, Correlation theory, Linear correlation, Multiple correlation, Analysis of variance, One-way ANOVA, Two-way ANOVA, Factorial designs.

References

[1] Murray R Spiegel, Statistics: Schaum's outline series
[2] F. J. Dixon and W. J. Massey, Introduction to statistical analysis
[3] S. N. Deming and S. L. Morgan, Experimental Design: A chemometric approach
[4] Zivorad R. Lazic, Design of experiments in chemical Engineering
[5] J. N. Miller, J. C. Miller, Statistics and chemometrics for analytical chemistry, Sixth edition

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NON-SUBJECT ASSIGNMENTS

CY 591: Viva Voce

In addition to the formal assessment carried out by the method of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

CY 592: Mini-Project

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the Mini-Project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provide useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.

CY 593: Seminar

As a part of the course curriculum, all trainees have to make a seminar presentation. For this purpose, the trainee is asked to choose a topic of presentation based upon his/her aptitude and area of research interest. The objective of this exercise is to inculcate skills in the trainee on aspects such as analysis of the experimental data, details discussion on the results and hypothesis presented and drawing of meaningful conclusions. A Seminar Committee constituted for this purpose evaluates the presentation based upon attributes such as scientific content, quality of presentation and ability of the trainee to defend the subject of presentation. A maximum of 100 marks have been allocated for the seminar.

Homi Bhabha National Institute
(A university established under Section 3 of the UGC Act. 1956)
Indira Gandhi Centre for Atomic Research
Kalpakkam – 603 102 Tamil Nadu, India

PGD in Chemical Sciences Courses under IGCAR (Program Code: CHEM00)

Homi Bhabha National Institute
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Chemical Sciences Courses offered in HBNI & Course coordinators

CH-1 : Mathematics and Computational methods (6 credits)

CH-2 : Chemical Thermodynamics (6 credits)

CH-3 : Electrochemistry and Corrosion Science (4 credits)

CH-4 : Introduction to Materials Science and Engineering (6 credits)

CH-5 : Analytical Chemistry for Nuclear Fuel Cycle (6 credits)

CH-6 : Chemical Instrumentation and Laboratory Techniques (6 credits)

CH-7 : Health Physics and Radiation Sciences (6 credits)

CH-9 : Chemistry of Fuel Cycle-I(6 credits)

CH-10 : Chemistry of Fuel Cycle-II: Actinide chemistry and separation science (6 credits)

CH-11 : Materials for Nuclear Reactors and Fuel Cycle Processing Systems (6 credits)

CH-12 : Nuclear and Radiochemistry (6 credits)

CH13 : Corrosion Science and Engineering (6 credits)

CH-14 Quantum Chemistry & Group Theory (6 credits)

CH-15 : Molecular Spectroscopy (6 credits)

CH-16 : Lasers and Application (6 credits)

CH-17 : Nanomaterials and Advanced Chemical Sensors (6 credits)

CH-RM: Course on Research Methodology (3 credits)

CH-1: Mathematics, computational methods, numerical analysis and computer programming

Course content

1. **Differential Equations & Integral Transforms:** Linear differential equations: Series method of solution; Legendre, Lagurre and Hermite differential equations. Use of ladder operators for solutions to differential equations; applications to quantum chemistry.

Orthogonal Polynomials and Special functions – Dirac Delta function, gamma function, error function. Introduction to Fourier series, Fourier transform and Laplace transform – applications in quantum chemistry and spectroscopic techniques – FT-NMR, FT-IR.

Convolutions of functions, use of Fourier transforms in convolution, Applications in chemistry.

2. **Vectors:** Vector differentiation and integration: Concepts of gradient, divergence and curl and their physical significance. Orthogonal vectors, Gram-Schmidt process – applications in quantum chemistry. Vector fields in space – Gauss and Stokes theorem with applications.

3. **Matrix Algebra:** Elementary operations and elementary matrices. Rotation matrices, Similarity transformations; Applications of numerical techniques in matrix algebra to evaluate eigenvalues and eigenvectors; Diagonalization and inversion of matrices. Applications in chemistry.

4. **Numerical Methods:** Newton-Raphson method for finding roots, differentiation, integrations by quadrature techniques, solutions of differential equations.

Book suggested

1. Advanced Mathematics for Engineers and Scientists, M.R. Spiegel, Schaum's Outline Series(1983).
2. Mathematical Methods for Physics Engineering, K.F. Riley, M.P. Hobson and S.J. Bence, Cambridge University Press (1998).
3. Theory and Problems of Vector Analysis, M.R. Spiegel, Schaum's Outline Series (1981).
4. Computer Oriented Numerical Analysis, V. RajaRaman, Prentice Halls India, 3rd ed. (1999)
5. Mathematical Physics, E. Butkov, Addison-Wesley Publishing Company, California (1968).

CH-2: Chemical Thermodynamics

Course content

1. **Laws of Chemical Thermodynamics:** Thermodynamic laws, thermodynamic properties of the system, criterion for equilibrium, Heat engines, Helmholtz energy, Gibbs energy, Closed system, Maxwell's equations, Gibbs-Helmholtz equation.

2. **Behaviour of Gases:** Gas laws, ideal gas and deviations from ideality, Vander Waal's equation, equation of state, critical phenomena,Thermodynamic treatment of non-ideal gases, gas mixtures.

3. **Solutions:** Raoult's and Henry's laws, activity of a component in solution, Gibbs-Duhem equation, Properties of Raoultian ideal solutions, Colligative properties, Non ideal and regular solutions, Partial and Integral thermodynamic property evaluation, alpha function, Gibbs free energy of formation of regular solutions, Criteria for stability of regular solutions, Miedema's model, associated solution model, sub-regular solutions, Models for ternary systems such as Colinet's model.

4. **Phase Equilibria:** Phase rule, Gibbs Free energy as a function of temperature and pressure, Equilibrium between a vapor and a condensed phase in a single component system, Graphical representation of phase equilibria in a single component system, Gibbs energy and thermodynamic activity, phase diagrams- single component, binary and ternary diagrams, simple calculation of thermodynamic properties from phase diagram, pressure-composition diagrams, CALPHAD and models for optimization of phase diagrams.

5. **Reactions in Gases and Condensed Phases:** Reaction equilibria in homogeneous and heterogeneous media, effect of temperature and pressure on equilibrium constant, Le Chatlier's principle, Reaction equilibria in H2/ H2O, CO/CO2 systems, Ellingham diagrams, Effect of phase transformation, use of different standard states for representing reactions in condensed phases, phase stability diagrams, application of phase diagrams in material systems.

6. **Statistical Thermodynamics:** Entropy and disorder in an atomic scale, concept of microstate, most probable microstate, influence of temperature, Boltzmann equation, partition functions, configurational entropy and thermal entropy.

7. **Experimental Thermodynamics:** Calorimetry - classification of calorimeters, different types of calorimeters, heat capacity measurements, thermochemical calorimetry, estimation of thermodynamic quantities.

Vapor pressure measurements- static methods, transpiration, boiling point method, isopiestic method, Knudsen effusion method , Langmuir evaporation method, role of mass spectrometry for study of vaporization reactions, second and third law methods, Gibbs energy functions from spectroscopy data, measurements at very high temperatures.

Galvanic cell EMF methods for activity measurements, - solid electrolyte and molten salt EMF methods.

Measurement of oxygen and carbon potentials – gas equilibration/ EMF methods

Determination of phase diagrams- spot technique, thermal analysis, enthalpies of transformations, transformation temperature, order of transformation, DTA, TGA, thermal expansion, resistivity- as a function of temperature , thermal diffusivity, measurement of thermal diffusivity and thermal conductivity.

Books Suggested:

1. Physical Chemistry, G W Castellan, Addison Wesley, 1971
2. Introduction to Metallurgical Thermodynamics, David R Gaskell, McGraw Hill, 1973.
3. Physical Chemistry, P W Atkins, 7th Ed, Cambridge University Press, 2004.
4. Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering, K Denbigh, Cambridge University Press, 1981.
5. Chemical and Process Thermodynamics, 2nd Ed, B G Kyle, Prentice Hall, 1992.
6. Thermodynamics, G N Lewis, M Randall, revised by K S Pitzer and L Brewer, McGraw Hill, 1961.
7. Differential Scanning Calorimetry: An Introduction for Practitioners, G W H Hohne, Springer Verlag, 1996.
8. Characterisation of high temperature vapours, Ed by J L Margrave, John Wiley, New York, 1967.
9. Physicochemical Measurements in Metal Research, Ed by R F Bunshah, Wiley Interscience, New York, 1970.

CH-3: Electrochemistry

Course content

1. Electrolytes – Different electrolyte systems (aqueous, ionic melts and solid electrolytes) and their conductivities; Debye-Huckle theory, Techniques for measuring electrical conductivities - DC and AC techniques

2. Electrochemical cells - Electrochemical potentials, Nernst equation and electrochemical series, Molten salt and solid electrolyte based cells

3. Electrode processes and kinetics – Diffusion layers & characteristics of the diffusion layers, over potentials, Butler-Volmer and Tafel equations, polarisable and non-polarisable electrodes, reference electrodes, voltammetric techniques, polarography, Cyclic Voltammetry, rotating electrodes and micro-electrodes, chronpotentiometric and chronoamperometric techniques, elucidation of mechanisms of electrochemical reactions.

4. Applications of electrochemical principles - Electro-analytical techniques and electrochemical sensors; energy conversion and storage systems (fuel cells and batteries); thermochemical data measurements.

Reference Books:

1. "Electrochemical Methods: Fundamentals and Applications**",** AJ Bard & LR Faulkner, Wiley, New York, 1987.
2. "Electrode Dynamics**",** AC Fisher, Oxford University Press, Oxford, 1996.
3. "Electrochemistry", **P**.H. Reiger, Prentice-Hall International, Englewood Cliffs, 1995.
4. "Solid electrolytes and their Applications", (Ed) E.C.Subba Rao, Plenum, New York, 1980.
5. "Electrochemistry", C. M. A. Brett and A. M. O. Brett, Oxford University Press, 1993.
6. "Laboratory Techniques in Electroanalytical Chemistry", 2nd Ed., by P. T. Kissinger and W. R.Heineman, Marcel Dekker, 1996.
7. "Chemical Sensor Technology", Vol.2, (ed) T.Seiyama, Kodansha Ltd., Tokyo, 1989.
8. "Chemical Sensor Technology", Vol.3, (ed) N.Yamazoe, Elsevier, Amsterdam, 1991.
9. "Solid State Gas Sensors", P.T.Mosley and B.C.Toefield, Adam Hilger, Bristol, 1987.
10. "Advances in Electroanalytical Chemistry", Vol.2, A.J.Bard, Macel Dekker, New York, 1967.
11. "Fuel Cell Systems", L.J.M.J.Blowmen and M.N.Mugerwa, Plenum Press, New York, 1993.

CH-4: Introduction to Materials Science & Engineering

Course content

1. **Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.

2. **Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.

3. **Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.

5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.

6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.

7. **Phase Diagrams & Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley & Sons, N.Y., 2003.

7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

CH-5: Analytical Chemistry for Nuclear Fuel Cycle

Course content

1. **Instrumental Methods – Principles and Applications:**

Spectrochemical Methods: Detectors- Photomultiplier Tube (PMT), Charge Coupled Device (CCD), Charge Injection Device (CID), Spectrometers – Czerny Turner, Echelle, Sample Introduction Devices – Flame, Electrothermal, Laser Ablation, Direct Sample Insertion Devices, Interferences, detection limits, sensitivity, Absorption Spectrometry – Flame Atomic Absorption Spectrometry, (FAAS), Electrothermal Atomic Absorption Spectrometry (ETAAS), Optical Emission Spectrometry (OES) with Inductively Coupled Plasma (ICPOES), Glow Discharge (GDOES), Fluorescence Spectrometry – Laser Induced Fluorescence (LIF), Recent advances – Continuum Source (CS-AAS), Single Atom Detection.
Mass Spectrometry: Mass Analysers – Magnetic, Quadrupole, Time of Flight (TOF), Ion Cyclotron Resonance, Features – Resolution, Dispersion, Abundance, Sensitivity, Detectors – Faraday Cup, Channeltron, Daly, Ion Sources –Thermal Ionisation (TI), Electron Impact, ICP, GD, Laser Ablation (LA-ICP), Secondary Ionisation (SI), Resonance Ionisation (RI), Matrix Assisted Laser Desorption and Ionisation (MALDI), Hyphenated Technique – ICP-MS, HPLC-MS, GC-MS.

Thermal Methods: Thermogravimetric Analysis (TGA), Derivative Thermogravimetric Analysis (DTG), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Evolved Gas Analysis (EGA).

Nuclear Methods: Activation Analysis – Neutron Activation Analysis (NAA), Charged Particle Activation Analysis (CPAA), X-ray fluorescence (XRF) spectrometry, Ion Beam Analysis – Backscattering Spectrometry (BS), Particle Induced □-ray Emission (PIGE), Nuclear Reaction Analysis (NRA), Elastic Recoil Detection Analysis (ERDA), Particle Induced X-ray Emission (PIXE).

2. **Separation Techniques – Principles and Applications:**

Solvent Extraction Technique: Conventional, Liquid Membranes – Bulk, Supported and Emulsified, Solid Phase Extraction (SPE).

Ion Exchange: Conventional and Membranes.

Chromatography: Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion chromatography (IC).

3. **Statistical Methods in Chemical Analysis:** Methods of sampling and associated errors, Classification of errors, Propagation of errors, treatment of errors, Normal distribution, Tests of Significance and Confidence Limits. Method of Least squares – linear and non-linear, weighted least squares formalism, constrained least squares fitting

4. **Laboratory Experiments (any 5):**

Determination of trace impurities in high purity materials by AAS.

Application of Electroanalytical Methods to trace analysis

TGA and DTA study of inorganic compounds

Neutron Activation Analysis of trace constituents in a complex matrix

Analysis of an alloy sample by EDXRF

Anion analysis by ion selective electrode.

Chromatographic separation and measurement of the components in a mixture

Isotopic Analysis by Mass Spectrometry

Books suggested:

1. Fundamentals of Analytical Chemistry, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
2. Principles of Instrumental Analysis, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
3. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).
4. Statistics for Analytical Chemistry, J. C. Miller and J. N. Miller, 2nd Edition, Wiley (1998).

CH-6: Chemical Instrumentation and Laboratory Techniques

Course content

1. **Passive Circuit Elements and Configurations:** Circuit behaviour of resistors,inductors and capacitors; the potential divider and the wheatstone Bridge (resistive and capacitive), R-L-C-circuits as filters and resonance circuits.

2. **Electronic Devices and Their Role in Power Conversion and Amplification:** The junction diode, SCR, triacs and their role in rectification and AC power control; bipolar transistor and IGBT and their role in linear/switched mode power supplies and in amplification of signals; constant current power supplies Inverter circuits; issues in measurement of signals - Concept of input impedence and the role of J-FETs and MOSFETs.

3. **Operational Amplifiers and their Various Functionalities:** The basic OP-AMP and its desired characteristics; the inverting amplifier, the non-inverting amplifier, summing configuration;

The differentiator and integrator circuits; comparator; precision rectifier; waveform generation.

4. **Fundamental Issues Related to Chemical Instrumentation:** Role of chemical instrumentation in the nuclear fuel cycle, with relation to selectivity, sensitivity and automation amenability.

The basic anatomy of excitation with energy source-interaction with analyte-detection of the effect produced; issues related to selectivity; sensitivity and detection limits; sources of noise and measures to minimize the effect; boxcar integrator, lock-in-amplifier.

5. **UV-VIS-IR Instruments:** Phenomenon of resonant absorption and Beer's law of photometry; implementation of Beer's law in a spectrophotometer; compensation for spectral response of the detector; slit servo mechanism for compensation of optical emission.

Atomic absorption spectrophotometer-flame ionization, compensation for molecular absorption, hollow cathode lamp excitation for high specificity.

Atomic emission spectrometry-principles, instrumentation and data interpretation

Laser fluorescence spectrometry-laser basics, three stage power supply for flash lamp excitation.

Non dispersive spectrometer- FTIR - principle, data collection scheme.

6. **X-Ray Spectrometry:** Generation of X-Rays, The X-Ray tube, setting the energy and intensity; Bragg's law; X-Ray fluorescence, X-Ray diffraction, ESCA for surface analysis.

7. **Mass Spectrometry:** Ion sources-thermal ionization, Knudsen effusion and electron impact ionization, inductively coupled plasma source, Laser induced vapourisation, spark source.

Magnetic analysers, quadrupole analysers, time-of-flight analysers.

Detectors-faraday, SEM, Channeltron.

Mass scanning, peak centering, signal handling and digitization and counting.

8. **Thermal Analysis:** Thermal excitation - furnaces, temperature profiling and furnace power control.

Thermal effects - TGA, DTA, DSC, dilatometry.

Thermal measurements - thermocouples, RTDs, signal conditioning and handling.

9. **Additional Methods of Analysis:** Gas chromatography - mobile and stationary phases; separation on the basis of retention time; TCD and FID detectors.

Instrumentation for pH meters and conductivity meters; automated titro-processors and applications of coulometry.

Radioactive assay based on multi-channel gamma ray spectrometry.

10. **Digital Electronics:** Logic gates; flipflops, counters, astable and monostable multivibrators; decoders; logic families; data conversion-various types of ADCs and DACs.

Microprocessor systems-processor architecture, memory circuits, I/O subsystems; interfacing techniques; assembly language programming.

11. **Laboratory Techniques:** Machine Drawings Projections: orthographic – 1st & 3rd Angles

pictorial; Oblique: Perspective. Conventional representation of common features and sections;

Dimensioning and tolerancing; Scales, lines and lettering; Threads; Fastenings. Brief Introduction of AutoCAD and its use, common drawing and edit commands.

Vacuum systems - equipment for vacuum generation - rotary pumps, diffusion pumps, ion pumps, turbo molecular pumps; Generation of high temperatures, measurement of vacuum and temperatures, centrifuges, chemicals and laboratory safety.

12. **Vacuum Generation and measurements:** Kinetic theory of gases – Velocity distribution – Mean free path – Monolayer formation – vacuum units – Viscous and molecular Flow regimes – Reynold's and Knudsen Numbers viscosity and thermal conductivity of gases – Gas release from solids – vaporization – out gassing – diffusion – permeation – Vacuum pumps – Titanium Sublimation pumps – Ion pumps – Cryogenic pumps and maters for construction of Vacuum chamber.

Gauges: Thermal conductivity, cold cathode, hot cathode ionization gauges and their Principle of operation.

Books suggested:

1. Principles of Instrumental Analysis, D. A. Skoog and J. Leary, McMillan Publishers,
2. Instrumental Methods of Analysis, H. H. Willard, L. L. Merritt, Jr., J. A. Dean, F. A. Settle, Jr. CBS Publishers and Distributors, New Delhi 1986.
3. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).

CH-7: Health Physics and Radiation Sciences

Course content

1. **Interaction of Radiation With Matter:** Ionization in gaseous medium, Bragg's curve, stopping power, Bethe equation, range of particles and straggling, LET, attenuation and absorption of beta particles, backscattering, photoelectric, compton and pair production processes for gamma radiation, variation with gamma energy and Z of medium, attenuation and absorption of gamma rays, elastic and inelastic scattering of neutrons.

2. **Radiation Detection and Measurement:** Principles of radiation detectors, counting characteristics, detection efficiency and energy resolution, dead time and counting statistics, Gas filled detectors, scintillation processes and detectors, organic and inorganic scintillators, NaI(Tl), LaBr3, semiconductor detectors, p-n junctions, germanium and silicon detectors, room temperature semiconductors, neutron detectors including bubble detectors, solid state nuclear track detectors, nuclear probes - positron annihilation, perturbed angular correlation, mossbauer effect.

3. **Shielding and Dose Calculations:** Shielding (beta, gamma and neutron sources).

Shielding from mixed sources; calculation of dose for point, line and volume sources.

4. **Dosimetry:** Definition of various dosimetric terms (exposure, absorbed dose, equivalent dose, effective dose, concept of radiation and tissue weighting factors and their importance, Activity, Specific activity (SI units and Old units), radiological, biological and effective half-life and their relation and the concept of the same and their importance. Concept of ALI and DAC.

5. **Radiation Protection Principles:** Radiation protection philosophy, objectives and principles of radiation protection, Dose limits to occupational workers and members of public, Dose constraints, Investigation limits. Types of exposure (natural, occupational, medical and public).

External and internal exposures; routes of intake of radioactive material. Use of personal dosimeters (Film badge, TLDs, pocket dosimeters). Calculation of internal dose, Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given), exposure-dose relationship, Bragg-Gray principle.

Fundamentals of ICRP respiratory model, entry through ingestion, GI track model, wholebody counting and bioassay techniques.

6. **Radiation Protection Procedures:** Procedures followed in radiation work places, supervised and controlled areas, work permits, contamination control methods (air-borne, surface and personnel), swipe samples, and rubber areas, spill pack (gloves + absorbing paper), decontamination and de-corporation techniques; bore wells and inspection chambers; precautions during radioactive source storage and handling.

Types of radiation monitors / radioactivity measurement methods adopted for radiation protection. Personnel monitoring, area monitoring and stack monitoring.

7. **Waste Management:** Radioactive waste classification and management – An overview.

8. **Emergency Preparedness:** Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, counter measures.

9. **Nuclear Fuel Cycle Applications:** Radiological aspects and environmental impact of FBRs. Criticality safety and Radiological aspects in nuclear cycle facilities.

10. **Regulatory Details:** Atomic Energy Act, National and International regulatory bodies, their role and responsibilities, Radiation Protection Rules, Nature of duties and responsibilities of Radiation Safety Officer / Health Physicist, radio toxicity and classification of laboratories, design of lab for radioactive work, Safe handling of radioisotopes, Transport of radioactive materials.

11. **Basic Radiobiology:** Interaction of ionizing radiation with living cells, Ionizing radiations, excitation and ionization process, basic structure and components of cell, chemical and biological consequences of radiation action, radicals and reactions in cell killing, direct and indirect effect and relevant biological damage.

12. **Molecular and Cellular Effects of Radiation:** Radiation action and organizational level in cell, Damage to DNA, single and double structural breaks in units membrane dose and survival curve, cellular radioactivity, radiobiological effectiveness and linear energy transfer Dzz dose, rate effect, dose fractionation, Mitotic delay, chromosome aberration and mutations by radiation action on cells.

13. **Modification of Biological Effects of Radiation:** Oxygen effect, OER, Chemical radio sensitizers, Chemical radio protectors, Mechanisms of action and importance in nuclear research programme.

14. **Radiobiology and Radiotherapy:** Radiation and cancer, cell cycle and radiosensitivity, rationale of using radiation for tumor cell kill, problems.

15. **Basics of Radiation Chemistry:** Interaction of high energy radiation with matter, G-values, radiation induced reactions in solids, liquids and gases.

Laboratory Experiments:

1. Plancheting, alpha counting and spectroscopy
2. Counting characteristics of gas detectors
3. Half life determination and attenuation coefficient determination
4. High resolution gamma spectrometry
5. Dose Measurements: Whole Body Counting laboratory, Bio-dosimetry laboratory, TLD personnel monitoring services laboratory.

Demonstrations:

1. **Use of Personnel Protective Equipment (PPE):** Proper checking and wearing of gloves, and other plant dresses (shoe covers, boiler suits, overcoats etc).

Respirators (dust, gas mask, self contained breathing apparatus, and fresh air-line) TLD, Film badge, neutron film, criticality badge and bubble detector

2. **Use of Radiation Monitoring Equipment: Installed and Portable Radiation Monitors:** AGM (audio and visual alarm, setting up of alarm limits); staplex air sampler (estimation of air-borne activity-both alpha and beta-gamma), different types of survey meters (low to high range), ALSCIN and GM based contamination monitors (side window and end window, hand and foot monitor, cloth monitor), continuous air monitor, criticality alarm system.

Books suggested:

1. Introduction to Health Physics by Herman Camber
2. Biological Effects of Radiation by J. E. Coggle
3. Radiobiology for Radiologist by Eris J. Hall
4. Detection and Measurement of Radiation - Glenn T Knoll.

CH-9: Chemistry of Fuel Cycle-I

Course content

1. Recovery of the starting compounds bearing U, Pu or Th from their primary and secondary sources. Mining, beneficiation, pre-concentration, purification and recovery.

2. **Oxide Fuels:** Preparation of UO2, PuO2, MOX and ThO2. Physical and chemical properties, phase diagrams of relevance, control of phase composition and stoichiometry, fuel fabrication flow sheet and quality control.

3. **Advanced Ceramic Fuels:** Carbides U-C, Pu-C, U-Pu-C, U-Pu-C-O and U-Pu-C-O-N, Nitrides U-N, Pu-N, U-Pu-N. Physical and chemical properties, phase diagrams of relevance, control of phase composition and stoichiometry, fuel fabrication flow sheet and quality control.

4. **Advanced Fuel Fabrication Techniques:** Oxides, Methods based on sol-gel and novel techniques. Carbides; sol-gel method, direct pressing and arc casting.

5. Preparation of U, Pu and Th.

6. **Alloy Fuels:** Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-RM, U-Pu- MA), dispersions and composites – Salient physical and chemical properties, relevant phase diagrams, fabrication and quality control.

7. **Inert Matrix Fuels for Partitioning and Transmutation:** A brief account on the current developments.

8. **Fuel – Clad Interaction:** Significance of FCCI and FCMI. Specifics pertaining to oxide, carbide and metallic fuels. Role of chemical thermodynamics in the prediction and understanding of Fuel clad chemical compatibility.

9. **In Pile Behaviour of Fuels:** Chemistry and redistribution of fission products, role of chemical potentials of the constituents in the breach of clad in oxide, carbide and alloy fuel pins and detection mechanisms.

Books suggested:

1. Donald R. Olander, Fundamental aspects of nuclear reactor foel elements fundamental aspects of nuclear reactor foel elements, Springfield, BTIS, 1985.
2. H. J. Matzke, Science of Advanced LMFBR fuels, North Holland, Amsterdam, 1986.
3. M. Benedict and T.H. Pigford, Nuclear Chemical Engineering, Mc Graw Hill, New York, 1957. (Specific journal articles and other references will be cited during the lectures)

CH-10: Chemistry of Fuel Cycle–II

Course content

1. **Actinide Chemistry:** Discovery of actinide elements, electronic structure, oxidation states, inter-conversion of oxidation states, complexes of actinide ions, actinide contraction, comparison of actinides with lanthanides. Actinides in environment.

Purification of actinides using techniques such as ion-exchange, Solvent Extraction, Liquid membranes and Chromatographic Methods.

Hydrolysis, colour, spectroscopy and magnetic properties of actinides, nuclear properties of actinides, decay modes.

Thorium: isotopes, occurrence and production; Uranium: isotopes, occurrence, resour0ces and production.

Transuranium Elements: production of transuranic elements, Neptunium, Plutonium, Americium and Curium; Actinide synthesis by heavy ion reactions.

Fission Product Chemistry.

2. **Aqueous Reprocessing:** Introduction to nuclear fuel reprocessing; Need for reprocessing; PUREX, TRUEX, THOREX.

Latest developments. Solvent extraction for actinide purification; basic principles, introduction to extractants, classification of extractants.

Purification of uranium, plutonium; lanthanide actinide separations.

3. **Pyrochemical Reprocessing:** Introduction to non aqueous reprocessing: Objectives and advantages of non aqueous reprocessing in fast reactor fuel cycle, Advanced fuel cycle flowsheets involving non aqueous reprocessing, Recent trends in pyrochemical reprocessing of oxide and metallic fuels.

Oxide electrowinning flowsheet, Pyrochemical reprocessing of metallic fuels (IFR process) - Integral Fast Reactor Concept, Differences in electrorefining and electrowinning.

4. **NUMAC:** Importance of Nuclear Material Accounting; techniques used for analysis of nuclear materials.

NUMAC with techniques such as Potentiometry, Coulometry, Amperometry.

Mass Spectrometry, Calorimetry, Gamma counting, neutron counting etc. Advantages and drawbacks of individual methods.

5. **Post Irradiation Techniques:** Introduction to post-irradiation examination methods of nuclear reactor fuels; importance of PIE methods, burn-up measurements; NDE testing of fresh fuel pins.

Non-destructive evaluation of irradiated fuels (X-ray and neutron radiographic examination of fuel pins, Fission gas analysis, Metallographic examinations).

6. **Nuclear Waste Management:** Introduction - industrial waste, nuclear waste & its speciality, generation of radioactive wastes, radioactivity in the environment, Solid, liquid & gaseous wastes, international classification. Basic philosophy & methods of radioactive waste management, environmental monitoring. HLW & spent fuel waste. Radioactive waste immobilization matrices & their ultimate disposal.

Reference Books

1. "**Handbook of Physics and Chemistry of Rare Earths: Lanthanides Actinides**" G.T. Seaborg, Vol.18,(Eds., K.A. Schneider, Jr., L. Eyring, G.R. Choppin and G.H. Lander), Elsevier Science, Amsterdam (1994).
2. "**The Chemistry of Actinide Elements**", J.J. Katz, G.T. Seaborg and L.R. Morss, Vol. 1 and 2, 2nd Ed., Chapman and Hall, New York (1986).

3. "**Handbook of Physics and Chemistry of Actinides**", A.J. Freeman and C. Keller,North Holland Amsterdam, Vol.3 (1985), Vol.4 (1986), and Vol.6 (1991).

4. "**The Chemistry of Transuranium Elements**", C. Keller,Verlag Chemie GmbH, Germany (1971).
5. "**Summary of the Properties of Lanthanide and Actinide Elements**" G.T. Seaborg and D'E.Hobart in 'Frontiers in Nuclear Chemistry', Eds. D.D. Sood, A.V.R. Reddy and P.K. Pujari, IANCAS publication, Mumbai (1996)
6. "**The Chemistry of Plutonium**" J.M. Cleveland, Gordon and Breach Science Publishers, Newyork, 1970

7. "**Solvent Extraction of Metals**", A. K. De, S. M. Khopkar and R. A. Chalmers, Van Nostrand, Reinhold (1970).
8. "**Ion Exchange and Solvent Extraction : A Series of Advances**", Editors J. A. Marinsky and Y. Marcus, Marcel Dekker Inc. (1998).
9. "**Ion Exchangers**", F. Helfferich, McGraw Hill (1962).
10. "**Introduction to Modern Liquid Chromatography**", L. R. Snyder and J. J. Kirkland, 2nd Edition, Wiley (1979).
11. "**Analytical Chemistry**", R.V.Dilts, Van Nostrand (1974).
12. "**Modern Practice of Gas Chromatography**", by R.L.Grob and E.F.Bary, 4th Edition, Wiley-Interscience.
13. "**Practical Supercritical Fluid Chromatography and Extraction**", M. Caude, D. Thiebaut, Eds.) Harwood Academic Publishers (1999).
14. "**Supercritical Fluid Extraction**", M.A.Mchugh and V.J.Krukonis, Butterworth Heinemann, 2nd Edition, 1994
15. "**Fundamentals of Analytical Chemistry**", D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
16. "**Principles of Instrumental Analysis**", D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
17. "**A text book of Quantitative Analysis**", A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).

CH-11: Materials for Nuclear Reactors and Fuel Cycle Processing Systems

1. Fundamentals of reactor physics and different reactor systems

a) Fission reactors: Thermal reactor, fast reactor, advanced reactor, b) Fusion reactors: Thermonuclear reactor

2. Health Physics and Radiation Sciences

Interaction of radiation with matter, Radiation detection and measurement – use of gas filled detectors, scintillators, semi-conductor detectors, neutron detectors, Radiation Units and Limits.

Hazards Control and Evaluation, Biological effects of radiation, Dose and dose limits for occupational workers and members of public, Radiation Protection Procedures, Dosimeters.

Transport and release, Classification of nuclear waste and their management –Emergency Preparedness, Radiation Chemistry, G-values, radiation induced reactions in solids, liquids and solids.

3. Introduction to Reactor Materials

Moderators (Requirements, properties of D_2O and graphite), C**ontrol rod materials (**Requirements, properties), **Coolants** (Requirements, properties and handling - water, liquid sodium, lead-bismuth alloys, helium, CO_2), **Cover gas (**Cover gas purification, monitoring for hydrogen, fission gases)

4. Introduction to Coolant chemistry:

Na, Pb-Bi and Pb-Li chemistry: Monitoring and maintaining purity of coolants, on-line monitoring using EC monitors, sampling and analysis.

Water chemistry (Introduction to fast reactor water chemistry, condenser cooling and process water chemistry, de-mineralising plant and condensate polishing unit chemistry, on-line monitoring, biological shield cooling water chemistry, related analytical techniques, Chemical aspects of corrosion in liquid metal coolant systems

5. Fuel reprocessing: Chemistry of Actinides with respect to reprocessing, Aqueous methods - Purex, Thorex, use of novel extractants, Non-aqueous methods - pyrochemical processes.

Books Suggested:

1. S. Glasstone, Source Book on Atomic Energy, Allied East-West Press Pvt. Ltd., NewDelhi.
2. S. Glasstone and Sesonske, Nuclear Reactor Engineering, Chapman Hall, London, 1994.
3. H.U. Borgstedt and C.K. Mathews, Applied Chemistry of the Alkali Metals, Plenum Press, 1987.
4. C.C. Addison, The Chemistry of the Liquid Alkali Metals, John Wiley and Sons, 1984.
5. Power Plant Chemistry: A practical guide, Buecher Braid, Penwell, Oklahoma, 1997.
6. Modern Power Station Practice, III Edition, Pergamon, NY, 1992.

CH-12: Nuclear and Radiochemistry (CH12)

Course content

1. **Nuclear Properties:** Concept of nucleus, nuclear spin, parity, electric and magnetic moments, isomerism, nuclear mass and binding energy, elemental abundance, radioactive decay laws, radioactive equilibria, Bateman's equation, liquid drop and shell models.
2. **Nuclear Structure and Decay Modes:** Nuclear force, structure of complex nuclei, liquid drop, shell and collective models, nucleon emission, beta decay, gamma de-excitation and internal conversion, selection rules.
3. **Nuclear Reactions and Accelerators:** Basic principles and energetics, cross sections, nuclear fission, charge and mass distribution in fission, compound nucleus reactions, direct reactions, types and details of accelerators.
4. **Radiochemical Separations:** Concepts of traces, chemical yields, radiochemical purity, applications.
5. **Nuclear Techniques:** Nuclear probes, PAC, NDA and on-line monitoring.
6. **Radio-isotope Production:** Basic principles of isotope production in both reactors and accelerators, Szilard - Chalmers effect and its utility, concept of generators, Moly generators.
7. **Applications of Radioisotopes:** Concepts of nuclear medicine and radio-pharmaceuticals, SPECT, PET, brachytherapy and and teletherapy Radio-immuno assay, industrial, agricultural and biological applications.

Laboratory Experiments:

1. Fission product separation and transient equilibrium.
2. Separation of actinides using ion-exchange or solvent extraction
3. Neutron activation analysis.

Books Suggested:

1. Nuclear and Radiochemistry (1981) - G. Friedlander, J. Kennedy, J.M. Miller and J.W. Macias
2. Atomic Nuclear (1955) - R.D. Evans
3. Source book of atomic energy (1969) - S. Glasstone
4. Essentials of Nuclear Chemistry (1982) - H.J. Arnikar
5. The chemistry of Transuranium Elements (1971) - J. Keller
6. G.R. Chopin and Rydberg: Nuclear Chemistry, Theory and Applications, Pergamon Press, Great Transuranium elements and transactinides.
7. Manual for reactor produced isotopes, IAEA-TECDOC-1340 (1999)
8. Radionuclides in therapy - R.P. Spencer, R.H. Sievers, A.M. Friedman. CRC Press (1987
9. Radioimmunoassay: Principles and Practice, M.R.A. Pillai and S.D. Bhandarkar, 2nd Edition, BARC, 1998
10. Industrial applications of radioisotopes - G. Foldiak

CH-13: Corrosion Science and Engineering (CH13)

Course content

1. **Thermodynamics of Aqueous Corrosion:** Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.

2. **Kinetics of Aqueous Corrosion:** Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.

3. **Forms of Corrosion:** General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion.

Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.

4. **Corrosion in Reactor and Reprocessing Plants:** Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.

5. **Prevention and Control of Corrosion:** Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.

6. **Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.

7. **Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, "Corrosion and corrosion control – An introduction to corrosion science and engineering", Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, "Corrosion Engineering", Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.
4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

CH-14: Quantum Chemistry and Group Theory

1. Fundamental principles

Brief review of the fundamentals of quantum mechanics – postulates, measurements, operators, de Broglie equation, Heisenberg principle, Schrodinger Equation.

2. Exactly solvable problems

Particle in a box with walls at infitine and finite potential; Double box potential, tunneling, effect of barrier height on splitting of degenerate energy levels and its application in understanding double well potential. Particle in a ring. Simple harmonic oscillator, rigid rotor, hydrogen atom problem solution using both the power series method and ladder operators.

3. Approximation methods

Variation method, perturbation theory for time-independent and time dependent systems; Many-electron systems: Hartree-Fock theory and beyond; Chemical binding in simple molecular systems: Valence bond and molecular orbital theories; Concept of LCAO and introduction to ab-initio and semi-empirical molecular orbital calculations of molecules.

4. Group Theory

Symmetry elements and operations, point groups, matrix representation, reducible and irreducible representations, the Great Orthogonality theorem, direct product representation, projection operators.

5. Applications of Group Theory in Chemistry

Vibrational problem, hybridization, SALC, ligand field theory.

Reference Books

1. "Quantum Chemistry", I. N. Levine, Allyn & Bacon, Inc. (Boston) 5ed. (2000).
2. "Introduction to Quantum Chemistry", F. S. Levine, Cambridge Univ. Press (2002).
3. "Quantum Chemistry", W. Kauzmann, Academic Press (1957).
4. "Chemical Applications of Group Theory", F. A. Cotton, Wiley Eastern Limited, (1989).
5. "Group Theoretical Techniques in Quantum Chemistry", C. D. H. Chisholm, Academic Press (1976).

CH-15: Molecular Spectroscopy

1. Vibrations and rotations of diatomic molecules, selection rules, nuclear spin statistics.

2. Electronic spectroscopy of diatomic molecules, coupling of angular momentum, Hunds coupling cases, term states of molecules, potential energy functions – analytical and numerical (e.g. RKR), Dissociation energy, Franck Condon principle, numerical methods to evaluate Franck Condon factors.

3. Vibrations of polyatomic molecules – classical mechanics of vibrations, symmetry and normal vibrations – applications of group theory.

4. Experimental techniques in spectroscopy: Fourier transform spectroscopy (FTIR, FT-RAMAN), time resolved FTIR and its applications in absorption and emission studies. Laser based experimental methods, Introduction and application of Terahertz spectroscopy.

5. Studies on ultrafast processes: Nanosecond and picosecond laser flash photolysis, fluorescence time domain spectroscopy with special emphasis on energy transfer and electron transfer reactions and studies on excited state properties**.**

6. NMR & ESR: Basics of NMR and ESR, Multipulse techniques in NMR, FTNMR, 2D-NMR. Time domain ESR, Electron Nuclear Double Resonance (ENDOR)-principle and applications.

Reference Books:

1. "Introduction to Lasers Physics", K. Shimoda, Springer Verlag, 1984 Berlin
2. "Laser Spectroscopy basic concepts and Instrumentation", W. Demtroder, Springer 2003, Berlin.
3. "Molecular Spectroscopy", C. N. Banwell, 4 Edn, Tata McGraw Hill, Delhi.
4. "Infra red spectra of Inorganic and coordination compounds", K. Nakamoto, 5 Ed, John Wiley 1978, NewYork.

CH-16: Lasers and Their Applications

Introduction to Lasers

1. Rate equation for absorption, induced and spontaneous emission, Einstein's A and B coefficients – Concepts of laser action and population inversion – rate equations for two, three and four level systems.

2. Laser and its sub-systems – Optical amplifier – optical resonator – excited state pump – Properties of laser beams – Spatial and temporal coherence.

3. Different types of passive resonators, modes of a passive resonator – Active resonators – Gain & Threshold condition for lasing actions – laser modes – Gain saturation and mode competition – spatial and velocity hole burning.

4. Wavelength and Intensity stabilization of lasers – turning of wavelength of lasers – prisms, grating and elations – controlled wavelength turning – Selection of axial modes, Experimental realization of single mode.

5. Generation of short pulses – Q-switching and mode locking – active and passive methods

6. Principles of various types of lasers – UV, vis & IR lasers, metal vapour lasers, solid state lasers, Gas lasers, Dye lasers, Semiconductor-diode laser and free electron laser

Laser Spectroscopic Techniques:

Important features of lasers useful for spectroscopy – monochromaticity, directionality, high intensity, tunability, short pulses etc. Advantages of lasers for spectroscopy – high sensitivity and selectivity. Short review of spectral line broadening mechanisms.

Doppler-limited spectroscopy
a) High sensitivity methods of Absorption – frequency modulation, intracavity absorption.
b) Photoacoustic spectroscopy; c) Resonance ionization spectroscopy combined with mass spectrometry – multiphoton processes; d) Optogalvanic spectroscopy

Laser Induced Fluorescence: a) Molecular Spectroscopy by LIF; b) Experimental aspects and advantages of LIF (c) LIF in supersonic molecular beams

Laser Raman Spectroscopy: (a) Linear Raman Spectroscopy; (b) Non-linear Raman Spectroscopy – Stimulated Raman scattering (c) Coherent Anti-Stokes Raman Spectroscopy (CARS)

Analytical applications of lasers: a)Laser induced break down spectroscopy, cavity ring down spectroscopy; (b) Atmospheric measurements with LIDAR

Laser material interactions: a) Vaporization, desorption and ablation. b) Surface modification; c) Laser cooling (d) Laser Induced Chemical Reactions/ Laser Isotope Separation

Reference Books:

1. “Introduction to Lasers Physics”, K. Shimoda, Springer Verlag, 1984 Berlin
2. “Laser Spectroscopy basic concepts and Instrumentation”, W. Demtroder, Springer 2003, Berlin.
3. “Principles of lasers”, O. Svelto and D. C. Hanna, Plenum, 1989, New York
4. “Chemical and biochemical applications of lasers-vol I & III”, C.B. Moore, (Ed) Academic Press, New York (1974)
5. “Lasers”, P.W. Milonni and J.H. Eberly, World Scientific, Singapore (1981)

CH 17 - Nano materials and advanced chemical sensors

Introduction
Nanoscale– its importance, definitions, nanomaterial science- One dimension, Two dimensions (carbon nanotubes, inorganic nanotubes, nanowires, biopolymers), Threee dimensions (nanoparticles, fullerenes C-60, dendrimers, quantum dots) properties (electrical, optical, mechanical & chemical)

Synthesis and characterization
Synthesis -Chemical methods (precipitation, sol-gel, CVD, ion-exchange, dispersion), Physical methods (milling, PVD, pyrolysis, ion-implantation). Consolidation of nanopowders – sintering introduction, theories of sintering, sintering of nanomaterials, novel methods for consolidation of nanopowders. Characterization – X-ray techniques, spectroscopic techniques, electron beam techniques, optical methods

Applications
Structural and functional ceramics, coatings, sensors, power sources, additives and catalysts, composites, lubricants, magnetic materials, medical implants & nuclear ceramics. Sintering – introduction, theories, methods for consolidation and sintering of nanostructured materials

Introduction to chemical sensors
Fundamental definitions and principles; rationale of sensor design and operation; basic theoretical considerations

Electrochemical Sensors
(Potentiometric sensors, Voltammetric and Amperometric sensors)
Ion selective electrodes(ISEs) – principles, solid (glass and fast ion conductor based) and liquid membrane based electrodes, Electrochemical gas sensors, Semiconductor devices (ISFETs, MOSFETs), Conductance gas and vapour sensors based on metal oxides, semiconductors and conducting polymers. Biosensors- oxygen and glucose biosensors; mediated enzyme electrodes and enzyme field effect transistors (ENFETs).

Piezoelectric Sensors
Piezoelectricity and mechanical resonance: stress, strain and polarization; constitutive relationships; equations of wave motion and wave representation.
The transverse-shear mode sensor, or quartz crystal microbalance: application to gas- and liquid-phase sensing; applications to VOC sensing, immunosensing and biosensors.

Optical Sensors
IR and UV sensors - semiconductors - optical irradiation – recombination - Quantum efficiency - p-n junctions - IV characteristics - forward bias and reverse bias - applications.

Micro Electro Mechanical System (MEMS) based sensors and electronic noses
Cantilever based sensors – Sensing Principles, types of cantilevers, use of different detection techniques, examples and applications
Chemometrics as applied to chemical detection and identification; Olfaction and electronic noses; Salient features

Sensor fabrication methods
Sensor configurations and geometries, Use of nano-materials in sensors
Thin/thick film formation techniques (physical, chemical and LB film formation techniques), MEMs based sensor fabrication
Surface analysis and characterization

Practicals

Testing of a solid electrolyte based potentiometric oxygen sensor
Testing of an amperometric sensor for oxygen
Fabrication and testing of a thick-film hydrogen sensor

References

1. Fundamentals of Nanostructured materials, Eds. D. Fiorani (World Scientific, Singapore, 1994)
2. Nanoparticles and Nanostructured Films: Preparation, Characterization and Applications, Ed. J.H. Fendler (Wiley-VCH, New York, 1998)
3. Chemistry of Nanomaterials Vol 1 and 2, Eds. C.N.R. Rao, A. Muller, A.K. Cheetam, (Wiley-VCH, Weinheim, 2004)
4. Nanoscience and Nanotechnology (Ed.) B.S. Thomar, IANCAS Bull., Vol. VI, No.2, April 2007.
5. J. Janata, Principles of Chemical Sensors, Kluwer Academic Publishing Plenum, Dordrecht, 1989.
6. T. Seiyama Ed. , Chemical Sensor Technology, Vol. 1 and 2 Elsevier, Amsterdam, 1988.and 1990
7. Chemical Sensor Technology, Vol. 3, (N. Yamazoe Ed.)Elsevier, Amsterdam, 1991.
8. Chemical Sensor Technology, Vol. 4 (S. Yamauchi Ed), Elsevier, Amsterdam, 1992
9. H. Baltes, W. Gopel, J. Hesse Eds. , Sensors Update Volumes 1 to 6 , Wiley-VCH, Weinheim, 1996.
10. W. Gopel, J. Hesse, J.N. Zemel Eds., Sensors, A Comprehensive Survey, Vol. 7, Wiley-VCH, Weinheim, 1993.
11. R.W. Cattrall, Chemical Sensors, Oxford Univ. Press, Oxford, 1997.
12. K.T.V. Grattan, B.T. Meggitt Eds. , Optical Fiber Sensor Technology, Vol. 4: Chemical and Environmental Sensing, Kluwer Academic Publishing, Dordrecht, 1999.
13. ‘Solid State Gas Sensors’, (eds. P.T. Moseley, B.C. Toefield), 1987, Bristol, Adam Hilger.
14. S.R. Morrison: ‘The Chemical Physics of Surfaces’, 1; 1978, New York, Plenum Press.

CH-RM: Course on Research Methodology

Unit-I - Objectives and types of research: Motivation and objectives – Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Unit-II - Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem – Literature review – Primary and secondary sources – reviews, treatise, monographs-patents – web as a source – searching the web - Critical literature review – Identifying gap areas from literature review - Development of working hypothesis.

Unit-III - Research design and methods – Research design – Basic Principles- Need of research design –– Features of good design – Important concepts relating to research design – Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Unit-IV – Value of Statistics; Errors and Statistics – Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results – students's t test; F-test; Chi Square test; propagation of errors.

Unit-V - Reporting and thesis writing – Structure and components of scientific reports - Types of report – Technical reports and thesis – Significance – Different steps in the preparation – Layout, structure and Language of typical reports – Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation – Planning – Preparation – Practice – Making presentation – Use of visual aids - Importance of effective communication –.Computers in Chemistry, Usage of packages such as, Excel, AIM2000, ChemCraft, etc. Manuscript drafting based on "Experimental data and Literature Survey". **Unit-VI** - Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialisation – Copy right – Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights – Reproduction of published material – Plagiarism - Citation and acknowledgement - Reproducibility and accountability. [7 hrs]

REFERENCES

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3. Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Ess Publications (2 volumes)
4. R. Paneer Selvam – Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
5. Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
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7. Vogel’s Text Book of Quantitative Inorganic Analysis, ELBS.

BACK TO MAIN

GOVERNMENT OF INDIA

BHABHA ATOMIC RESEARCH CENTRE

PGD IN ENGINEERING SCIENCE (PROGRAM CODE: ENGG00)

SYLLABUS

Orientaion Course for Engineering Graduates and Science Post Graduates (OCES)

BARC Training School, Mumbai

HUMAN RESOURCE DEVELOPMENT DIVISION

MUMBAI 400085

PREFACE

The Department of Atomic Energy (DAE) has the multi pronged mandate of the utilisation of the power of the atom towards generation of power, development of advanced technologies, directed research in various scientific and engineering disciplines, production of radioisotopes for societal applications in medicine and agriculture and towards national security. In order to become self reliant and self sustaining in this high technology area, the need for generating highly skilled manpower and ensuring its continuous availability was indispensable. Thus in 1957, the BARC Training School (BARCTS) was established as a centre for in house training of professionals. These professionals today form the backbone of the Nuclear Power Programme. More than 9000 trainees have graduated from BARC TS over the last 61 years and provide the technological leadership in DAE for all its important programmes. Over the last five and a half decades, the BARCTS has grown into a model institute, recognised internationally as a school of excellence.

The academic activities of BARCTS are carried out by the Human Resource Development Division (HRDD) from its campus situated at Anushakti Nagar, well away from the hustle and bustle of Mumbai, nestling between wooded hills and sylvan surroundings, close to the BARC premises. This crucible of learning has been a focus of attraction to many a bright young talent, eager and willing to learn, guided and mentored by an academia drawn from the pool of experts available within DAE. Hailing from some of the best universities in India, they are nurtured with care and concern, by means of a holistic approach to training and personality development. A judicious mix of academics, practical training and soft skills training is imparted at the Training School and at the state of the art laboratories of BARC. A well equipped hostel with sports, recreation, and internet facilities provides the right environment needed for wholesome development. The lure of a professionally challenging career with opportunities for upgradation of skills, an objective merit recognition based career growth pattern and attractive compensation packages have attracted the best talents to BARCTS.

The BARCTS has two principle programmes, the One-Year **Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)** and the **DAE Graduate Fellowship Scheme (DGFS)**

Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)

OCES is the flagship programme of the BARC Training School and its affiliates. Under this scheme, engineering graduates from eight engineering disciplines- Mechanical, Chemical, Metallurgy, Civil, Electrical, Electronics, Instrumentation & Computer Science and Science Post-Graduates from Physics, Chemistry & Biological Sciences are selected and imparted a

rigorous one year training in the field of Nuclear Science and Technology. In addition to the above 11 disciplines, selected post graduate candidates from the Physics and Chemistry disciplines are also inducted into a course specifically designed for the purpose of providing a holistic training in all aspects of radiological safety. This course has been named as “Radiological Safety Engineering’ course.

The curriculum provides multidisciplinary training in topics relevant to the nuclear industry, frontier areas of science and technology and some super specialized areas. Training is imparted by adjunct faculty comprising the scientists and engineers working in various projects of DAE. In this manner, not only the objective of training but also the greater task of seamless and effective knowledge transfer from the expert to the acolyte is carried out successfully. The scheme also ensures the retention of the trained manpower within the Department thereby maximising the benefits of the training programme to the Department.

A total of about 150 courses in the above disciplines comprising more than 4000 lectures are delivered by more than 500 adjunct faculty members from BARC and other educational institutes during this period.

OCES Training Objectives: It involves one year of academic and training programme at the BARC Training School. The training programme aims to ensure that the selected candidates are provided with the necessary facilities and opportunities to acquire knowledge and develop skills for meeting the challenging technological goals of the country in the field of nuclear S&T. The training courses are organized in a structured manner as detailed below

- Foundation courses impart multidisciplinary training in the topics relevant to the nuclear industry.
- Core courses bring all selected candidates from different universities to the same or common level of understanding in the core subjects of the respective disciplines.
- Elective courses impart training in few specialized areas in respective disciplines.

OCES graduates are also eligible for the award of Post Graduate Diploma in Nuclear Science/Engineering & Technology of HBNI. After joining the DAE, the eligible OCES graduates can undertake one year project work leading to the award of M.Tech./M.Phil. Degree of the HBNI.

DAE Graduate Fellowship Scheme (DGFS)

In order to meet the requirement of highly specialised professionals in specific areas, DAE initiated the DGFS Programme for inducting engineers at MTech level in collaboration with the six IITs viz. Bombay, Delhi, Kanpur, Kharagpur, Madras, Roorkee and BHU in addition to some other elite institutes such as NIT Rourkela and ICT, Mumbai. The scheme strengthens the research-education linkage with premier institutes of the country in the areas of interest to DAE and provides useful synergy between the nuclear sector and the academia

Under this scheme, trainees selected for the OCES programme as well as one of the above institutes pursue the M.Tech degree under the sponsorship of DAE. On completion of the MTech degree, the candidates are absorbed into DAE as a Scientific Officer with advance increments. These Fellows then undergo a 4-month Orientation Course for DGFS Fellows (OCDF) after successful completion of M.Tech.

Orientation Course for DGFS Fellows (OCDF)

Several topics of interest to the Department do not form part of the MTech curriculum. To provide an exposure to such topics, the DGFS Fellows undertake a four months orientation course in the BARC Training School **(Orientation Course for DGFS Fellows- OCDF)** after successful completion of their MTech. Programme.

This document furnishes the course structures of all disciplines and syllabi of the courses conducted by the BARC Training School under each discipline.

CONTENTS

SYLLABUS

ENGINEERING SCIENCES

Annexure-I

REVISED CREDITS FOR COURSES IN ENGINEERING SCIENCES

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (MECHANICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for PVP	EN610	60	6	250
2	Computational fluid Dynamics and Heat Transfer	EN611	50	6	200
3	Finite Element Method	EN621	30	4	125
4	Fracture Mechanics	EN622	40	4	150
5	Mechanics of Solids	EN624	40	4	150
		Core Total	**220**	**24**	**875**

ELECTIVES (MECHANICAL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Machine Design	EN711	25	2	100
4	Material Science in Nuclear Engineering	EN712	25	2	100
5	Multi-scale material modelling	EN715	30	4	125
6	Nuclear Emergencies	EN716	35	4	150
7	Reliability Engineering	EN718	25	2	100
8	Vibration	EN721	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CHEMICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25	2	100
2	Advanced Mass Transfer	EN604	25	2	100
3	Code design for PVP	EN610	30	4	125
4	Computational Fluid Dynamics and Heat Transfer	EN611	50	6	200
5	Nuclear Chemical Engineering	EN628	35	4	150
6	Process Dynamics and Control	EN634	45	6	200
7	Process Modeling, Simulation and Optimization	EN635	45	6	200
	CORE TOTAL		**225**	**30**	**950**

ELECTIVES (CHEMICAL) – Any 3 Courses - 9 CREDITS

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Material Science in Nuclear Engineering	EN712	20	2	75
4	Membrane Technology	EN714	35	4	150
	ELECTIVES TOTAL (APPROX)		**90**	**8-10**	**350**

	THEORY TOTAL	**535**	**62-64**	**2175**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 535; Total Credits: 106-108; Total Marks: 2775

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - METALLURGY

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (METALLURGY)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	2	75
2	Extractive Metallurgy	EN620	40	4	150
3	Mechanical Metallurgy	EN623	30	4	125
4	Nuclear Materials	EN628	50	6	200
5	Nuclear Metallurgy	EN629	30	4	125
6	Physical Metallurgy	EN630	40	4	150
7	Process Control & Instrumentation	EN631	25	2	100
		CORE TOTAL	**230**	**26**	**925**

ELECTIVES (METALLURGY) Any 3 Courses- 9 Credits

S.No.	Subject Title		Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Image processing and Machine Vision	EN710	30	4	125
4	Materials Characterization	EN713	20	2	75
5	Multi scale Material Modeling	EN715	30	4	125
6	Nuclear Chemical Engineering	EN628	35	4	150
7	Nuclear Emergencies	EN716	35	4	150
8	Welding Science & Technology	EN723	25	2	100
		ELECTIVES TOTAL (APPROX)	**90**	**8-12**	**350**

	THEORY TOTAL	**540**	**58-62**	**2150**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 540; Total Credits: 102-106; Total Marks: 2750

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CIVIL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1	30	4	125
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2	30	4	125
3	Design Basis Hazards & Geotechnical Engg	EN621	40	4	150
4	Earthquake Engineeing & Structural Dyanmics	EN609	45	6	200
5	Finite Element Method	EN626	30	4	125
6	Mechanics of Solids	EN624	40	4	150
	Core Total		**215**	**26**	**875**

ELECTIVES (CIVIL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Struct Dynamics & Earthquake Engg	EN724	30	4	100
2	Construction Materials, Management & Quality	EN614	30	4	100
3	Safety & Reliability of Civil Engineering	EN722	25	2	100
4	Project Management	EN717	25	2	100
	ELECTIVES TOTAL (APPROX)		**80**	**8-10**	**300**

	THEORY TOTAL	**515**	**58-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 520; Total Credits: 102-104; Total Marks: 2600

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECRICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	20	2	75
2	Computer Based System Design I	EN612	25	2	100
3	Electrical Systems for Nuclear Power Plants	EN618	30	4	125
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**195**	**22**	**800**

ELECTIVES (ELECTRICAL) Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design II	EN702	25	2	100
2	Artificial Intelligence and its Applications	EN703	30	4	125
3	Computer Based System Design II	EN704	25	2	100
4	Digital Signal Processing & Image Processing	EN706	30	4	125
5	Image Processing & Machine Vision	EN710	30	4	125
6	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
7	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**525**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECTRONICS)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	4	125
2	Advanced Nuclear Instrumentation	EN605	40	4	150
3	Embedded & Computer Based Sys. Design	EN619	45	6	200
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**200**	**28**	**825**

ELECTIVES (ELECTRONICS) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Embedded Electronics Software	EN707	25	2	100
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**60-66**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 104-110; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (INSTRUMENTATION)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40	4	150
2	Computer Based System Design I	EN612	25	2	100
3	Modern Control Systems Design and Simulation	EN625	35	4	150
4	Reactor C&I and Human Machine Interface	EN636	40	4	150
5	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
6	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		EN639	**20**	**775**

ELECTIVES (INSTRUMENTATION) Any 3 Courses-- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	125
2	Computer Based System Design II	EN706	25	2	100
3	Digital Signal Processing & Image Processing	EN707	30	4	125
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**8-12**	**350**

	THEORY TOTAL	**525**	**54-58**	**2075**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-102; Total Marks: 2675

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25	2	100
2	Computer Graphics & Visualisation	EN613	35	4	150
3	Distributed Computing	EN616	45	6	200
4	Networking & Information Security	EN6627	40	4	150
5	Reactor Control Engineering	EN637	15	2	75
6	Software Engineering and Formal Methods	EN640	40	4	150
	CORE TOTAL		**200**	**22**	**825**

ELECTIVES (COMP. SCIENCE AND ENGINEERING) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Data Base Management System & Web Technology	EN705	30	4	100
3	Digital Signal Processing & Image Processing	EN706	30	4	125
4	Embedded Electronics Software	EN707	25	2	100
5	Feedback Control System	EN708	25	2	100
6	Image Processing & Machine Vision	EN710	30	4	125
	3 ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

FOUNDATION COURSES

EN501: Accelerator Physics and Technology

Basic Accelerator Physics (5)

- Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons;
- Ion sources.
- General equations of motion in a combined electric and magnetic field, beam rigidity; relativistic expressions, weak and strong focusing principle; condition for strong focusing.
- Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.
- General design of a cyclic accelerator.
- Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;
- Matrix techniques in beam optics; first order transfer matrix of dipole, quadrupole, transfer matrix of a drift space; quadrupole doublet;
- Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters
- Introduction of normal (room temperature) DC and pulsed magnets, construction features. Superconducting coils, magnets and their construction features.
- Momentum compaction; Phase stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.
- Synchrotron radiation sources; spectrum of emitted radiation; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators.

RF Linacs (12)

Introduction to Linacs

- Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.
- Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac
- Transit time factor and the energy gained in a linac.
- Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.
- General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature RF structures.

Proton Linac

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.
- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
- Introduction to Space charge effects.
- Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Accelerator Driven Systems & RF electron accelerators

Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.

Accelerator Technology (13)

General

- Material selection for Accelerator components
- Mechanical Design and fabrication issues; tolerances, surface finish, etc
- Thermal management in accelerator systems
- Alignment requirements of accelerator magnets and RF structures, methods and instruments for alignment and surveying in accelerators.

Ultra High Vacuum Systems

Basic concepts in Vacuum

- The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
- Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
- Basics of low pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, Sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.

Cryogenics Systems

Introduction to Cryogenic Engineering

- General and basics, Cryogenic properties, Basic cycles
- Large Cryogenic Systems for Accelerators

Cryogenic Equipments

- Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

References

1. Principles of RF Linear Accelerators, T. P. Wangler, (John Wiley & Sons Inc., 1998)
2. Introduction to Accelerator physics – Arvind Jain
3. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer, (John Wiley & Sons Inc., 1982)
4. An Introduction to the Physics of Particle Accelerators - M. Conte, W.W. Mac Kay.
5. Handbook of Accelerator Physics and Engineering - A. Chao, M. Tigner.
6. Particle Accelerator Physics (Vol 1 and Vol 2) - Helmut Widemann.
7. Principles of Charged Particle Acceleration – Stanley Humphries.
8. Fundamentals of Beam Physics - James Rosenzweig.
9. An Introduction to Particle Accelerators - E. J. N. Wilson.
10. Accelerator Physics - S. Y. Lee.
11. The Physics of Particle Accelerators, An Introduction - Klaus Wille.
12. The Principles of Circular Accelerators and Storage Rings - Philip Byrant.
13. Introduction to Vacuum Technology-Compiled by K.G. Bhushan, BARC

EN 502:Engineering Maths-I (15) (All Engg)

- Overview of arithmetic errors in computations
- Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
- Linear systems solutions by direct methods, iterative methods and acceleration techniques.
- Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
- Linear systems: Eigen values.
- Non -Linear systems: Newton-Rapson & Successive Approximation methods
- Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
- Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
- Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 503: Engineering Maths-II (20) (ME Group)

- Introduction to discretization methods and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations, wave equation
- Formulation of the matrix methods by equilibrium concepts (1D-heat conduction, 2D-truss and 1D-hydraulic flow examples).
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's methods, Piecewise approximations. Basis of Finite Element Method, energy principles in structural mechanics and principles of minimum potential energy, assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit methods.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.
- Finite element formulation for laminar and turbulent flows.
- Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
- Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
- Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
- Response Surface Method 2K+1, factorial design, 3k factorial design
- Monte Carlo Method
- Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Artificial Intelligence and Genetic Algorithm
- Artificial Neural Network
- Gram-Schmidtt Orthogonalization
- Transformation of matrix

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 504:Engineering Maths-II (20) (MT)

Applications in Materials Science:

- Use of matrix in crystallography. Stereographic analysis, lattice correspondence, orientational relationship, applications to twinning and martensitic. transformations,
- Tensor analysis in phase transformation and deformation studies
- Analysis of diffusion data, Solutions of diffusion equations - error function and Eigen value analysis, Polynomial fitting of diffusion profiles.

Application in thermodynamics of metallurgical systems:

- Temperature dependence of thermodynamic quantities, graphical and analytical integration of Gibbs-Duhem equation. Introduction to database for thermodynamic tables
- Analysis and synthesis of phase diagrams, introduction to first principles calculations of phase diagrams with computer demonstration, cluster variation and Monte Carlo methods

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wilev, 1966.
2. Todd R.J. "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods.
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McCraw-Hill Book Co. 1983.
6. Rajaraman V,, "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C. "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis

1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B,, "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers. 1968.
11. Conte S.D,, "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo,McGraw Hill. 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G,, "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis". Addison Wesley, 1984.
15. Rajsekaran S,, "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987; •
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation' Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.-• •
19. Acton, "Numerical Methods That Work"
20. Forsythe et. al,, "Computer Methods for Mathematical Computations"
21. Forsythe et. al,, "Computer Solution for Linear Algebraic Systems"
22. Golub Gene H., "Matrix Computations"
23. Griffiths D. V., "Numerical Methods Engineers: A Programming Approach"
24. Williams P. W,, "Numerical Computation.
25. Strang G,, "Applied Mathematics"
26. Crank J,, "Mathematics of Diffusion"
27. Worked Examples in the Geometry of Crystals: MKDH Bhadesh
28. Materials Science & Technology, Vol.4; Rudman.

EN 505: Engineering Maths-II (20)(EE Group)

- Transforms: Laplace & solution to ODE, Bilinear & Z transforms, Discrete cosine transforms & compression, Entropy & Haufman coding for compression
- Solution of Matrix Differential Equation: Existence & uniqueness of solutions, Solution of Non-Linear continuous time state equation, Solution of Linear time varying continuous time state equation, Solution of linear time invariant continuous time state equations
- Basic Procedure for Designing Conservational Logic: Quine McCluskey method, Iterative consensus method, Design example
- Design of Sequential Circuit Using Sequential Machine Flow Chart: Sequential machine flow chart, Reading reduced dimension maps, Output function synthesis, Next state function synthesis, State assignment & design examples
- Counting Statistics and Error Prediction: Statistical models -Binomial, Poisson and Gaussian distributions, Application of statistical models: Error propagation, Optimization of counting experiments, Limits of detectability, Distribution of time intervals

References:

1. F R Grantmacher, "The Theory of Matrices", New York: Chelsea Publishing Co., 1960.
2. R Bellman, "Introduction to Matrix Analysis", II ed., New York, McGraw Hill, 1970.
3. E Kreyszig, "Advanced Engineering Mathematics, 5th ed., Wiley Eastern Ltd., 1985.
4. Paul R Halmos, "Finite Dimensional Vector Spaces", and New York: D Van Nostrand Co. Inc., 1965
5. Bajpei et.al, "Numerical Methods for Engineers and Scientists"
6. Dahlquist et.al, "Numerical Methods"
7. G Strang, "Applied Mathematics"
8. Golub Gene H, "Matrix Computations"
9. Numerical Methods for Scientists and Engineers, By H.M.Antia, Hindustan Book Agency,New Delhi.
10. Numerical Methods for Mathematics, Science and Engineering, Mathews(IInd Ed), Prentice Hall of India.

EN 506:Health Physics and Radiological & Industrial Safety (20)

Health Physics

Introduction

- Radiation sources, its interaction with matter and units**:** Natural and Induced radioactive sources,
- Units of radioactivity, half-life and decay constant, specific activity.
- Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter.
- Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given).
- Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given),
- Exposure-dose relationship, Bragg-Gray principle.

Biological effects, Radiation Protection and Regulation:

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Importance of radiation protection programme in DAE.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.

- Radiation protection philosophy,
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Principles of radiation detection and monitoring

- Basic operating principles ofa) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type ofRadiation monitors/Radioactivity measurement methods adopted for radiation protection should be taught.

Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management.
- Personal monitoring, area-monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures:

- Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper),
- Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation, Protective equipments

Nuclear Accidents, Emergency Preparedness and Management:

- Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

INDUSTRIAL SAFETY ASPECTS

Introduction:

- Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques

Hazards due to physical agents:

- UV and IR radiation, Lasers, Microwave radiation; noise, heat

Chemicals hazards:

- Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals

Evaluation:

- Instrumental methods, air sampling methods, liquid effluent monitoring

Occupational exposure limits:

- Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50

Handling, storage and control:

- Engineering control measures and safety features,
- Safety management techniques such as safety audit, Personal/ administrative control, and Medical control

Fire and explosion hazards:

- Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits,
- USNFPA Classification of Flammable/combustible liquids: flammable gases;
- Engineering safety for prevention of fire and explosion,
- Hazard area classification, selection of equipment, detection and extinguishing systems.

Hazard identification, assessment and control:

- Hazard identification: Concept of risk and Risk management
- Formal methods of hazard identification and assessment:
- Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies
- Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation.

Management of major hazard Installations:

- Plant Layout and Engineering Design Consideration
- Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic Releases,
- Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment,
- Emergency Planning Guidelines, Development of Emergency Plan

Health and safety regulatory aspects:

- Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate.
- EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

References:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute Of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment And Control; Vol-1, 1996 2 Edition, Frank P Lees.

EN 507:Material Science in Nuclear Engineering (EE) (20)

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction methods --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices.
- Material characterization techniques --- XRD, RBS, SEM, TEM, EDAX, XPS, IR and Raman Spectroscopy.
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials, mechanical properties and measurement techniques, strength and ductility, creep, fatigue and wear testing
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Reactor core materials, Zircalloys, Zr-Nb alloys --- fabrication, properties and applications in reactors
- Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels) --- fabrication, properties and applications.
- Chemistry of fuel materials: Production of Uranium, Plutonium and Thorium.
- Heavy water: Production process, purification, properties and applications.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)

2\. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)
3\. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)
4\. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)

EN 508: Nuclear Fuel Cycle Technology(35)

An overview (1)

FRONT END

Mining, Milling and Associated Processing of Indian Uranium Resources(1)

- General Introduction
- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.

Case Studies (1)

- Jaduguda and Turamdih Uranium Ore Processing
- Tummalapalle Uranium

Metal Purification using Hydro-Metallurgical Processes (1)

- Process, Equipment, Quality control

Metal Production by Metallothermic Reduction Processes (1)

- Process, Equipment, Quality control

WasteManagement and Safety (1)

- Associated wastes, characterisation and management

BACK END

Reprocessing (4)

- Nuclear fuels and generation of Pu239 & U233
- Spent fuel management options.
- Characteristics of spent fuel (RR, PHWR, AHWR ,FBR&LWR).
- Reprocessing by PUREX -Head end operations, solvent extraction cycles including the conversion of nitrates to oxides.
- Reprocessing of AHWR and FBR spent fuels.
- Prevention of criticality in reprocessing plants.

Waste Management (3)

- Waste sources.
- Radioactive waste classification.
- Management of low and intermediate level wastes.
- Vitrification of high level liquid waste.
- Schemes for partitioning of high level waste including recovery of valuable fission products.
- Storage and disposal of radioactive wastes.
- Various decontamination techniques to address alpha bearing materials.

Instrumentation & Control (3)

- Measurement techniques for level, pressure, temperature, interface density and flow Instrumentation and control associated with transfer devices—steam jets, pumps and air lift pots
- Interlocks related to major equipments like pulse column, dissolver, evaporator, joule melter and ion exchange column
- Computerised data acquisition and control system

Radiation Monitoring System (2)

- Area monitoring instruments, stack monitors, criticality alarm systems, effluent monitors,PCW & steam condensate monitors
- Single line diagram for Class-4, Class-3 and UPS
- Earthing, cabling, lightening protection system, VF drives

Civil (1)

Design aspects of back end technology facilities- Design classification and seismic categorization, considerations for external events, Standards/codes for design

Metallurgy (2)

- Corrosion aspects and material of construction for reprocessing and waste management plants.
- Degradation modes of SS 304L in nitric acid.
- Welding techniques, quality assurance and special requirement for in cell equipment.

Mechanical (7)

- Spent fuel transportation- shipping cask design and regulatory requirement.
- Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
- Remote handling system in reprocessing.
- Automation in plutonium powder handling.
- Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
- Sampling system. Transfer devices and valves for radiochemical plants.

Features of Radiochemical Plant (7)

- Layout considerations and design philosophy for back end operation.
- Control of radiation exposure including shielding and barriers.
- Ventilation aspects and Off gas handling and treatment.
- Utilities requirement for back end.
- Mechanical design aspects of metallic and joule melter.
- Radiation shielding windows.
- Remotisation and remote handling in vitrification plants

EN 509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40)

Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulas gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

1. Wakil M.EI, "Nuclear Power Engineering", McGraw- Hill.
2. Strosal and Vapet, "Power Plant Engineering & Economics".
3. Lewis E.E., "Nuclear Power Reactor Safety", Wiley Inter Science.
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von-Nostrand, 1981.

Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time.Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
  - Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio, blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly
  - Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
  - Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination

References:

1. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors", Pergamon Press
2. Yevick J.G., "Fast Reactor Technology", Plant Design, M.I.T, Press.

Module 3:Advanced Reactor Concepts (6)

Introduction(1)

- Need for Advanced Reactors and in what way these are different from conventional reactor
- International initiatives – INPRO, GIF etc.
- Definition of sustainability and INPRO areas of sustainability
- Brief Description of the INPRO Guidelines and Methodology to Evaluate INES
- Basic principles, User requirements, Key Indicators, Allowable parameters etc.

Directions of Development in the World(1)

- GIF and other advanced reactor concepts

Indian Programme on Advanced Reactors and Associated Challenges (2)

- AHWR
- AHWR-LEU
- CHTR, IHTR, MSBR etc.

Reactor Physics Design Challenges(1) ADS and applications(1)

EN 510:Reactor Physics & Engineering (55)

Module 1 :Nuclear Reactor Physics (33)

Properties of Nuclei

Binding energy-formula and interpretation, nuclear forces, nuclear structure.

Fission Process

- Fission rate and reactor power
- Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
- Fissile, fertile and fissionable materials
- Fission product activity after shut down –decay heat.

Interaction of Neutrons with Matter

- Production of neutrons

Concept of microscopic cross section:

- Inelastic and elastic scattering

Variation of cross-section with energy

- Fast, resonance and thermal ranges
- 1/v law of neuron cross-section
- Resonance absorption, Doppler effect.
- Eta vs E curve conversion & breeding concept
- Thorium utilization

Diffusion of Neutrons
- Fick's law and its validity
- Steady state neutron diffusion equation
- Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.

Chain Reaction
- Four Factor formula
- Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
- Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,

Slowing Down Process
- Neutron slowing down
- Slowing down power/ moderating ratio of moderators
- Slowing down with spatial migration
- Fermi age concepts, migration length
- Multi zone reactors
- Ideas of reflectors/blankets, reflector savings, form factor.

Heterogeneous Reactors
- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

Reactor Kinetics
- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

Core Burn Up
- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

Neutron Poisons
- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

Reactivity Coefficients
- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Module 2: Reactor Engineering & Radiation Shielding (22)

Reactor Engineering (14)
- Introduction to reactor system & Indian Nuclear power programme
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems
- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR),
- Fast reactors;
- Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
- Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.

Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.

- Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
- Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.

Nuclear Fuel Cycle (2)
- Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
- Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
- Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
- Advanced fuel cycles

Radiation Shielding (6)
- Source of various neutron & Gamma radiation within the reactor system
- Attenuation of neutrons & gamma rays

- Dose rates for gamma rays for various source geometries
- Buildup factors for homogeneous & multiple layer shields
- Removal diffusion theory for neutron attenuation
- Coolant activation, heat generation
- Streaming of radiation through gaps & void in the shield

CORE COURSES

E601: Advanced Chemical Reaction Engineering (25)

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
- Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
- Reactor design: counter-current moving bed reactors, fluidized bed reactors.
- Advanced topics in reaction engineering- three phase reactors, photochemical reactors, integral reactor-separators, complex systems.
- Examples from nuclear chemical engineering.

References:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

EN602: Advanced Electrical Engineering Design-I (20)

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Methods, Finite Element Methods, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Methods: MFL Technique, Eddy current Technique, Remote Field eddy current Methods. (5)

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronics Circuit Design Techniques (30)

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Programmable Logic Devices: PLD, CPLD and FPGA, Technology architecture (4)
- Hardware Description Languages: VHDL – language details (6)
- Digital Circuit Design using VHDL: Design methodology and optimization, Design of a multiplexer, counter, finite state machine etc., test bench (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. Actel HDL Coding Style Guide, 2009 edition, Published by Actel Corporation, Mountain View, CA 94043. Free softcopy available on Actel website (www.actel.com).
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles

10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25)

- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Rate based approaches for design.
- Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors.
- Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors.
- Adsorption and ion exchange equipment.
- Membrane separation and other advanced mass transfer processes.
- Process intensification approaches.

References:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)

EN605: Advanced Nuclear Instrumentation (40)

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and methods of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems ,Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.

Reactor Instrumentation:

- Fundamental Considerations / Philosophies, requirements, and scope.
- Measurement ranges of reactor neutron flux and considerations
- Types of neutron detectors FC,10B, BF3, CIC and SPND for in-core and out-of-core use.
- Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR,LR, Lin, LinR and ρ)
- Noise reduction techniques, considerations and practice: EMI Interference, Grounding and shielding.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma Monitors, Neutron Monitors, Contamination Monitors, including networking and RADAS.

References

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

EN606: Advanced Operating Systems (25)

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Processs Subsystem : Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem : Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Interprocess Communication : Message Queues, Shared Memory, Semaphores, Mailboxes, Sockets, Fundamentals of Socket Programming, Remote Procedure Calls [1][6]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing, Features of distributed Unix, Logical time, Concurrency Control [1][5]
- Unix Shells: Unix Shell Commands & Fundamentals of Shell Programming [1][2]

- Linux: Packaging and Distribution, Loaders, Virtual Terminals, Internal and External Drivers, Threads, Interfaces, X Window System, Hard Disk Partitions, File System Enhancements, Extended File Systems, Virtual File System, System Tuning. [3, 9, 10]

References:

1. The Design of Unix Operating Systems : Maurice J. Bach, Prentice Hall
2. Unix Programming Environment : Kerninghan & Pike, Prentice Hall
3. Linux Internals : Rubini, O'Reilly & Associates
4. Operating Systems Concepts: Silberschatz, Galvin, John Wiley
5. Distributed Operating Systems : Tanenbaum, Prentice Hall
6. Unix Network Programming : W. Richard Stevens, Prentice Hall
7. Xlib Programming : Adrian Nye, O'Reilly & Associates
8. Inside Windows NT , David A. Solomon, Microsoft Press
9. Demblon & Spitzner, http://learnlinux.tsf.org.za/courses/build/internals/internals-all.html
10. Tigran Aivazian, http://www.faqs.org/docs/kernel_2_4/lki.html or http://students.mimuw.edu.pl/SO/Linux-doc/LinuxKernel-2.4.pdf

EN607: Applied Process Instrumentation (40)

- Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables:
- **Flow**: Differential pressure flow elements: Orifices , venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters. Applications and limitations of various flowmeters. Two phase flow measurements.
- **Pressure**: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.
- **Level**: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
- **Temperature**: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
- **Temperature transmitters**- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
- **Analytical Instrumentation**: Conductivity, pH, ORP and Turbidity measurement.
- **Other Measurements**: Relative humidity; viscosity and density measurement
- **Control valves:** Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
- **Instrument Impulse lines and instrument fittings**: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
- **P & I Diagrams, loop and hook up diagrams:** P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

EN 608 Civil Engineering Design of Concrete and Steel Structures

EN 608.1Civil Engineering Design of Concrete and Steel Structures-I (30)

Introduction to various structures of nuclear facilities Classification of structure and design basis

Radiation protection objectives, defense in depth, safety functions, safety classification, seismicclassification, quality classification, design classification, design for natural and man induced events.

Design Loads:
- Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
- Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
- Severe Environmental Loads: operating basis earthquake,severe windincluding gust effect and aerodynamic instability, design basis flood load,tsunami.
- Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind- induced missile

Design of RC structures:
- DesignofRC structures as per IS456,AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 ,designloadcombinations,design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies

Design for shrinkage, creep & heat of hydration:

Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies..

Foundation design
- Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
- Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
- Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

EN 608.2 Civil Engineering Design of Concrete and Steel Structures-II (30)

Introduction to Prestressed Concrete structures

Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.

Design of lined and unlined containment structures

Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.

Design of steel structures of nuclear facility

Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections,design of embedded parts and anchor boltsas per AERB and ACI standards, case studies.

Design of water-retaining structures

Design of overhead and underground tanksusingun-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.

Design of cooling towers

Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

References

1. IS 456 (2000) "Plain and Reinforced Concrete – Code of Practice ".
2. ACI 318 (2014) "Building code requirements for structural concrete".
3. ACI 349 (2013) "Code requirements for Nuclear Safety related concrete structures".
4. RCC-G "Code of Practice for Design of Prestressed Nuclear Containment Structures". 5. ISO 14000
6. Raju, N. K. (2006), "Prestressed concrete", Tata McGraw-Hill Education.
7. ACI 207 (1995) "Effect of restraint, volume change and reinforcement on cracking of massive structures".
8. Bowles, J. E. (2001) "Foundation analysis and design", Tata McGraw-Hill Education.
9. Rao, N.S.V.K. (1988),"Vibration analysis & foundations dynamics", Wheeler publishing.
10. IS 2974-1, 1984,"Code of practice for design and construction of machine foundations".
11. Arya, S.C., Oneill, M.W. and Pincus, G. (1979), "Design of structures and foundations for vibrating machines", Gulf Publishing Co.
12. Manohar, S. N. (1984) "Tall Chimneys design and construction", Mcgraw-Hill Book Comp.
13. ANSI/AISC N690 (1984), American and National Standard – Nuclear facilities, "Steel safety related structures for design fabrication and erection".

EN 609 Earthquake Engineering and Structural Dynamics(45)

Introduction to Seismology
- Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA),Design Basis Earthquake,Concept of

Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra
- Seismic instrumentation for micro-earthquake and strong motions.

Structural Dynamics
- Introduction to dynamic loading, different types of dynamic loadings, concept of damping,derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
- Single degree of freedom of system (SDOF)–undamped& damped system, free & forced vibration; Response to harmonic and impulse loading,concept of transmissibility and vibration isolation,estimation of damping of structural system using free & forced vibration approach;response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
- Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
- Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies)& eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
- Introduction to dynamics of continuous system

Seismic Response Analysis of Structures
- Seismic response analysis using response spectrum and time history approach
- Modal superposition method, Modal combinations and spatial combinations, missing mass correction
- Time history analysis using direct time integration,
- Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction

Random vibrations
- Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.

Special Seismic Design Considerations

Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain, curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures;Seismic Design Optimization, Principles of performance based design, dynamic response control techniques such as base isolation, dampers etc.

Seismic Requalification of Existing Installations

Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection, review basis ground motion, evaluation of seismic margin capacity, retrofitting.

Case Studies

Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear installments.

References

1. Chopra, A.K. (2007), "Dynamics of structures: Theory and application to earthquake engineering", Prentice Hall.
2. Clough, R. W. and Penzien, J. (1993). "Dynamics of structures", McGraw Hill, Inc.
3. Mario Paz and William Leigh (2006), "Structural Dynamics-Theory and Computation", Springer.
4. Thompson, W. T. (1972),"Theory of Vibrations with Applications" Prentice-Hall, Englewood Cliffs.
5. ASCE 4-98 (1998), "Seismic Analysis of Safety related Nuclear Structures and Commentary on standard for seismic analysis of safety related nuclear structures".
6. AERB/SG/S-11, "Seismic Studies and Design Basis Ground Motion for NPP Sites".
7. IAEA SAFETY STANDARDS SERIES No. NS-G-3.3 (2002), "Evaluation of Seismic Hazards For Nuclear Power Plants".
8. IS 1893-1 (2002), "Criteria for Earthquake Resistant Design of Structures".
9. IS 13920 (1993),"Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces".
10. Dowrick D.J., "Earthquake Resistant Design"
11. Park and Pauley, "Reinforced Concrete Structures"
12. Pankaj Agrawal, Manish Shrikhande, (2006), Earthquake Resistant Design Of Structures
13. AERB monograph, (2008), SEISMIC SAFETY OF NUCLEAR POWER PLANTS

EN 610: Code Design for PVP (60)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin- walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
- Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material

and allowable stresses. Design of saddle supports.

- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 and Div.2.
- Difference between metallic pressure vessel and FRP pressure vessels

Nuclear Pressure Vessels and Piping (30)

- Monotonic and Cyclic Stress-Strain Curve, Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Failure modes of pressure vessels, Ratchetting and shakedown.
- Organization of Boiler and Pressure vessel Sec. Ill code. Safety classification and Criterion for selection of ASME sec. Ill classes. Design loadings and service loadings as per NCA 2140.
- Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Definition of B, C and K stress indices.
- Design of Nuclear piping as per Sec. Ill div.1. Design rules for standard support as per NF 3400, Design rule for piping support - NF 3600.
- ASME code rule for component support
- Design rule for Plate and shell- Type support as per NF 3200, Design rule for Linear-type support - NF 3300.
- Design rule for component support - NF 3500, Core support structure Design - NG 3300.
- Fracture Toughness requirements for materials for pressure vessels, pipings and boltings.
- Failure Analysis Diagram.
- Protection against Nonductile Failure - Appendix G, Basis of Low Cycle fatigue Design. Fatigue evaluation of vessels.
- Strain concentration factor ' Ke', Local strain approach: Neubar and Zarka rule, Elastic and elastic-plastic fatigue analysis of nuclear pipings, Leak-Before-Break Design Concept.
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec. Ill.
- NDE requirements, Examination of welds, Acceptance standard.

References:

1. Harvey J.F., “Pressure Vessel Design”, CBS Publication
2. Brownell L.E., and Young E.D., “Process Equipment Design” Wiley Eastern Ltd., India
3. ASME” Pressure Vessel and BoilerCode”, Sec. VIII, Div. I and Div. II, 1985
4. American StandardCode for Pressure Piping”, - B31.1, 1972
5. American Standard Code for Pressure Piping”, - Petroleum, Refinery Piping, B31.3, 1972
6. “Standard of Tubular Exchanger Manufactures Association”, 7th Edition, 1988.

EN 611: Computational Fluid Dynamics & Heat Transfer (50)

Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):

- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme
- Laminar Boundary Layer and Forced Convective Heat (5):
- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
- Convective heat transfer for internal and external flows
- Low and high Prandtl number limits and different thermal boundary conditions
- Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer (5):

- Reynolds decomposition for turbulence
- Prandtl's mixing length theory, Mixing length models
- Structure of turbulent boundary layer over flat plate and through circular cylinder
- Calculation of friction factor and drag coefficient
- Analytical and semi-analytical correlations for calculating heat transfer coefficients
- Analogy between heat and momentum transfer

- Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
- Turbulence Modeling:
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
- Reynolds stress models: algebraic and differential models
- Low Reynolds number models
- Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
- **Natural Convection (3):**
- Basic Equations of natural convection
- Boussinesq approximation
- Derivation of Dimensionless groups from basic equations
- Analytical approximations
- Numerical solution of approximate equations

Numerical Solution of Complete Fluid Flow and Energy Equation (10):

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation
- Streamfunction-vorticity-temperature formulation
- Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
- Primitive-Variable (P-V-T) formulation
- Pressure velocity coupling for incompressible flow:
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
- Simple grid generation techniques for structured grid:
- Elliptic, parabolic and hyperbolic equation method
- Grid adaptation
- Domain decompositions in CFD and heat transfer
- SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer (12):

- Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
- Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.
- Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
- low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
- Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
- Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.
- **Heat Transfer With Phase Change (10):**
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
- Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model)
- Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)
- Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
- Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
- Critical Flow: Models for single – phase and two-phase critical flow.

References for CFD:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.

14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor &Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

EN 612: Computer Based System Design- I (25)

Hardware Design

- Overview of microprocessors and peripherals: 8086, 68000, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications
- Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL)
- Case Study: Design of a single board computer with shared memory interface, I/O board design using ADC, DAC etc with emphasis on signal conditioning and isolation
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues

EN 613: Computer Graphics and Visualization (35)

- Introduction overview, Graphics software/hardware and types of graphics applications (1)
- 2D/3D Geometric Transformations, Affined transformations-Translation, Rotation, Scaling, Shear and reflection. (3)
- Homogeneous coordinates, composite transformations, rotation with qutenion, current transformations and matrix stacks. (3)
- Two dimensional viewing 2D viewing – window, viewport, viewport transformations, clipping operations, line clipping algorithms – Cohen-Sutherland, Liang-Barsky, polygon clippimg algorithm – Sutherland-Hodgman. (4)
- Three dimensional graphics – Planer geometric projections – parallel and perspective, Mathematics for projections, classical three-dimensional viewing, specifying views, viewing transformations, 3D clipping operations. (4)
- Hidden surface removal, object space and image space approach, back face culling, z-buffer algorithm, LOD.(2)
- Illumination and shading – Basic illumination models, light sources, material properties, polygon shading methods – flat, gouraud and phong shading, ray tracing methods. (2)
- Color - Color perception, color models – RGB,CMY,HSV (1)
- Visual Realism – Depth cuing, texture mapping, transparency, shadow, steropsis. (2)
- Curves and surfaces – Representation of curves and surfaces, Algebric and geometric form, Blending functions, interpolation, Hermite, Bezier, B-spline curves and surfaces, Rational polynomials, NURBS (5)
- Modern Graphics Architecture – Graphics Pipeline, GPU, PCI Express (2)
- Case Study – Using OpenGL (3)
- Scientific Visualization – Introduction, Geometry (Structured & Unstructured Grids), Data Representation (Scalar, Vectors), Volume Rendering (Marching Cubes, Ray Casting) (3)

EN 614 Construction Materials, Management and Quality Assurance (30)

Construction Materials

- Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
- Reinforcement: Passive and active (Prestressing)
- Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
- Paints
- Water-proofing materials & membranes

Shuttering/Formwork

Design philosophy, different design requirements, climbing shutter design, slip form work.

Prestressing system

Cable ducts, anchorage and grouting, qualification of Prestressing system

Quality Assurance (QA)

- QA in Civil Engineering design
- QA in materials
- QA in construction
- QA in operation & maintenance
- Inspection during construction, Regulatory inspection

Construction Procedure & Construction Safety

- Dewatering, rock excavation, consolidation grouting

- Construction safety, Job Hazard Analysis.

Contract Management

Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication

References:

1. Singh, K. A. N."ISO 9000-Quality Systems", Dolphin books, New Delhi.
2. Quality systems requirements (QS 9000) – Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 3rd edition
3. Quality system assessment (QSA) Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 2nd edition
4. CPWD Works Manual (2012), Central Public Works Department, Government of India, Published by DIRECTOR GENERAL, CPWD, NIRMAN BHAWAN, NEW DELHI-110 011.
5. Manual of Internal Inspection/DAE Works Procedure (2010), Department of Atomic Energy, Government of India.
6. ATOMIC ENERGY (FACTORIES) RULES (1996), Atomic Energy Regulatory Board, Government of India.

EN 615: Corrosion (15)

- Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables, composition and heat treatment. (3 Lectures)
- Forms of corrosion: uniform attack; corrosion rate measurements, Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion, low temperature sensitization, corrosion of weldments; stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen embrittlement, hydrogen attack, corrosion fatigue; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, failure analysis, specification tests, advanced methods for on-line corrosion monitoring. (7 Lectures)
- General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification. (1 Lecture)
- Corrosion in the nuclear industry – Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. corrosion in fluoride and ammonia containing environments; liquid metal corrosion. low alloy steels, stainless steels and Ni and Cu base alloys, protective magnetite formation on carbon steel, stress corrosion cracking of stainless steels and nickel base alloys. high temperature oxidation and hydriding of zirconium alloys, materials for fast breeder reactor system. Effects of radiation on corrosion (4 Lectures).

References:

1.Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. Corrosion – L.L. Shrier (Ed.) Vol.I & II, 1963.
5. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
6. Modern Electrochemistry, Vol. 1 & 2 – J. O.M. Bockris and A.K. Reddy
7. Corrosion of Stainless Steels – A.J. Sedricks.
8.Stress Corrosion Cracking – Materials Performance and Evaluation – Ed. Russel H. Jones, ASM Int., 1993
9. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN 616: Distributed Computing (45)

Advanced Computer Architecture

- Advances in CPU Architecture
  a. Advancements in CPU architecture – Dynamic Instruction level parallelism, Branch prediction, register renaming
  b. Static instruction level parallelism - EPIC, VLIW
  c. Hyperthreading
- Multi core architectureAdvances in Memory
  a. SDRAM, DDR, DDR-2
  b. Registered ECC, FB-DIMM
  c. CPU – Memory Interfacing techniques - FSB, Hypertransport, Quickpath
- Advances in I/O interfaces
  a. Shared I/O bus
  b. Switched I/O fabric
  c. Serial and parallel I/O bus
  d. Case studies - PCI, PCI-X, PCI-Express, PCI-Express Gen2
- Advances in Interconnect techniques
  a. Shared and switched networks
  b. Interconnect fabrics

  c. Approaches for improving interconnect performance
  d. Case studies – Ethernet, Infiniband, SCI
- Cache
  a. Associative, Direct mapped
  b. Write through, Write back
  c. MESI
  d. Shared caches
- Advances in storage systems
  a. Direct attached storage, Network attached storage, Storage Area Networks
  b. File level and block level accesses
  c. Storage protocols
  d. Case studies - ATA, SATA, SCSI, SAS, Fiber channel
  e. Case studies - FC, iSCSI, iSER, SRP

Parallel Computing

- Introduction to High Performance Computing
  a. Need for HPC
  b. Applications of HPC
  c. HPC Overview – Conventional Supercomputers, Parallel Computers, Classification (SISD, SIMD, MIMD)
- Pipelining, Vector processing, SIMD
  a. Pipeline, Speedup and Efficiency of pipeline
  b. Pipeline stalls, out of order execution
  c. Techniques to improve pipeline efficiency
  d. Superscalar, Superpipelined, VLIW, EPIC architecture
  e. Vector processors, vector instruction sets, registers
- MIMD Architecture
  a. Classification of MIMD machines
  b. UMA, NUMA, CC-NUMA, COMA, NORMA
- Interconnection networks and topologies
  a. Interconnection Concepts – Bandwidth, Latency, Network Diameter, Bisection Width, Node degree, Static and Dynamic Networks
  b. Various topologies – Ring, Hypercube, Torus, Mesh, CLOS, Fat tree etc.
- Current Parallel Architectures
  a. Parallel Vector processor
  b. Symmetric Multiprocessors
  c. CC-NUMA
  d. Massively Parallel Computers
  e. Clusters of workstations
- Clusters
  a. Classification of clusters
  b. Cluster software
  c. File systems for clusters
- Software concepts of High Performance Computing
  a. Parallelism – Algorithmic, Geometric, Event, Data
  b. Granularity – Coarse and Fine grains
  c. Speedup, Efficiency, Amdahl’s and Gustaffson’s Laws
- Parallel Programming Models
  a. Shared Variable Model
  b. Message Passing Model
  c. Threads Model
  d. Data parallel Model
- Design of parallel algorithms
  a. Data dependencies
  b. Data partitioning
  c. Communication patterns
  d. Synchronization
  e. Load balancing
- Parallel Programming Environments
  a. Parallel Languages
  b. Parallel Extensions to Sequential Languages
  c. Parallel APIs – MPI, OpenMP
- Parallelization of example programs – Dot product, Matrix Multiply, etc. at the pseudo code level
- Message Passing Interface (MPI)
  a. Introduction to MPI
  b. MPI constructs
  c. Example programs in MPI
- Benchmarking
- Case studies – ANUPAM series of parallel computers

Grid Computing

- Introduction to Grid Computing
  a. Evolution of Grid Technology comparison with contemporary technologies,
  b. Issues of virtualization, events that have lead to grid computing, client-server, peer-peer, operating system perspective,
  c. Overview of Grids: Formal definition of Grids - how do they work?
  d. How are they different from clusters? Computational Grids, Data Grids, Production Grids worldwide - Applications of Grid.
- Components of Grid
  a. Grid Security- concepts of single sign on, How the security requirements are met?
  b. Concept of Digital certificate- How RSA works? - Working of Kerberos
  c. Concepts of Myproxy services
- Grid Resource management
  a. Issues in Grid Resource management
  b. Abstract model for Grid Resource Management
- Grid Scheduling
  a. Issues in Grid Scheduling
  b. Taxonomy Of Grid Schedulers
  c. Resource Discovery issues
- Visualization and interactivity in Grids, High Performance Computing in Grids- Grid enabled MPI – MPI-G2
- Grids Services
  a. How are they different from Web services?
  b. Concepts and their implementation
- Data Management in Grids
- Information services- Building information services in Grids
- Grid Portals, Their Purpose, Issues in Portal design, discussion on portlets
- Grid Workflow
  a. Concepts
  b. Taxonomy of Grid Workflow
- Semantic Grids
- Virtualization
  a. Concept
  b. Its utility in Grid Computing
- Grid Enabling Applications
  a. Issues
  b. Implementations
- Discussion about GRID standards
  a. OGSA
  b. OGSA-DAI
- Comparative study of different Grid Middlewares
  a. Lacuna in current Grid Architectures
  b. Grid as operating system of operating systems
- Case study of Middlewares:
  a. GT4,
  b. Glite
  c. DAE Grid
- Future of Grids - Concepts of Cloud Computing

References

1. Advanced Computer Architecture, Kai Hwang
2. Scalable Parallel Computing, Kai Hwang, Zhiwei Xu
3. Introduction to Parallel Computing, Ananth Grama, George Karypis, Vipin Kumar and Anshul Gupta
4. High Performance Computing – Paradigm and Infrastructure, Laurence T.Yang, Minyi Guo
5. Storage Networks Explained, Ulf Troppens, Rainer Erkens, Wolfgang Muller
6. Computer Organization and Architecture: Designing for Performance, William Stallings
7. Grid Computing – Making the Global Infrastructure a Reality, Fran Berman, Geoffery Fox, Anthony J. Hey
8. The Grid2 Blueprint for a new Computing Infrastructure, Ian Foster, Carl Kesselman
9. Grid Computing for developers, Silva
10. Current Journal Articles in the area of Parallel Computing, Computer Architecture and Grid Computing

~~EN 617~~

EN 618: Electrical Systems for Nuclear Power Plants (30)

- Interaction of Nuclear Power Station With The Grid Number of evacuation lines; Optimum size of NPP in grid; Brief introduction to Power System Analysis - Short circuit, load-flow and stability studies, Tariff and Capacity factor.
- Ehv Switchyard Design Switching schemes; Clearances; Com parison between types of svvitchyards; Brief introduction to equipments in switchyard and their functions; Lightning arresters and insulation co-ordination; Lightning protection.

- Protection Line protection; Generator protection; Transformer protection; Motor protection.
- Selection of Transformers Accessories; Types; Specifications and testing; Voltage regulation calculations.
- Selection of MV & LV Switchgear Types; specifications and testing, MCCS; Distribution boards; Generator circuit breaker; ELCB.
- Motors In NPP Types of motors; Radiation withstand requirements; Performance requirements.
- Station Auxiliary Systems of NPP Class 1, 11, Ill and IV systems classifications; Nature of electrical loads and supply voltages; Effect of voltage variation on Electrical equipments and remedial measures; Emergency transfer system; Load shedding scheme; Auto transfer schemes; synchronizing schemes.
- Class 1 e requirements Cabling, lighting & grounding Specific requirements for safety related electrical equipments & systems in NPR Cabling, Lighting, Grounding systems in NPP; Bus ducts. Introduction to seismic qualification of electrical equipments., Electrical system control from Control Room. Introduction to []G sets, UPS & Batteries.
- Billing and metering scheme for a typical NPP. Introduction to brushiess and static excitation systems for Generators. Introduction to SCADA systems.

References:

1. Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity :.CBProblems and Remedial Measures. IAEA Report - Technical Reports Series No. 271.
2. Elements of Power System Analysis - W.D. Stevenson
3. Electrical Transmission & Distribution Hand Book - Westinghouse Electrical Co., USA
4. Protective Relays - Application Guide, GEC Measurements.
5. Manual on Layout of Substations - CBIP, New Delhi
6. The J & P - Transformer Book
7. The J & P - Switchgear Book
8. Utilization of Electrical Energy - E. Openshaw Taylor
9. Cabling - Siemens Hand Book
10. Illumination Engineering Society - IES Lighting Hand Book
11. Modern Power Station Practice - Volume D - Electrical System & Equipment, British Electrical International.
12. Standard Hand Book for Electrical Engineers - Donald G. Fink and H. Wayne Beaty
13. IEEE-80 - IEEE Guide for Safety in AC Substation Grounding
14. IEEE-308 - Criteria for class 1E Equipments for Nuclear Power Generating Stations
15. IEEE-323 - Qualifying class 1E Equipments for Nuclear Power Generating Stations
16. Indian Nuclear Power Programme with PHWR - Published by Directorate of E & P A, NPCIL, Bombay
17. IS-3716 - Application Guide for Insulation Coordination
18. IS-2309 - Code of Practice for the Protection of Buildings and Allied Structures Against Lightning
19. Handbook of Batteries and Fuel Cells - McGraw Hill Book Company

EN 619: Embedded & Computer Based System Design (45)

Module I [22]

Part A - Microprocessor based Design [10]

- 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
- Introduction to Microcontrollers and comparison with Microprocessors
- Introduction to DSP Processors

Part B [12]

- ARM processor: architecture details and introduction to programming
- Board level buses: I2C and SPI
- Introduction to USB

Module II [23]

Part A – Computer based hardware design [8]

- Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
- Industry standard bus systems: ISA, PCI, VME: Mechanical, electrical, functional and procedural specifications
- Multi processing, bus arbitration and Plug and Play
- System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
- Design Case Study:
- I/O Board design, bus interface (ISA, PCI) FIFO and shared memory interfaces.

Part B - Computer Communication and Networks [7]

- Overview of asynchronous and synchronous communication standards
- Encoding (NRZ, Manchester),
- Ethernet, Industrial networks, Field Bus, CAN bus
- Networking hardware: Cables, Hubs, switch and routers.

Part C - Software development for embedded and PC based systems (8)

- Basic RTOS concepts
- C programming for ARM based applications
- Programming for PC based systems:
  - Interface between applications & device drivers
  - Windows: Programming of I/O, ISR, DMA

References:

1. Computer Networks. By: A.Tanenbaum

2. Principles of Communication. By: Taub and Schilling.
3. Microprocessors and Interfacing. By: D.V.Hall
4. CAN Application Note: Robert Bosch GmBH
5. Microcomputer System 8086/8088 family- Architecture, Programming and Design.
Yi -Cheng Liu & Glenn.A.Gibson.
6. The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486 and Pentium series: Architecture, Programming and Interfacing. By: Barry.B.Brey.
7. The Scientist and Engineer's guide to DSP. By: Steven.W.Smith
8. High speed digital design: A handbook of black magic. By: Howard Johnson & Martin Graham
9. Interference control in computer and microprocessor based equipment. By: Michel Mardiguian
10. Interfacing to the IBM Personal Computer. By: Lewis C. Eggebrecht
11. PCI bus system architecture – Mindshare publication
12. VME bus standard document
13. USB complete. By: Jan Axelson
14. ARM System Developer's Guide. By: Andrew Sloss, Dominic Symes, Chris Wright
15. Designing Embedded Hardware. By: John Catsoulis

EN 620: Extractive Metallurgy (40)

Principles of Metallurgical Thermodynamics (15)

- Thermodynamic Functions: Enthalpy, Entropy, Free Energy, Chemical Equilibria
- Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Phase Diagrams
- Solution Thermodynamics, Integral and Partial Molar Thermodynamic Properties
- Experimental Methods- Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.
- Computation of predominance area diagram and Phase diagrams

Kinetics(5)

- Principles of Chemical Kinetics, Homogeneous Reactions, Effect of Concentration, Effect of Temperature
- Theory of Reaction Rates, Heterogeneous Reactions, Reaction Models, Mass Transport Phenomena, Heat Transport Phenomena.

Process Metallurgy (25)

- Methods of attaining High Temperatures,Measurement of Temperature,
- Vacuum Metallurgy Principles and Equipments,
- Process Metallurgy of Rare and Refractory Metals,
- Resources of Special Metals, Beneficiation Methods, Physical, Chemical, Separation Methods, Halide Metallurgy, Vacuum Metallurgy, Electro Metallurgy, Reduction Processes, Refining Processes, Ultrapurification Processes,
- Preparative aspects of Special Materials and Alloys,
- Advanced Materials Processing Techniques,
- Reprocessing of irradiated nuclear fuels, Process Metallurgy of - Uranium, Thorium, Plutonium, Beryllium, Zirconium, Hafnium, Niobium, Tantalum, Rare Earths.

EN 621: Finite Element Techniques (35)

- **Introduction to FEM:** Weighted residual method, Galerkin's methods, Weak form formulation, Piecewise approximations. Basis of Finite Element Method, Variational principles, energy principles in structural mechanics, Element libraries 5
- **Element shape functions**: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements. 15
- **Bar element:** Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss
- **Beam element:** Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- **2D plane elements** – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- **2D isoparametric formulation** – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature.
- **Incompatible displacement model**: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements.
- **Introduction and Application to 3D elements:** Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Plate bending elements: Thin and Thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration

- **Shell element**: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking.
- **Introduction to Nonlinear problems:** Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method
- **Finite element applications for design**:Finite element modelling and discretization criterion, h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

References:

1. **Bathe K.J., Finite elemen**t procedures in engineering Analysis, Prentice Hall of India, 1990
2. Cook R.D., D.S. Malkus and M.E. Plesha, Concepts and Applications of finite element analysis, John Wiley, 2000.
3. Reddy J.N., An Introductions to Finite Element Method, 4th Edition, McGraw Hill, 1993.
4. Seshu P., Finite Element Method, Prentice Hall of India, New Delhi, Fourth printing, 2006.
5. Zeinkiewicz, O.C., and K. Morgan, Finite elements and approximation, John Wiley, 1983.
6. Zeinkiewicz, O.C., and R.L. Taylor, The Finite Element Method, Vol. 1 & 2, Tata McGraw Hill.
7. M. Asghar Bhatti, Advanced Topics in Finite Element analysis of Structures, John Wiley, 2006.

EN 622: Fracture Mechanics (40)

Linear Elastic Fracture Mechanics (5)

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks and concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture
- Superposition of K
- Plastic zone correction - Irwin's approach
- Basic design principles in LEFM
- **Plane stress vs. plane strain - Variation of toughness (KIc and Kc)**

Elastic-plastic Fracture Mechanics (5)

- J-integral as energy release rate
- J-integral as amplitude of HRR singularity
- J-integral as contour integral
- Laboratory measurement of J-integral - η factor approach
- Fracture resistance of materials – J-R curve and JIc and possible explanation for shape of J-R curve
- Stable and unstable crack growth – Tearing Modulus approach
- J-controlled fracture
- Basic design principles in EPFM
- **J-estimation schemes**

Laboratory measurements of material fracture properties (2)

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- KIc testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of JIc from J-R curve – blunting line equation and SZW

Limit load (2)

- Definitions of limit load
- Global and local limit load
- Basic expressions of limit load of some common geometries

R6 method (2)

- Basic principles of R6 method
- Sensitivity analysis

Fatigue (7)

- Conventional high and low cycle fatigue – S-N diagram, Coffin-mansion relation
- Fatigue crack growth under constant and variable amplitude loading
- Rainflow algorithm
- Environmental effects on fatigue crack growth
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- **Experimental determination of Paris law constants as per ASTM procedure Fracture assessments of welds (2)**
- Basic aspects of fracture assessment of welds – residual stress effect
- Special considerations in fracture toughness determination of welds

PTS and ASME reference/Master curve (6)

- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Warm pre-stress effect

- Reference ASME curve in assessment of PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Computational Fracture Mechanics(4)

- Barsoum's crack tip element and showing the singularity from shape function
- Evaluation of SIF by displacement correlation technique from FEM
- Evaluation of 2-D J-integral by contour integral technique
- Evaluation of 3-D J-integral by domain integral technique

Fracture Mechanism (4)

- Basic mechanism of ductile fracture – Void nucleation, void growth and coalescence
- Cleavage fracture- Mechanism of cleavage initiation
- Mathematical model of cleavage fracture toughness, explanation for scatter in cleavage fracture toughness, RKR model

Application of Fracture Mechanics Principles to Leak-Before-Break (1)

- History of LBB
- Basic concepts of LBB – three levels
- Application to Indian reactors

EN 623: Mechanical Metallurgy (30)

Elasticity and Plasticity

- Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
- Equations of equilibrium.
- Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria

Dislocations:

- Elastic stress field of edge and screw dislocation.
- Self energy of dislocations.
- Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP

Deformation Behaviour

- Single crystal deformation, critical resolved shear stress, Schmidt's factor, Thermally activated deformation, Strengthening mechanisms.

Creep of Metals and alloys

- Various stages of creep and creep laws
- Types of creep tests, evaluation of parameters of a creep test and its use
- Factors influencing creep resistance
- Deformation mechanism map and identification of creep mechanisms, Irradiation creep

Fracture Mechanics

- Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
- Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
- Concepts of R-curves, Evaluation of various fracture parameters, fracture control

Fatigue of Metals:

- High cycle and low cycle fatigue
- Factors contributing to fatigue failure and its mitigation
- Various stages of fatigue damage and Fatigue life improvement
- Fracture mechanics approach to characterize crack growth behavior

References:

1. Engineering Fracture Mechanics - S. A. Meguid.
2. Mechanical Metallurgy - G. E. Dieter
3. Mechanical Behaviour of Materials - T. H. Courtney
4. Elementary Dislocation Theory - J. Weertman & J. R. Weertman
5. Introduction to Dislocations - D. Hull
6. Mechanical Metallurgy : Principles and Applications - M. A. Meyers & K. K. Chawla
7. Deformation and Fracture Mechanics of Engineering Materials - R. W. Hertzberg

EN 624: Mechanics of Solids (40)

Introduction to Theory of Elasticity Mathematical Frame Work (2)

- Illustration of concepts of elasticity, Stress-strain curve, Isotropy, Homogeneity
- Illustration of equilibrium equation, Cauchy equation and stress strain relation in 1-D
- Solution of 1-D boundary value problems using theory of elasticity equations: (a) Natural frequency determination. (b) Solution under external excitation force to show resonance condition, stress wave etc.
- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Kronecker Delta, Permutation symbol ; Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of Stress (3)

- Description / Notations of Forces
- Description / Notations of Stress
- Component of stress
- Reciprocity of shear stress in 3D

- Stresses Transformation using direction cosines
- Stress Traction Vectors or Traction Vectors
- Stress component on an arbitrary plane
- Principal stresses
- Stress Invariants
- Mohr's Diagram for 3D state of stress
- Hydrostatic and Deviator components of stress
- Principle planes and their orthogonally
- Octahedral plane, Octahedral stresses
- State of pure shear

Analysis of Strain (2)

- Description / Notation of Strain in 3D
- Components of strain
- Strain Transformation using direction cosines
- Principle Strains, Strain Invariants
- Cubical Dilation
- Strain Deviator Tensor
- Maximum and Octahedral Shear Strains

Principles and Fundamental Equations of Elasticity (8)

- Strain and displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Stress and strain relationship
- Equations of equilibrium (Navier's Equations , Lame's equations)
- Strain Energy
- Uniqueness theorem
- Bounds on elastic constants
- Superposition Principles
- Saint-Venant's Principle
- General Solution Procedures for a elasticity problem

Two and Three Dimensional Formulation (8)

- Elasticity equation for Plane strain
- Elasticity equation for Plane stress
- Biharmonic equations
- Airy's Stress Functions
- Solution for beam bending problems
  a) Special cases by use of polynomials
  b) General solutions using fourier series method
- Solution in polar co-ordinates
  a) Tube subjected to internal and external pressure (Lame's problem) ; shrink fit
  b) Stress Concentration due to a circular hole in stressed plate (Kirsch's problem)
- Stress in spherical shell under internal and external pressure

Thermal Stresses (4)

- Thermal stress definition and their significance
- Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
- 2D thermal stress analysis
  a) The problem of circular disk
  b) The problem of circular cylinder
- 3D thermal stress analysis : The problem of sphere
- Transient thermal stress

Introduction to Plasticity (4)

- Stress-strain curve, Examples of Multiracial stress
- Different Yielding Criteria and their significance
- Yield Surface , Tresca and von-Mises
- Path dependence of Plastic Strains
- Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
- Prandtl-Reuss Equations
- Incremental or flow theory
- Deformation theory of plasticity, Hencky equations
- Plasticity Relations (plastic strain and total strain)

Theory of Plates

- Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
- Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.

- Introduction to analysis of Thick Plates

Theory of Shells

- Introduction to shell theory.
- Classification of shells, Membrane theory of shells of revolution and translation.
- Application to spherical, conical and cylindrical shells.
- Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
- Application to cylindrical shells, spherical and conical shells.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Piblications, Inc.
6. Plasticity Theory and Application, Alexander Mendalson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K .Chandrasekhara, University Press
9. Stresses in shell- W.Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN 625: Modern Control Systems Design and Simulation (35)

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analyti- cal methods of modeling.
- State Space Characterization State 5PaCe representation, solution of state equation, state Transition matrix, properties of STM, computation methods, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kaiman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Control- lability and observability of Discrete data systems.
- Stability liapunov,s stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design Guillemin-Truxal design Procedure, pole placement by state feedback. H,' meth- od, Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kaiman filter as OPtimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency re- sponse methods, Recurise Least square Identification technique.
- Introduction to Adaptive and Robust control.

References:

(Reference materials will be provided during the course)

EN 626 Design Basis Hazards and Geotechnical Engineering (40)

<u>Design Basis Hazards (Natural)</u>

Role of civil engineering in achieving overall nuclear safety: Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.

Introduction to hazard evaluation:

Hazard due to internal and external events, case studies.

Seismic Hazard

Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum

Flood hazard

- Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
- Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
- Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding

Wind hazard

Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India,Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.),

Solar radiation

Temperature map(Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)

Snow hazard

Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides

Design Basis Hazards (Human-Induced)

Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)

Geotechnical Engineering

Soil Mechanics

- Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
- Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
- Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability; Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.
- Bearing capacity – Determination of bearing capacity for soils and Rock.

Geotechnical and Geophysical investigations:

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

Soil Dynamics and Liquefaction

Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

References:

1. Kramer . S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. **IS** 875(Part 3) (1987) " Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. **IS** 875(Part 4) (1987) " Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance"
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – "Basic and applied soil mechanics".
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities'
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN 627: Networking and Information Security (40)

Networking

General Issues in the transport of data traffic over networks of digital transmission media.

- V.24, V.35, Modems, xDSL, Multiplexing

Circuit switching & Packet switching

- ISDN (BRI), PRI.

Datalink Layer

- Data link layer protocols, Medium access method, Flow control, Error Control
- Ethernet technologies, Bridge, Switching, Analysis of collision domain, Layer 2-based network attacks

Introduction to Satellite communication

- Satellite orbits, VSATs, VSAT network Topologies

Network Layer

- IP, IP Fragmentation, ARP, DHCP, Classes of IP address, CIDR, Layer 3 based network attacks, ICMP
- IP Routing algorithms, RIP, OSPF, BGP.

Transport Layer

- TCP & UDP, TCP Call establishment & Call termination, Sockets, TCP state machine, TCP timers
- RTP, Layer 4 based network attacks

Firewall
- Layer 3 firewall, Layer 4 firewall, Application based firewall

Network Applications
- FTP, DNS, Mail, application based attacks

Network Security
- Data security, type of possible attacks on data etc?
- Ecurity services for secure data communication?
- Like Identification, Authentication, Authorization, Data Integrity, Confidentiality, Non-repudiation, Replay, Availability etc.
- Cryptography and its services Cryptology, cryptanalysis.
- Components of cryptology like algorithms, Keys, Message Digest, Digital signature, Digital Certificates etc. with block diagram.

Types of Algorithms
- Symmetric and Asymmetric.

Symmetric Algorithm
- stream cipher algorithms
- Type of stream ciphers, Unconditional security with stream ciphers, one time pad, LFSRs, Linear complexity in LFSRs, Shanon's concept of perfect secrecy
- Type of possible attacks, Conversion of block ciphers onto stream ciphers etc.

Asymmetric Algorithms
- Diffie-Hellman, RSA with detail mathematics and applications.
- Key management methods for symmetric and asymmetric keys.
- PKI infrastructure, Digital certificates, digital signatures for asymmetric key managements. CRL (certification revocation list)
- Symmetric key certificates. Difference between symmetric and asymmetric key certificates etc.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN 628: Nuclear Chemical Engineering (35)

Intoduction

Role of chemical engineering in the nuclear industry

Recovery & processing of nuclear materials from ores / intermediates (5)
- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources , New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths : Occurrence, importance and separation.

Uranium Conversion / reconversion (6)
- Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF6: choice and problems, Fluorination of UF4, Purification and collection process for UF6, Conversion to UO2.

Isotope Separation (9)
- Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical- exchange: H2S-H20, NH3-H2, monothermal and bithermal process, salient features of equipment like contacting towers, tower internals. Heavy water plants in India. Final enrichment and upgradation plants. Distillation and electrolysis, Tritium removal.
- Laser based separation and new processes (2)
- A brief description of laser based isotopic separation processes.
- Fuel Reprocessing (6)
- Fuel Reprocessing: Introduction to Radiochemistry; Differences between a conventional chemical plant and radio chemical plant- Process and equipment limitations, criticality, safety and other hazards, numerical examples, ventilation, shielding, Typical compositions and burn-up of irradiated nuclear fuels.
- Thermal Reactor Fuel Reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements. Evolution of solvent extraction process fore reprocessing, 'PUREX' and 'THOREX' processes in detail; Head-end process, flow sheet, co-decontamination and partitioning cycles.
- Fast Reactor Fuel Reprocessing and Introduction to reprocessing of Thorium based fuels.

Nuclear Waste Management (7)

- Sources, characteristics and classification of radioactive wastes; general philosophies of management.
- Method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Discussion of the various chemical engineering operations involved. Use of desalination and membrane separation techniques in waste management.
- Conditioning of radioactive waste- cementation, bituminisation, use of polymers and vitrification methods.
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical Engineering in Decommissioning of nuclear facilities.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series,IAEA,Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)

EN 629: Nuclear Materials (50)

Melting & Casting (10)

- Introduction to vacuum measurement units and types of vacuum pumpsincluding diffusion pump & turbo- molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and methods to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits

Mechanical working of Metals (10)

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Methods of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Powder Metallurgy & Advanced Ceramics (30)

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production methods, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.
- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. "Introduction to Ceramics" by Kingery et al.
11. "Ceramics Through Chemistry" by Brinker et al.
12. "Electroceramics" by Buchanan
13. "Ceramics Fabrication Processes" by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman

16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
19. 'Ceramics Fabrication Processes" by Wang.

EN 630: Nuclear Metallurgy (30)

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post- Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradition effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels,definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister fomation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Bengamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brain R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN 631: Physical Metallurgy (40)

- Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor Stereographic projection, X-ray, Electron and Neutron diffraction Common Crystal structures and quasi crystals, Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics
- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation. Ordered omega and Hydride formation.
- Recovery, Recrystalization and Grain Growth

References:

1. Physical Metallurgy Principles - R. E. Reed-Hill
2. Modern Physical Metallurgy - R. E. Smallman
3. Introduction to Metallurgy - A. H. Cottrell
4. Physical Metallurgy - P. Haasen
5. Introduction to Physical Metallurgy - S. H. Avner
6. Structure of Metals - C. S. Barrett & T. B. Massalski
7. Crystallography and Crystal Defects - A. Kelley and G. W. Groves
8. Principles of Phase Diagrams in Materials Systems - P. Gordon
9. Thermodynamics of Alloys - C. Wagner
10. Introduction to Metallurgical Thermodynamics D. R. Gaskel
11. Physical Chemistry of Metals - L. W. Darken and R. W. Gurry
12. Metallurgical Thermochemistry- O.Kubuschewski

13. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering - K. Denbigh
14. Modern Chemical Kinetics - H. Eyring
15. Kinetics of Phase Transformations in Metals - J. Burke
16. Transformation in Metals - P. G. Shewmon
17. Phase Transformations in Metals and Alloys - D. A. Porter and K. E. Easterling
18. Diffusion in Solids - P. G. Shewmon
19. Modern Metallography - R.E. Smallman and K.H.G. Ashbee
20. Electron Optical Applications in Materials Science - L. E. Murr
21. Electron Microscopy and Analysis - P. J. Goodhew and F. J. Humphreys
22. Defect Analysis in Electron Microscopy - M. H. Loretto and R. E. Smallman
23. Thermoanalytical Method of Investigation - P. D. Garn
24. Thermal Analysis - T. Daniels
25. Methods of Surface Analysis - A. W. Czanderna (Ed.)

EN 632: Process Control and Instrumentation (MT)(25)

Principles of Measurement (2)

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.

Sensors, Transducers and Transmission methods for parameters (10)

- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical& Radiation Pyrometers.
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli’s Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

Principles of Automatic Control Systems (8)

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doeblin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN 633: Process Control & Instrumentation (EE)(30)

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysterisis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of following process variables
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter, Different types of standard pressure taps for orifices. Variable Area Flowmeters- Glass tube rotameters, armoured rotameters, bypass rotameters,
- Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs- Wire wound and thin film RTDs, self heating error, differential temperature measurement by using RTDs. Thermistors - Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer, two colour pyrometer.
- Pressure and Differential Pressure: Manometers-U tube, well and inclined manometers, mechanical pressure gauges- Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressureTransducers and transmitters, Smart pressure transmitters, Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauges, Mcleod gauge.
- Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass,

Purge system, capacitance probes, displacer type, ultrasonic type, nucleonic type and conductivity type level gauge.

- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- Distributed Control System: Programmable Logic Controllers, Smart Transmitters Control room concepts.
- P & I Diagrams: P &ID symbols, Typical P &ID.
- Class 1E Instruments in nuclear power plant: Definition of Class 1E equipment, various tests for Class 1E equipment qualification.

References:

1. ‘Fundamentals of Temperature, Pressure and Flow Measurements” – Bendict
2. “Instrument Technology”, Vols. 1 to 5, - E.B. Jones, Butterworth and London
3. “Mechanical and Industrial Measurements” - R.K.Jain, Khanna Publishers, New Delhi
4. “Measurement System, Application and Design”, Ernest D. Deophhlin.
5. “Fluid Meters” - ASME Publication
6. “Principles and Practice of Flow meter Engineering” - L.K. Spink, Published by the Foxboro Company
7. “Process Instruments and Control Handbook” - Edited by D.M. Considine, McGraw Hill
8. “Handbook on Applied Instrumentation”: Edited by D.M. Considine and S.D. Ross, McGraw Hill
9. “Instrument Engineer’s Handbook”, Part I & II: Edited by Bela G. Liptak, Chilton Book Company
10. “Instrumentation for Process Measurement and Control”, Norman A. Anderson, Hilton Co.
11. “Manual on the use of Thermocouples in Temperature Measurements” (ASME Publication by subcommittee 4).
12. “Process Control Systems: Application Design and Tuning”. F.G. Shinskey, Mcgraw Hill.
13. “Fluid Meters - Their theory and Application” Edited by H.S. Bean. ASME Publication

EN 634: Process Dynamics & Control (45)

Instrumentation , Controls & Computers(20)

- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real- time control applications.

Advanced Process Control (25) Background theory

- Introduction to state-space controls, state & measurement equations, general solution **o**f the state equation, state- transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.

Introduction to Advanced Process Controls

- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

EN 635: Process Modelling, Simulation & Optimization (45)

Simulation

- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Methods of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent methods.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution methods for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization:

- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies.Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals,evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.

- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

References:

1. Bisio, A and R.L.Kabel, 'Scale-up of Chemical processes', Wiley-Interscience,NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W.Hoffman, A.I.Johnson, D.R.Woods and P.T.Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Methods and Modelling for Chemical Engineers, Winley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain,A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)
6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs,E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Rekliatis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Methods & applications, John Wiley,N.Y (1983)

EN 636: Reactor Control and Instrumentation and Human Machine Interface (40)

Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
- Practical

EN 637: Reactor Control Engineering & Instrumentation -1(15)

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic methods (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant Tav program, constant pressure program, Boiler level and

pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., " Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN 638: Reactor Control Engineering & Instrumentation-2 (20)

- Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.
- Reactor Instrumentation
  - Measurement ranges of reactor neutron flux and considerations
  - Principles of detection and types of neutron detectors: in-core and out – of –core
  - Modes of signal processing: Pulse, Campbell, DC
  - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- Health Physics Instrumentation
  - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
  - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
  - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Contamination Monitors

References:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerl

EN 639: Reliability Engineering (EE)(20)

Introduction: Reliability Engg Applied to C&I Systems

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

Reliability Maths/Statistics

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

Fault Tolerance and Systems Reliability:

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

QA/QC Concepts in Brief:

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.

Environmental Qualification and Reliability Testing:

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

PSA/PRA Concepts in NPPs:

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

Additional safety concepts:

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
- Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc.

References:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
6. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
7. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
8. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
9. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
10. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), ('Formal Methods' has been explained).
11. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
12. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
13. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN 640: Software Engineering and Formal Methods (40)

Software Engineering (20)

- Importance of Software Engineering (1)
- Life cycle, Phases and Work-Products of different Phases, traditional models, agile models, Extreme programming (1)
- Project Management: Relationship to lifecycle, planning, control, Risk Management, Cost Models.(1)
- Requirements: Gathering, Categorization, Analysis, and Specification.(1)
- Software Architecture and Design: Architectural Styles, Design Notation, Design principles. (5)
- Object oriented Design: OOAD, Design Patterns (7)
- Testing: Principles of program Testing, Test Coverage, Static Analysis, and Tools for testing. (2)
- Support Activities: Configuration Management, Verification and Validation, Software Engineering Standards, Documentation formats, Tools and environments for Software Engineering (2)

Formal Methods (20)

- Introduction to Formal Methods, Role of Formal Methods in Software Life Cycle – development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, Statecharts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing - Assertions and their verification (dynamic and Static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)

- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic,, Case study from hardware and software, model cheking tools (SPIN, NuSMV etc.) (4)

References:

1. Software Engineering: Roger S. Pressman McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Adison-Wesley
3. Unified Modeling Language *User Guide*: G. Booch, J. Rumbugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I & II , Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K. McMilan, Kluwer, 1993

ELECTIVE COURSES

EN 701: Advanced Computational Techniques (30)

Programming Language C++

- C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.
- C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initialisers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogona Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions,parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

EN 702: Advanced Electrical Engineering Design-I I (25)

Special Electrical Machines

- Special Electrical Machines and their applications :Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

Pulse Power Technology

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

EN 703: Artificial Intelligence Methods & Applications (30)

- **AI Basics**Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert

Systems.

- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence **theorem,** Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification methods, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig
2. Genetic Algorithms in Search, Optimization, and Machine Learning, by David E. Goldberg
3. Neural Networks: A Comprehensive Foundation, by Simon Haykin
4. Reinforcement Learning: An Introduction, by Richard S. Sutton and Andrew G. Barto

EN 704: Computer Based System Design- II (25)

Communication, Networking, Realtime systems, RTOS and Software

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- USB
- Encoding schemes
- Local Area Networks
- OSI 7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Networking hardware – cables, hub, switch, router, etc
- Role of fibre optics in communication
- Fieldbus standards
- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking
- Realtime Systems, their characteristics and applications
- Realtime Operating Systems:
- Concepts of
- Process and threads
- Concurrency
- Latency, context switching
- Scheduling policies
- Inter process communication
- Semaphores
- Priority inversion
- Shared memory
- Common systems calls, Communication features in RTOS
- Comparative study of various RTOSs
- Integrated S/W development environment

EN 705: Data Base Management System and Web Technology(30)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

EN 706: Digital Signal Processing and Image Processing (30)

Digital Signal Processing

- **Introduction**

Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**

  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
- Fast Fourier Transform

Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- Digital filters

FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- DSP Applications

  Applications of digital signal processing in nuclear and other fields.

Image Processing

- **Introduction**

  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- **Image Enhancement**

  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- **Image Segmentation andAnalysis**

  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation; Boundary extraction and representation;
- **Morphological operations**

  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy- based methods;

  Image Compression Models, Error free compression, Lossy compression, Standards;

References:

1 Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
1. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles,
2. Algorithms and Applications, Prentice- Hall of India,1995.
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.
4. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine
6. Vision,Vikas Publishing House,2003.
7. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004

EN 707: Embedded Electronics Software(25)

Programmable Digital System Design, Representation & Synthesis [8]

- Introduction to HDLs, Introduction to PLD, FPGA, ASIC. Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Handel-C, VHDL. Introduction to Design Flows and EDA Design Tools.

Real-time Software [11]

- Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion,

Priority Inheritance

- Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development

Introduction to Microprocessors / Microcontroller and Interfaces [6]

- Introduction to Microprocessor and microcontroller, Synchronous and Asynchronous Standards, RS232C, RS485, FieldBus (Profibus, Foundation FieldBus, CAN, Ethernet , MIL-STD-1553B), TTP

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P.Singh & Renu Singh
3. Fieldbus Technology: by N.P.Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN 708: Feedback Control Systems (25)

- Introduction: The control systems, Basic elements of FIB control systems, Types of FIB control systems.
- Transfer Function: Transfer function of linear systems, Impulse response, Block diagrams, Signal flow graphs, Mason's gain formula, Polar plots, Bode plot.
- State Variable Characterization: State concept, State equation, Standard representation, State transition matrix and solution of state equations, relationship between state equations and transfer functions, Characteristic equation, Illus- trative examples of some electrical, mechanical, electromechanical systems.
- Time Domain Analysis: Test input signals, Time domain perform- ance characteristics, Transient response of a typical second order system, PID controllers
- Stability: Definition, Routh-Hurwitz criterion, Nyquist criterion. Relative stability, Gain and Phase margins.

EN 709:Fluid Power Technology (25)

Basic Fluid Power & Components

Basic principles of Hydraulics and pneumatics

- Fluid power introduction and fundamentals of fluid mechanics
- principle of pneumatics, basic definitions
- pressure – gauge, vacuum, absolute; flow
- Pressure loss, Power, torque, energy – mechanical, hydraulic etc. , power, force, speed, viscosity, hydraulic terms in fluid power, resistances, bulk modulus, Pascal's Law, law of conservation of energy
- Transmission and multiplication of force, Momentum theorem, Angular momentum theorem, continuity equation, Euler's equation of motion, Bernoulli's theorem, laws of compression, forces developed by jets on plates (curved plate, moving plate, etc.) orifice flow formula, flow measurement, pressure measurement, comparison of Pneumatics with Hydraulic power transmissions.

Hydraulic Fluids and pneumatic air

- Basic properties of hydraulic fluids and pneumatic air, compressibility, pour point, flash point, fire point,
- Desirable properties of fluid, undesirable properties of fluids,
- Types of fluid, composition of fluids, effects of additives to hydraulic fluids,
- Advantages of various types of oil.
- Advantages of oil vs. air as working fluid.

Fluid power pumps and compressors

- Function and purposes of pumps and compressors
- Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump. (ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps (iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
- Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
- Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.

Hydraulic and Pneumatic pressure control

Pressure Control Valves, construction and working principles of relief valves- direct acting and pilot operated relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Hydraulic fuse, pressure switch, Pneumatic Pressure regulating valves.

Flow control valves

Basic two way valves, non-compensated flow control valves, throttle valves, restrictor valve, needle valve, ball tip valve, check valves, control valve circuits, pressure compensated flow control valve, demand-compensated flow control, pressure, temperature-compensated, flow control valve, methods of speed regulation in pneumatics.

Directional control valves

Application of directional control valve (DCVs),, designs, construction and operation of check valves, pilot operated check valves, rotary and spool type valves, two way valves, shuttle valves, three way valves, diversion valves, four way valves, solenoid operated, control valves, operation of directional control valves, mounting interfaces, designation, type of actuation of DCVs, pneumatic direction control valves – two way, three way, four way valves, etc., solenoid operated, push button operated, lever operated pneumatic DCVs.

Actuators

Definitions, linear actuators – Hydraulic cylinders, Plunger type, , piston type, Single acting, double acting cylinders, spring return type, tandem and telescopic cylinder, construction of hydraulic cylinders, cylinder seals – piston seal, rod seal, wipes, wear pads, etc. mounting style of cylinders, Pneumatic reciprocating actuators.

Rotary actuators –motors and limited rotation rotary actuators, their types, construction, advantages, vane type single and double vane rotary actuators, rack and pinion type rotary actuators, gear motors – external and internal, gerotor motors, vane motors, Radial piston motors, non-rotating barrel type axial piston motors, advantages of hydraulic motors. Pneumatic rotary actuator, radial piston, vane, and axial piston type air motors etc.

Seals

Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

Pipes, Tubes and Hoses, fittings

Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.

Accessories

Hydraulic and pneumatic filters, their applications, working principles and designs, beta ratio, absolute filtration, nominal filtration, selection of filters, heat exchangers – types, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, types of pneumatic filters, regulators, lubricators, mufflers, dryers, reservoirs etc.

Hydraulic Circuit Design

- Introduction to fluid Power Symbols, Overview of IS 7513,
- Classification of hydraulic circuits, Criteria for designing open loop hydraulic circuits, Analyzing resistive loads, overrunning loads and inertial loads, Heat generation and control.
- Flow control circuits, Pressure control circuits, Direction control & check valve circuits, Cylinder circuits, Pump circuits, Hydraulic motor circuits, Accumulator circuits, Intensifier circuits, Regeneration circuits.
- Sizing of Hydraulic circuit components :
- Reservoir.
- Heat Exchanger: Oil to air heat exchanger, Oil to water heat exchanger.
- Filters: Sizing of suction filter, return line filter, pressure line filter, Beta ratio, Necessary sizing information for filters.
- Fluid Conductors: Flow v/s Pressure drop, Pressure losses, tube/ hose sizing, Pressure rating, Hose/ Tube designation, Calculation of pressure drop in straight lines, bends, fittings etc.
- Pumps: Fixed displacement, variable displacement pumps, Design of suction side and pressure side of pump
- Hydraulic cylinders and motors.
- Accumulator: Isothermal &Adiabatic charging / discharging of accumulator. Sizing of accumulator for various applications i.e. energy storage, shock absorber etc.
- Valves sizing: Direction, pressure & flow control valves.
- Hydraulic Circuit Dynamics considerations: Bulk modulus, Spring rates, natural frequencies, Transmission line dynamics, Pulses in transmissions, Energy controls, Load energy output interaction, system stability, damping, time constant, system response, hydraulic system parameters i.e. resistance, capacitance, impedance.

Advanced Hydraulic Control Circuits

- Various pilot operated valves, construction features, operation, and advantages.
- Modular valves, Stacked type direction control valves, flow control valves, pressure control valves and

combinations.
- Electrically modulated pressure control valves, flow control valves. Pulse width modulation,
- Proportional controls, Servo controls, construction, Uses, differences, operation, advantages and disadvantages.
- Cartridge Valves: Design and construction features of cartridge valves, Types and Operation of cartridge valves, Advantages of cartridge design.
- Advanced pump controls, load sensing, pressure compensation.
- Integrated Hydraulic Circuit:Construction , Advantages of integrated hydraulic circuit, Case study of PVG32 valve, Various modules of PVG 32 valve block, Features of integrated hydraulic circuit of PVG 32, Electronic control capabilities.
- Pneumatic control circuits, proportional and servo valve, proportional and servo actuators

Water Hydraulics and Component Design
- Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals.
- Case Study-1: Differential Pressure Reducing Valve: Conceptual design and sizing
- Case Study-2: Auto Differential Pressure Control Valve - Conceptual design and sizing.
- Case Study-3: Pressure Compensated Flow Control Valve - Conceptual design and sizing.
- Case Study-4: Pilot Operated Pressure Control Valve - Conceptual design and sizing

Electronics and Instrumentation for Hydraulics:
- Current/ Voltage Sources and its measurements, Electronic components –resistance, capacitor, transistors, Opamps etc. Basic circuits for Addition multiplication, division using Opamps. Digital electronics, Logic gates.
- Analog to Digital converters (ADC) and Digital to analog controllers (DAC), Signal conditioning circuits, filters.
- Sensors-Pressure measurement, pressure switches, Position measurement, limit switches-proximity switches, Velocity measurements, Temperature measurement, temperature switches, Viscosity, density measurement, Force, torque, strain measurements.
- Controllers, Closed loop and open loop controllers, Proportional, Integral, derivative controllers and its uses and characteristics. Analog and digital controllers, comparison between digital and analog controllers. Programmable logic controllers, different I/O modules, wiring sensors to PLC. Introduction to microcontrollers, Applications, programming.
- Data Acquisition, Communication buses RS232,RS485, CAN bus, MODBUS, CANOpen bus uses and applications.

Fluid Logic & Control:
- Need for Fluid Control.
- Building Basic Elements for Control Logic (AND, OR, NOT, NAND, NOR).
- Function Implementations using Control Logic.

Experiments :
1. Tuning of PID controller in rotary actuator test facility.
2. Speed control of hydraulic motor using PLC.
3. Measurement of cleanliness level of hydraulic oil samples using particle counter.
4. Qualitative analysis of oil samples using Ferrograph.
5. Establishing position control using frictionless hydraulic linear actuator.
6. Finding characteristics of Differential Pressure Reducing Valve.
7. Finding characteristics of Auto Differential pressure control valve.
8. Finding characteristics of Pressure Compensated Flow Control Valve.
9. Finding characteristics of Pilot Operated Pressure Control Valve.
10. Study of Rexroth/Bemco oil hydraulic power pack and carrying out pressure setting, flow setting etc. in the same.
11. Experiments on ROHYTAM
12. Testing of oil hydraulic filter using filter test set-up.
13. Dismantling & assembling of various valves and actuators.

EN 710: Image Processing & Machine Vision (30)

Image Processing
- Introduction: Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;
- Boundary extraction and representation;
- Morphological operations;
- Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy-based

methods;
- Image Compression: Models, Error free compression, Lossy compression, Standards;

Machine Vision

- Imaging model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflectance, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, Boundary representation,Mathematical Morphology;
- Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, The Generalized Hough Transform;
- High Level Vision: Scene interpretation;
- Texture – Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, Classification and recognition, Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

References:

1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine , Vision,Vikas Publishing House,2003.
6. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004.
7. Davies E.R., Machine Vision Theory Algorithms Practicalities, Academic Press.
8. D.A. Forsyth & J. Ponce, Computer Vision A Modern Approach, Prentice Hall,2003.
9. Horn B.K.P., Robot Vision, The MIT press, 1987.
10. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
11. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

EN 711: Machine Design (25)

Principles of Machine Design:

- Objectives of machine design, general design rules, design methods
- Lightening of' parts and rational design schemes,
- Rigidity of structures, Cyclical/ Contact/ Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs.
- Introduction to inventive problem solving.

Design and Drawing Practices

- Drawing standards, selection of tolerances, fits, and positional tolerances.
- Introduction to Drawing Practices: (matter from various drafting standards),
- Introduction to CAD (including introduction to various drafting and solid modeling softwares)

Sealing Methods

- Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric 'O' rings, mechanical seals, labyrinth, valve packings.
- Methods of sealing for high and ultra high vacuum.

Special Dimensional Inspection Techniques

- Description of special dimensional inspection techniques, gaging techniques including composite and paper gauging, Advanced inspection tools including co-ordinate measuring machines and form measuring machines.

Advanced Manufacturing Techniques:

- Precision machining, super finishing, advanced manufacturing
- Micro machining.

References:

1. "Mechanical Engineering Design" by Joseph E. Shigley.
2. "Machinery's Hand Book" (24th edition)
3. "ISO Standards Hand Book" 18.
4. "SKF Bearing Catalogue."
5. "Relevant IS standards."
6. "Friction, Wear, Lubrication, Tribology Hand Book" edited by Prof. I.V.Kragelsky & V.V Alisim.

7. "Gear Hand Book by" Dudley.
8. "AGMA Standards 218.01" Dec. 1982.
9. "Industrial Sealing Technology" by H.HUGO BUCHTER

EN 712: Material Science in Nuclear Engineering (ME) (20)

- Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.
- Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X- ray Radiography, etc. for welds.

Corrosion

- Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards

Metallurgy of steels

- Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
- Selection and application of advanced alloys.

Nuclear Materials

- Fabrication, properties and application of Zircaloy, Zr-Nb alloys
- Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications.

Advanced Polymeric materials and Composites

- Physical and Chemical Properties, corrosion, mechanicalproperties
- Equipment design with polymeric materials
- Fabrication principles; standards for design, fabrication and testing.

References:

1. "Introduction to Materials Science for Engineers" - James Shackelford
2. "Physical Metallurgy Principles & Practice" - V.Raghavan
3. "Introduction to Solids" - L.V.Azaroff
4. "Structure and Properties of Materials" - Wulff Series, Wiley Eastern, New Delhi
5. "Materials in Nuclear Application" - C.K.Gupta
6. "Nuclear Chemical Engineering" - Benedict and Pigford

EN 713: Materials Characterisation (20)

Microscopy Techniques

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
    - Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
    - Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High reolution electron microscopy
    - Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, Other modes of operation, Applications in failure analysis, fracture surfaces etc.
    - Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

X-Ray Diffraction and Applications

- Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production and detection of x-rays.
- Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
- Experimental methods in x-ray analysis; Laue methods, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates,

crystal size crystal perfection, crystal orientations:

Chemical Analysis (with applications in materials science).

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

Basics of Analytical Transmission Electron Microscopy,

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, llllcorrections
- Cliff Lorimer factor, thin film correction

Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
- Fundamentals of energy filtering and its uses in life sciences
- Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
- Case studies for metallic bulk samples, life science samples, nano-materials

Physical and Thermal Characterization Techniques

- **Thermal expansion**: Methods and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
- **Thermal Conductivity**: Methods and their principle, advantages and limitations of each method, data of nuclear Fuels
- **TGA/DTA/DSC**: Methods and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
- **Elastic Properties**: Methods and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
- **Hardness**: Different methods and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

EN 714: Membrane Technology (35)

Fundamentals and Overview of Membrane Processes: (5)

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Growth Potential, Classification and description of membrane processes
- Pressure driven membrane processes (MF, UF, NF and RO)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

Novel Membranes

- Features, transport mechanism and application areas
- Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Membrane Bio-reactor, Fuel cell membranes, Membrane sensors, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

Membrane Materials, Preparation and Characterization: (10)

- Material selection
- Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity Molecular weight and molecular architecture
- Membrane preparation techniques- Phase-Inversion, In-situ polymerization, Track-etching, Slip-casting, Sintering
- Membrane Casting Aspects for continuous casting
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of charged membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
- Surface characterization -pore size, roughness, in-homogeneities, and hydrophilicity
- Bulk characterization -porosity, permeation study through flux and solute rejection.

Engineering and Design Aspects of Membrane Technology (10)

- Transport through membranes-Preferential sorption-capillary model,Solution Diffusion model, Irreversible thermodynamics model
- Derivation of basic transport equation for RO membranes

- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants
- Pretreatment considerations, Water chemistry- turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control,Scaling assessment parameters (SDI, MFI)
- Materials of construction
- Process design and system design for water desalination-Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices -pelton wheel, turbo-charger and pressure exchanger
- Effect of operating parameters on membrane performance
- Membrane cleaning and protocols
- Trouble-shooting analysis of operating plants
- Post-treatment techniques
- Membrane autopsy, Reject disposal techniques and brine management.

Membrane Technology Applications (10)

- Techno-economics of membranedesalination plant - seawater / brackish water
- Design aspects of water recovery & recycle from spent streams including sewage Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle
- Hybrid membrane systems, Combo systems -membrane + conventional- for separation application
- Nuclear Desalination
- Membrane based water purification systems-RO/UF application in food processing, pharmaceuticals and Bio-technology
- Fractionation & Value Recovery.
- Zero Liquid Discharge (ZLD)

References

1. Membrane Technology & Applications by Richard W Baker (2008)
2. Membrane Handbook by Ho and Sircar (1992)
3. Transport Phenomena in Membrane by K. Lakshminarayanaiah (1970)

EN 715: Multi-Scale Material Modeling (20)

Introduction

- Spatial and temporal hierarchy of microstructure and dynamics in materials
- Types of models: quantum mechanical, atomistic, mesoscopic, continuum
- Multiscale approaches

Short review and elements of differential equations (numerical solution)

- Differential equations in discrete and continuum simulation methods
- Ordinary differential equations for particle dynamics
- Partial differential equations, conduction/diffusion equation

Atomistic models: Molecular dynamics

- The basics of classical molecular dynamics
- Initial conditions, creating lattice structures, introducing defects
- Defining and maintaining temperature and pressure
- Boundary conditions (periodic, stochastic, conducting, non-reflecting)
- Methods for constant temperature or/and pressure simulations
- Tricks of the trade (neighbor lists, force/energy tables, potential cutoffs, etc.)

Monte Carlo methods

- The basics of Monte Carlo
- Monte Carlo integration, thermodynamic averages
- Importance sampling, Metropolis scheme
- Lattice Monte Carlo, Ising model
- Multi-state Potts models (grain coarsening, recrystallization)
- Kinetic Monte Carlo (surface processes, thin film growth)

Interatomic potentials

- Introduction, Born-Oppenheimer approximation
- Pair potentials and their limitations
- Calculation of elastic constants from potential function

- Potentials for ionic systems, ceramics
- Many-body potentials for metals
- Many-body potentials for covalently bounded systems
- Forces from "first principles"

Analysis of the simulation results

- Equilibrium properties (energy, temperature, pressure, velocity distributions)
- Structural properties (geometrical tessellation, pair correlation functions, atomic level stresses)
- Dynamic properties (diffusion, time correlation functions)

Mesoscopic methods

- Discrete dislocation dynamics
- Strain and stress fields for edge and screw dislocations in an isotropic medium
- The equation of motion in Newtonian Dislocation Dynamics
- Examples from 2D and 3D simulations
- Current problems
- Coarse-grained models

Bridging the scale gaps between different simulation levels

- Simultaneous integration of the models
- Sequential integration of the models (hierarchical approach)
- Examples of combined methods (MD-FEM, MD-MC, etc.)

Modeling at microscale

- Mechanism of ductile fracture and cleavage fracture
- Gurson constitutive law for modeling ductile damage
- Roussiler constitutive law for modeling ductile damage
- Beremin's model for cleavage fracture
- Modeling of material under transition temperature
- Case studies

EN 716: Preparedness & Response to Nuclear Emergencies (35)

- Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
- Radiation Shielding & Study of Criticality parameters and control
- Nuclear Waste Management
- Nuclear Accidents/emergencies
- Transport of Radioactive material
- Radiological accidents/emergencies
- Effects of Hiroshima & Nagasaki bombing
- Detection of Nuclear detonation
- Nuclear weapons: effect (Blast, heat, Radiation and EMP)
- Medical decontamination with demonstration
- Nuclear weapon tests (atmospheric)
- Nuclear & Radiological terrorism (Method to contain and control)
- Chemical warfare & Biological warfare (Method to contain and control it)
- Emergency Response methodology/ Philosophy
- Systems and methodology for Radiological impact assessment
- Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities
- Emergency Monitoring & Shelters
- Civil defence WEB plan for Nuclear attack on major cities
- Monitoring of High radiation field area
- Lab Visits

EN 717: Project Management (25)

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
  - Resources of project.
  - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an

activity, earliest start time EST, latest completion time LCT.
- o Scheduling in a project by critical path method, CPM
- o Scheduling in a project by Precedence Diagram Method.
- o Use of Project Management Software for project planning, scheduling & monitoring.
- o Preparation of master control management milestone network, Level-1,2, 3 & 4 network.

- Preparation of Target Plan, updating of progress, monitoring variance & reporting
  - o Constraints of project and its effective management o Development of Six Monthly Plan and its review process o Resource based planning
  - o Physical & Financial Monitoring of project, Use of S-curve
  - o Capital Budgeting & expenditure control in a project
  - o Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis methods, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN 718: Reliability Engineering (ME) (25)

- Reliability Mathematics – Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
- Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
- Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
- Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
- System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
- Application of Reliability - PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

References:

1. Mishra, K.B., " Reliability Analysis and Prediction", Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M.,Reliability& Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., "Reliability in Engineering Design", John Wiley & Sons, 1977.
5. Balaguruswamy, E., "Reliability Engineering" Tata Mcgraw-Hill, 1984.
14. Provan, J.W., "Probabilistic Fracture Mechanics & Reliability", Martinus Nijhoff, 1987.
15. Nowak, A. S. and Collins, K. R., "Reliability of Structures" McGraw Hill, 2000.
16. Ayyub, B. M. and McCuen, R. H., "Probability, Statistics and Reliability for Engineers", CRC Press, 1997.
17. Haldar, A. and Mahadevan, S., "Probability, Reliability and Statistical Methods in Engineering Design",
18. John Wiley and Sons, Inc. 2000.

EN 719: Signal Conditioning, Recovery & EMI Aspects (25)

Review of Analog Signal Conditioning & Recovery Techniques

- Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types ofA/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

Theory of Quantization

- Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti- aliasing filters, fast algorithms for implementation.

Theory of Signal Analysis and Reconstruction

- Function space, orthogonal basis functions, Limitation of Shanon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

Review of EMI Aspects

- Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

EMI Modeling

- Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EN 720: Software Engineering (25)

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools.(3)
- Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods Testing principles, unit testing, integration testing, acceptance testing Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

EN 721: Vibrations (25)

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
- Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor;

Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinary.

- Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, aperiodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN 722: Safety and Reliability of Civil Engineering Structures (25)

Introduction to Probability Theory

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, ProbabilityDistributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

Structural Reliability

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment Method, Hasofer Lind Reliability Index, Rackwitz Fiesseler Method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

Probabilistic Safety Assessment

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

Industrial Safety

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

Safety assessment of existing structures:

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

Introduction to decommissioning of structures

References:

1. Hahn, G. J.and Shapiro, S. S. (1994), “Statistical Model in Engineering” Wiley-Interscience.
2. Ranganathan, R. (2000), “Reliability analysis and design of structures”,Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), “A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”, The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety Standard No. AERB/SS/CSE.
6. AERB (1996),“Atomic Energy (Factories) Rules”.

7. AERB (1991), "Safety Guide for Works contract", Safety Guide No. AERB/SG/IS-1
8. AERB (1996), "The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex", Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities".
10. Regulatory Guide 1.165 (1997), "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion", U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (25)

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- BeamWelding Processes
- Arc-Beam Hybrid WeldingProcesses
- Study of welding arc characteristics
- Metal transferduringarcwelding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on themacro-andmicro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high coolingrates
- Phenomena of hot-crackingand coldcracking
- Residualstresses anddistortion duringand afterwelding
- Residual stressmeasurements
- Application ofaboveprinciplesto welding ofcarbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

EN724: Advanced Structural Dynamics and Earthquake Engineering(CE) (30)

I. Introduction to Structural Dynamics and Earthquake Engineering

II. Performance Based Design of structures, systems and components subjected to earthquake loading

Concepts of performance bases, Seismic demand, Capacity of structures, systems and components, performance levels, energy dissipation and damping.

II. Seismic and Vibration Control

Concepts of seismic and vibration control, Passive control using Yielding dampers, friction dampers, tuned mass dampers, Tuned liquid damper, etc., Semi active and active control strategies.

III. Base Isolation Techniques

Concepts of vibration and seismic isolation, laminated rubber bearings, Lead plug bearings, Friction Isolation System etc.

V. Testing and Modal analysis

Need of testing, Methods of testing, qualification of systems by testing, data processing using FFT and Wavelets, modal analysis for frequency, mode shapes and damping. Causes and types of experimental error, statistical analysis of data.

VI. Seismic and Vibration Instrumentation

Measurement Methods and Applications: Measurement of displacement, velocity, acceleration, pressure, forces, strain and optical methods of measurements; Data Acquisition and Processing.

Types of inputs: analog and digital signals, calibration and uncertainty, Measurement System: Performance characteristics, linearity, dynamic range, sensitivity, stability, accuracy, bandwidth, noise, repeatability, hysteresis- threshold- resolution, readability and span.

VII. Fluid-structure interaction techniques

Coupling of fluid with structure, Dimensionless numbers in fluid-structure interactions, Added mass and added stiffness, Fluid sloshing, Flow induced vibration, Flow over bluffed bodies, Vortex shedding.

VIII. Multibody Dynamics

Rigid-Body Kinematics, Kinematics for General Multibody Systems, Modelling of forces in multibody systems, contact forces, friction effect, Equations of Motion of Multibody Systems.

Numerical integration methods for free standing objects, spring-mass system with friction, Runge Kutta methods, error estimation, Computer programs.

Text / Reference Books

1. A. K. Chopra, "Dynamics of structures", Prentice Hall, 4th edition, 2007.
2. S. S. Rao, "Mechanical vibration", Prentice Hall, 5th edition, 2014.
3. Holman, "Experimental Methods for Engineers", 6e, McGraw-Hill, 1994.
4. Doeblin, Engineering Experimentation, McGraw-Hill, 1995.
5. Hans-Joachim Bungartz Michael Schäfer, "Fluid-Structure Interaction Modelling, Simulation, Optimization", Springer-Verlag Berlin Heidelberg 2006.
6. Soong, T.T. and G.F. Dargush, "Passive Energy Dissipation Systems in Structural Engineering", Wiley & Sons, New York, 1997
7. Farid Amirouche, "Fundamentals of Multi Body Dynamics, Theory and Applications", Springer Science, 2006

NON-SUBJECT ASSIGNMENTS

EN 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

EN 592.1: Process Control Trainer (15)

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

Expt 1

Introduction to typical process under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.

Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

Expt 2

Optimisation of process control - using ultimate sensitivity method.

Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.

Optimum gain and integral / differential time constants are calculated using empirical formulae.

Expt 3

Feed forward control configuration - study of process response in comparison with normal feedback control. Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

Expt 4

Smart Differential Pressure transmitter.

Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.

Re range transmitter using HART communicator.

Re configure transmitter for linear and square root characteristics.

Expt 5

Final control element - Linear pneumatic control valve.

Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.

Virtual instrumentation and wireless data communication between controller and PC.

EN 592.2: Nuclear Detectors (15)

A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.

NaI(Tl) γ- Ray Scintillation Detector

This experiments imparts training on the use of NaI(Tl) detector using known γ- Ray sources (Co^{60} & Cs^{137}) , plotting of calibration curves and identification of unknown sources.

α-Particle spectroscopy using a Solid State Detector

This experiment imparts training on the use of the Solid State Detector using known α-Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup. **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter , testing counting statistics of the counter and studying absorption behaviour of β-rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN 593: Mini-Project Work (300)

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.). Project runs on a part time basis for 11 weeks from mid May to Mid July.

BACK TO MAIN

BARC TRAINING SCHOOL - AMD CAMPUS

ORIENTATION COURSE FOR ENGINEERING GRADUATES & SCIENCE POST-GRADUATES (OCES)

SYLLABUS

GEOSCIENCES

Course No.: 102
Subject: Nuclear Physics and Radiation Detection

S. No.	Topics	Chapters
1	Nuclear Physics	Structure of nucleus - Atom, Electron, Proton and Neutron, the Proton-Electron hypothesis of the constitution of the nucleus, Proton-Neutron hypothesis
		Magnetic and Electric property of the Nucleus
		Additional Properties of Atomic Nucleus
		Natural Radioactivity - Basic theory of Radioactive disintegration, disintegration constant, Half-life, Mean-life
		Radioactive equilibrium, Units of Radioactivity
		Alpha decay - Velocity and Energy of Alpha Particle, Absorption of Alpha Particle, Range, Ionization and Stopping Power, Range-Energy curve, Nuclear Energy Levels and the Theory of Alpha Decay;
		Beta decay - Velocity and Energy of Beta Particle, Absorption of Beta Particle, Range, Ionization and Stopping Power, Range-Energy curve, Nuclear Energy Levels and the Theory of Beta Decay, Symmetry law and Non-conservation of parity in Beta Decay
		Gamma decay - Gamma decay, Internal Conversion, Nuclear energy levels theory, Absorption of gamma ray with matter; Interaction of radiation with matter - Interaction of charged particles, Interaction of gamma rays: Photoelectric effect, Compton scattering, Electron-Positron pair-production;
		Natural decay series - Uranium Series, Thorium Series, and Actinium Series
		Radioactive growth and decay: Mathematical explanation of growth and decay curve
		Disequilibrium: Secular Equilibrium, Transient Equilibrium, Ideal Equilibrium
		Nuclear fission: Discovery of Nuclear fission, Fission cross-section and threshold, Neutron emission in fission and theory of fission process, Energy distribution in fission process
		Nuclear fusion: Discovery of Nuclear fusion, theory of fusion process, Energy distribution in fusion process; Counting statistics: Explanation of Binomial
		Distribution, Poisson Distribution and Gaussian Distribution
		Propagation of errors; Artificial radioactivity: Explanation of Induced Radioactivity, Radioactivity cross-section.
2	Radiation detection and measurement	General properties of detectors - Efficiency, Resolution, Dead time of the detectors; Gaseous detectors - Ionization Chamber, Proportional Counter
		Geiger-Muller Detector etc; Scintillation detectors

S. No.	Topics	Chapters
		The basic function of a scintillation detectors, photo multiplier tube and its function
		Various types of Scintillation detectors, Detection mechanism of NaI(Tl); Semiconductor detectors
		The Basic principle of Semiconductor Detector, Energy Gap, Various types of semiconductor detectors and its principles, Resolution, Fano factor; Neutron detectors
		Slow and Fast Neutron detection methods
		Nuclear Reaction of Interest in Neutron Detection
		Counters based on Neutron Moderation
		Other detectors - Explanation of Cherenkov Detectors, Photographic Emulsions, Thermoluminescent Dosimeters, Track Etch Detectors etc. Pulse processing and measurements - Pre amplifier, Amplifier and MCA etc.
3	Lab	
3.1	Gamma ray spectrometry	Measurement of gamma ray energy for the estimation of Ra(eq), ThO2 & %K
		Beta-Gamma technique
		Explanation and practice of technique used for the estimation of U3O8 in the sample
		Gamma ray logging & core analysis
		Explanation and practice of technique used for Gamma ray logging
		Shielded Probe Logging, and analysis of core samples
3.2	Instrumental Neutron Activation Analysis (INAA)	Principle and operation of INAA
3.3	Radon Emanometry	Methods for the measurement of Radon: CCT-Method, SSNTD Method, and ROAC Method
4	References	1. Radiation Detection and measurement – By G.F.Knoll. 2. Nuclear Physics- By D.C.Tayal. 3. The Atomic Nucleus- By R.D.Evans. 4. Measurement and Detection of Radiation- By N. Tsoulfanidis. 5. Nuclear Physics -by Irving Keplan 6. Basic Electronics, - Bernard Grob

S. No.	Topics	Chapters

Course No : 103
Subject: Basic Geophysics for Geologists

S. No.	Topics	Chapters
1	Introduction	Geophysical methods and the associated physical properties
		Classification of geophysical methods
		Role of geophysical methods in mineral exploration
		Effectiveness and limitations of various geophysical techniques with special reference to uranium exploration
		Geophysical signatures of uranium deposits
2	Magnetic and gravity methods of prospecting	Magnetic Method - Earth's magnetic field and its variations
		Magnetic properties of materials, Remnant magnetization
		Instruments for measuring magnetic field
		Field surveys, Corrections Reduction of magnetic data
		Magnetic anomalies due to bodies of simple geometry
		Gravity Method -Earth's gravity field and its variations, Figure of Earth, Isostacy, Absolute and relative measurements of gravity field
		Instruments for measuring gravity field, Field surveys, Reduction of gravity data Interpretation of gravity and magnetic data
		Anomaly patterns, Characterization of anomalies. Anomalies due to bodies of simples geometry (1D, 2D and 3D).
		Variation of magnetic anomaly in relation to magnetic latitude, azimuth and dip of the body, Ambiguity in interpretation of data, Forward and inverse modeling
		Applications and field examples
3	Electrical methods	Classification of electrical geophysical method
		electrical properties of rocks
		Self Potential method: Origin of self potentials field equipment and survey, anomalies due to bodies of simple shape

S. No.	Topics	Chapters
		Interpretation, field examples and applications
		Resistivity method: Ohm's law,
		True and apparent resistivity
		Geoelectrical sections, Different electrode arrays, resistivity profiling and sounding
		Field equipment
		Interpretation of field data
		typical resistivity profiles over simple geological structures, use of Master curves for interpretation of data over multilayered medium
		Applications and Field examples
		Induced Polarization method: Origin, Membrane polarization, Electrode polarization, Time domain and frequency domain measurements, Parameters measured, Field equipment
		Typical profiles, Interpretation, Applications, Field examples
		Electromagnetic methods: Classification of methods
		Elementary theory of propagation of electromagnetic waves.
		Primary, Secondary and Resultant fields, Skin depth
		Frequency domain methods: Fixed source method, Moving source-moving receiver method, Very low frequency (VLF) method
		Ground penetrating radar technique, Parameters measured
		Field equipment
		Presentation of data
		Applications and field examples
		Time Domain method: Principle, Merits and demerits
		Survey configuration, Field procedure and equipment, typical profiles
		Applications and field examples Natural source EM methods.
		Telluric and magnetotelluric methods: Sources and the frequencies studied, Typical profiles, Applications and field examples.
4	Seismic methods	Elastic constants, Longitudinal, Transverse and Surface waves

S. No.	Topics	Chapters
		Hooke's law, reflection, refraction and diffraction from multilayered media
		Seismic energy sources and detectors
		Refraction seismic: Principle, Critical angle, critical distance, Velocity inversion, Refractions at parallel and non-parallel interfaces. Source-detector arrays, Fan shooting, applications and case histories
		Reflection seismic: Principle, Acoustic impedance. Time-distance graph, Reflections at parallel and non-parallel interfaces, Field procedures, Common Depth Point technique
		Applications and field examples.
5	Borehole logging methods	Objectives, different logging techniques, Principles
		Instrumentation and operational procedures of Self Potential, Electrical resistivity, Induction, Magnetic susceptibility, Sonic, Caliper, density, I.P. and radiometric logging techniques
		Applications and field examples
6	Tutorials	Computation of magnetic and gravity anomalies over regular shaped bodies;
		Smoothing of data by filtering techniques
		Estimation of mass from gravity data
		Interpretation of vertical electrical sounding curves
		Preparation of pseudo-sections of resistivity and IP data
		Interpretation of HLEM data using standard curves
		Interpretation of seismic refraction data by graphical and analytical methods
		Identification of formational boundaries from well logs.
7	References	1. Ramachandra Rao, M.B., 1975 Outlines Of Geophysical Prospecting - A Manual For Geologists, Prasaranga, University Of Mysore, Mysore,. 2. Bhirnasankaram V.L.S. 1990. Exploration Geophysics An Outline , Association Of Exploration Geophysicists, Osmania University, Hyderabad,. 3. Telford W.M., Geldart L.P., Sheriff, R.E. and Keys D.A. 1976, Applied Geophysics By Oxford And Ibh Publishing Co. Pvt., Ltd., New Delhi,. 4. Rama Rao, B.S. and Murthy, I.V.R. 1978, Gravity And Magnetic Methods Of Prospecting Arnold Heinemann Publishing, New Delhi,

S. No.	Topics	Chapters
		5. L.L. Nettlton, 1976, Gravity And Magnetic In Oil Prospecting , Mcgraw Hill 6. Dobrin, M.B An Introduction To Geophysical Prospecting 1984, Mcgraw Hill. 7. Telford W.M., Geldart L.P., Sheriff, R.E. And Keys D.A. 1976, Applied Geophysics By Oxford And Ibh Publishing Co. Pvt., Ltd., New Delhi. 8. Parasnis, D.S. 1997 Principles of Applied Geophysics. Chapman & Hall 9. Sumner, J.S.1976, Principles of Induced Polarisation for Geophysical Exploration. Elsevier. 10. Philip Kearey 2007, An Introduction To Geophysical Exploration, Michael Brooks, Ian Hill Blackwell. 11. Electromagnetic Methods In Applied Geophysics.Applications Ed. Misac N Nabighian, Society Of Exploration Geophysicists 1997 12. Dobrin, M.B., 1984.An Introduction To Geophysical Prospecting By Mcgraw Hill, New Delhi, 13. W.M., Geldart L.P., Sheriff, R.E. And Keys D.A. 1976. Applied Geophysics By Telford Oxford And Ibh Publishing Co. Pvt., Ltd., New Delhi, 14. C.L. Liner, 2004, Elements of 3d Seismology, Pennwell Corporation, U.S. 15. R.E. Sheriff and L.P. Geldart, 1995 Exploration Seismology, Cambridge University Press. 16. E.S. Robinson and C. Coruh, 1988. Basic Exploration Geophysics, John Wiley And Sons, New York 17. O.Serra, 2003. Well Logging And Geology, Technip, Paris 18. O. Serra, 1984. Fundamentals of Well Log Interpretation, Elsevier. 19. R.M. Bateman, 1985, Open hole Log Analysis And Formation Evaluation, Reidel, Dordrect. 20. G. Asquith and C. Gibson, 1982. Basic Well Log Analysis for Geologists, Academic Press, London

Course No.: 104
Subject: Basic Geology for Geophysicists

S. No.	Topics	Chapters
1	Introduction to geology	The origin and internal structure of the Earth
		Composition of crust mantle and core
		Surface and internal processes: geomorphic processes and sedimentation; orogenic processes, mountain building, volcanism, metamorphism and rock deformation

S. No.	Topics	Chapters
		Rock structure: folds, faults and joints, brittle and ductile deformation, lineation and foliation
		Principles of stratigraphy
		Geological Time Scale, correlation and geochronology
		Elements of Indian stratigraphy
		Precambrian shield areas
		Important Phanerozoic successions, elements of Himalayan geology.
2	Introduction to minerals and their identification	Major rock forming silicates and common ore minerals
		Brief introduction to the formation and classification of common igneous, sedimentary and metamorphic rocks
		primary igneous and sedimentary structures, unconformity, dip and strike.
3	The dynamic earth	Continental drift, theory of plate tectonics
		different types of plate margins, association of metallic deposits in different tectonic settings
4	Introduction to ore forming processes and mode of occurrence of common ore deposits	Epigenetic and syngenetic deposits. Classification of ore deposits
		Orthomagmatic processes and examples of orthomagmatic deposits
		Pegmatitic and pneumatolitic deposits
		Classification of pegmatites, skarn and metasomatic deposits
		Hydrothermal processes Examples of modern ore solutions, aqueous transport of metals and deposition of metals from ore solutions, meteoric and juvenile solutions and their discrimination
		Hydrothermal deposits forms and classifications
		Weathering, supergene enrichment and residual deposits.
		Sedimentary deposits, deposits formed by mechanical transport and by chemical precipitation, Eh-pH diagrams
		Metamorphic and metamorphosed ore deposits.
5	Lab	Identification and interpretation of geological features in topographic maps
		Identification and interpretation of structural elements in geological maps: Faults, folds, unconformities

S. No.	Topics	Chapters
		Construction of geological cross-sections, stratum contours, isopach maps
		Stereographic plotting of planes and lines
		Study of stratigraphic maps of India
		Analysis of folds, Analysis of faults, Strain measurements
		Identification and description of hand specimens of common silicate minerals, common igneous, sedimentary and metamorphic rocks, common sulphides and oxide ore minerals and economic rocks
		Introduction to optical identification of minerals
6	References	1. Evans, A.M. Ore Geology and Industrial Minerals - An Introduction, Oxford Blackwell Scientific Publ, London, 1993. 2. Guilbert, J.M.andPark, C.F.Geologyof Ore Deposits, Freeman, W.H, 1986. 3. Jensen M.L. and Bateman, A.L. Economic Mineral Deposits, Wiley, 1979. B.J.Skinner, and S.C.Porter, The Dynamic Earth – An introduction to Physical Geology, Wiley, 1989 4. G.W. Tyrrel, The Principles of Petrology: an introduction to science of rocks, BI Publications, India. 1985. 5. D.R.Prothero and F.Schwab, Sedimentary Geology: An introduction to sedimentary rocks and stratigraphy, Freeman and Co., New York 6. B.J. Skinner and S.C.Porter, the Blue Planet, Wiley, 1995. 7. P.D. Duff, (Ed). Holmes, Principles of Physical Geology, 4th Edition. ELBS, 1992. 8. H.H.Read, and J.Watson, Introduction to Geology I and II. Macmillan, 1978. 9. G.H.Davies, Structural geology of rocks and regions, Wiley, New York, 1996

Course No.: 105

Subject: Uranium Geology, Survey , Prospecting

S. No.	Topics	Chapters
1	Introduction	Objectives and challenges
		Geological considerations, time and project value estimation, terrain, legal, political and local issues
2	Uranium in the crust	Distribution of uranium - crustal abundance
		Time bound character
		Uranium in different rocks and minerals with some examples;.
		Classification of uranium deposits; uranium deposits in the world
3	Exploration guides	Controls of mineralization – stratigraphic, structural, lighological and other controls;
		Stratigraphic guides: earl
		Lithological guides
		Structural guides - fault, fracture, foliation and their intersections, fault-breccia systems;
		Geochemical guides - Indicator/pathfinder elements,
		Mineralogical guides - Poly metallic mineralisation- Pb, Cu, Ni, Co, Se, As, Au, Ag, Te and Zn and sulphide mineralization
		Weathering and alteration, diffusion aureole, leakage anomaly, dispersion and mobility patterns, K2O/ MgO, U, Ni, As, V, Mn and B abundances,
		Geochemical association of uranium with other trace elements
		Proterozoic basal Quartz- Pebble Conglomerate (QPC) type
		Proterozoic unconformity type
		Porous, permeable carbonaceous matter rich Mesozoic sandstone type
		Intrusive and reactivated granites
		Carbonaceous/ graphitic metapelites
		Graphitic schists, black shales
		Calcrete
4	Exploration methodology	
		Literature survey and conceptual modeling - study of available maps, identification of favourable parameters and

S. No.	Topics	Chapters
		geological environments;
		Reconnaissance and detailed survey – geological mapping from exploration point of view by remote sensing and ground surveys, narrowing down the target area;
		Uranium mineralogy – primary and secondary uranium minerals, their field identification.
5	Geochemical techniques	Stages of geochemical survey (Planning, deciding parameters for exploration, Orientation survey, Reconnoitory survey, detailed surveys)
		Hydrogeochemical techniques (Uranium and radium in surface and ground water, sampling);
		Lithogeochemical and pedogeochemical techniques (choosing grid pattern, sampling techniques),
		interpretation of analytical data
6	Radiometric techniques	Ground radiometric survey, gross gamma and spectometric measurements, demonstration of field equipments,
		Traverse planning, background radiation and anomaly detection, evaluation of anomaly
		Isorad mapping, channel sampling, shielded probe logging and radiometric assay of grab samples
		radon emanometry - isotopes of radon, migration, sampling techniques (CCT, SSNTD, ROC) and limitations
		Helium survey - principle, diurnal variation, sampling system, uses
7	Prospecting for uranium	Sampling: point, grab, grid samples; channel sampling; sample volumes; Sampling by drilling,
		stratigraphic, reconnoitary, exploratory and evaluation drilling;
		Planning of boreholes, choosing location and grid pattern,
		Borehole plan, selection of type of drilling(non-core/core),
		Lithological and geophysical logging
		Drift/deviation
		Borehole correlation sections,
		Preservation core, core skeletonization, sampling of boreholes sludge/core, comparative study of physical and chemical assay results of boreholes
		Estimation of disequilibrium.
		Assaying, rock density;
		Averaging of assay values from one location – samples of equal length/unequal lengths
		Averaging of assay values from different locations – evenly spaced samples, unevenly spaced samples;

S. No.	Topics	Chapters
		Compensation for varying rock density; erratic assays;
		Recent trends in uranium exploration
		Present status of uranium supply and demand, new discovery of uranium deposit in the world and in India; Case studies using different exploration techniques with examples from India and World.
8	References:	1. Economic Mineral Deposit-Alan M. Bateman 2. Uranium Supply and Demand-Michael J.Spriggs, Uranium Inst London 3. Uranium resources, production and demand summary-OECD-NEA and IAEA 4. World uranium deposits: uranium exploration geology; Proceedings of a panel, IAEA, Vienna-S. H. U. Bowie 5. Uranium Geology and Exploration -Richard H. De Voto 6. Classification of Uranium deposits-F. J. Dahlkamp 7. Radioactivity in geology: principles and applications- E.M.Durrance

Course No.: 106
Subject: Surveying, Drilling and Mining

S. No.	Topics	Chapters
1	Surveying	Types of surveys and applicability
		Principles and methods of surveying & mapping
		Surveying Equipment – Compass, The Transit, Optical Distance Measuring
		Modern surveying electronic equipments - Digital levels, Digital theodolites, EDMs and Total stations
		Principles, working and applications
		Survey Methods - Co-ordinate methods, Bearings, Traversing and Trilateration (Topo)
		Detail Survey, Orientation and position, Determination of True bearing, Horizontal and vertical control, Accuracy standards;
		Positioning – Introduction, Differential positioning,
		GPS instruments, Global Positioning Augmentation Systems; Errors in measurements – Blunders, Systematic errors, Random errors, Most probable value, Average error, Standard deviation
		Analysis and adjustment of measurements
		Distribution, Adjustment of errors by Approximate method and Least squire method

S. No.	Topics	Chapters
		Coordinate System in Geodesy - Geocentric Cartesian Coordinates, Topocentric Cartesian or local geodetic Cartesian Coordinates, Geodetic Coordinates, Planimetric Cartesian coordinate
		Datums - Horizontal datums - Everest spheroid, WGS – 84, datum transformation; Vertical datums - Mean Sea Level, Geoid, EGM 96
		Projection – Polyconic projection, Traverse Mercator projection (TM Projection), Universal Transverse Mercator Projection
2	Tutorials	Adjustment of instrument errors by approximate method and Least square method. Datum transformation exercises.
3	Drilling	History of Drilling; Methods of soil sampling - Auger, Drive sampling;
		Rock Drilling – Percussive, Attritive, Rotary Cutting, Shearing etc.,
		Rotary reverse circulating, Rotary with down hole motors, Cable tool method;
		Diamond Drilling - Diamond quality, types of diamond bits, natural and synthetic diamonds, Rotary core drilling equipment, Drilling standards, circulating media, Drilling fluid properties
		Controlled Directional Drilling - Deviation in drilling, Measurement of deviation and control, Tools for directional drilling, Downhole motors
		Various types of drills in use in AMD
	References:	1. Drilling Technology by C.P. Chugh 2. Drilling Technology Part 1 & 2 by British Drilling Association 3. Thomas, L.J. An Introduction to Mining, Methuen, Brisbane, 1978. 4. Sinha, R.K. and Sharma, N.L. An Introduction to Mineral Economics, Wiley Eastern, 1993. 5. Chatterjee, K.K. An Introduction to Mineral Economics, Wiley Eastern, 1993.

Course No.: 107
Subject: Theory of Fields

S. No.	Topics	Chapters
1		Mathematical and physical fields, Continuity, Scalar and Vector fields.
		Static fields in free space, Coloumb's law, Newton's law, Field intensity, lines of force, charge density, Curl of vector, Stoke's theorem, Gauss's law, Gauss's divergence theorem, Poisson's and Laplace's equations, Electrical dipole, Double layer. Dielectrics and conductors, Polar and non-polar dielectrics.

S. No.	Topics	Chapters
		Harmonic functions, orthogonal curvilinear, spherical and cylindrical co-ordinates, Method of images, Green's theorem, Green's function, Green's equivalent stratum, Dirichletand Neumann problems
		Electric fields in conductors, Ohm's law in integral and differential forms. Magnetic fields, Magnetic flux, Magnetic vector potential, Induction in magnetic media, Relation between gravity and magnetic potentials. Electromagnetic induction.
		Laws of induction, Electric and magnetic energy densities, displacement currents, Poynting's theorem
		Electromagnetic radiation from an oscillating dipole.
	References:	1. V.L.S. Bhimasankaram And S.V. Seshagiri Rao, 1973, Theory Of Fields, Osmania University, Hyderabad, 2. Alexander A. Kaufman, 1992, Geophysical Field Theory And Method: Gravitational, Electric And Magnetic Fields. Academic Press.

Course No.108
Subject: Geochemistry and Geochemical Exploration

S. No.	Topics	Chapters
1	Geochemistry	Geochemistry as a branch of Chemistry, Brief understanding of the periodic table and inter-relationships between various elements, Hunds rule, Aufbau principle, Pauling's exclusion principle, Ionisation energy, electron affinity, electronegativity etc
		Primary geochemical differentiation, Geochemical classification of elements, geochemical associations
		Distribution of Major and trace elements in primary and secondary environment,Partition coefficient/ distribution coefficient and separation constants, Stable isotopes, Geochemical cycle of Uranium, Geochemistry of uranium, REE Geochemistry
		Eu and Ce anomaly interpretations
2	Geochemical thermodynamics	Equilibrium thermodynamics, state functions, ideal and real gases, equations of state, properties of vapours and solutions
		Laws of thermodynamics, reversible and irreversible processes, internal energy, enthalpy, heat capacity and entropy, calorimetric measurements
		Gibb's free energy in relation to temperature and pressure. Chemical potential, Gibb's-Duhem equation, heterogeneous equilibria and phase rule
		Standard states, activity and fugacity. Ideal solutions, Henry's law, Roults law

S. No.	Topics	Chapters
		Non-ideal solutions
		Phase diagrams.
3	Water chemistry	Solutions and solubilities, solute-solvent, solubility product and ion activity product
		Ionic strength of the solution, Debye-Huckel theory, Davies equations, units of concentration- molarity, molality, mole fraction, equivalents and normality
		pH and Eh concepts, Nernst equation (derivation), Geochemical fences, Limits of water stability
		Ore Genesis-Physico-chemical environment of ore genesis, Major theories- Origin due to Internal processes, Magmatic segregation, Magmatic deposits, Sublimation
		Hydrothermal deposits, metamorphic deposits, Contact metasomatism and wall rock alterations. Origin due to surface processes-Evaporation, residual and mechanical concentration/accumulation
		Origin due to secondary processes-Oxidation and Supergene enrichment.
4	Geochemical Exploration	Geochemical surveys–litho geochemical, hydro geochemical, pedo geochemical, Geobotanical /biogeochemical and Atmo geochemical techniques, Pathfinder and indicator elements
		Dispersion - Primary dispersions-Zonality, Wall rock alterations
		Secondary dispersions-mechanical, Gaseous, Residual, outcropping concealed and superimposed
		Hydro geochemistry- Significance of Eh, pH, T°C, Ec. solubility index and its significance in the secondary environment
		Eh-pH Diagrams constructions and their Significance
		Soil geochemistry, ionic potential and geochemical separation. Geochemical maps
	Tutorials	Evaluation Analysis & Interpretation of Geochemical Data (litho- pedo- hydro- biogeo & atmo- geochemical data) using conventional techniques and through use of various geo-software
		Derivation and interpretation of Partition coefficient/ distribution coefficient and separation constants.REE data normalisation using different rock standards, Eu and Ce anomaly interpretations
		Gibbs free energy in relation to temperature and pressure
		Gibbs- Duhem equation, construction of phase diagrams, solubility product and ion activity product, derivation of solubility index, Nernst equation (derivation), Calculation of limits of water stability using thermodynamic data, Geochemical fences, construction of Eh-pH Diagrams, Preparation of various geochemical maps
	References	1. Mason, B. Principles of Geochemistry, Wiley Eastern, 1982.

S. No.	Topics	Chapters
		2. Krauskopf, K.B. and Bird, D.K. Introduction to Geochemistry, McGraw-Hill International Edn., 1995. 3. Anderson, G.M. and Crerar, D.A. Thermodynamics in Geochemistry- the Equilibrium Model, Oxford Univ. Press, NY, 1993. 4. Wood, B.J. and Fraser, D.G. Elementary thermodynamics for geologists. Oxford, 1977. Nordstrom, D.K. and Munoz, J.L. Geochemical Thermodynamics, The Benjamin/ Cummings Publishing Co., Inc. 1985.

Course No. : 109
Subject: Seismic methods

S. No.	Topics	Chapters
1		Basic concepts, Hooke's law, Elastic wave propagation Wave equation, Elastic constants, Elasticc waves, Huygene's and Fermat's principles, Snell's law, Reflection, refraction and diffraction from multilayered media; Factors affecting seismic wave velocities, Partition of energy at an interface, acoustic impedance, Reflection and transmission coefficients, Zoeppritz's equation, Structure of Earth; Seismic refraction method - Head wave refraction, critical angle, Time distance curves, Critical distance, Geometry of refraction paths – two layer and multilayer media; Velocity inversion/hidden layer problem, Field lay outs, Fan shooting, Interpretation of refraction data – graphical and analytical approaches; Seismic reflection method- Principle, Time-distance graph, Geometry of reflection paths – horizontal reflector, dipping reflector; Common depth point technique, Stacking chart and CDP diagram for normal and crooked profiles, Static corrections, NMO, Velocity analysis, Migration, Wavelet propagation, attribute analysis. Wide angle reflections; Deep seismic soundings; Field procedure; Vertical seismic profiling; 3D and 4D seismic exploration, Seismic tomography, Basic concepts; Data acquisition; Energy sources – dynamite, vibroseis, hammer, airgun, Detectors – geophone, hydrophone; Grouping of geophones, Noise profile analysis, Source-detector arrays, Directional shooting, Instrumentation, Digital seismic recording- general lay out, pre-amplifier, filters, multiplexers, A-D converter, AGC, SEG formats; Telemetry systems;
2	Tutorials	Construction of wavefronts for two and three layer cases, Interpretation of refraction data –graphical approach (Mean minus T and Hale's methods) and analytical approach (Generalised reciprocal method).; Construction of CDP diagram and stacking chart for normal and crooked profiles; NMO correction; Determination of velocity and interface from reflection data; Plotting of reflection points on dipping reflecting layers; Noise profile analysis and optimum group spacing; Seismic data processing from demultiplexing to migration using standard software package; Simulation of seismic responses by finite element and finite difference methods.
3	References:	1. C.L. Liner, 2004, Elements Of 3d Seismology, Pennwell Corporation, U.S. 2. R.E. Sheriff And L.P. Geldart, 1995 Exploration Seismology, Cambridge University Press. 3. E.S. Robinson And C. Coruh, 1988. Basic Exploration Geophysics, John Wiley And Sons, New York

S. No.	Topics	Chapters
		4. Dobrin, M.B., 1984. An Introduction To Geophysical Prospecting Mcgraw Hill, New Delhi, 5. Encyclopedic Dictionary Of Exploration Geophysics. Sheriff, R.E. Society Of Exploration Geophysicists, 1984

Course No. 110

Subject: Remote Sensing and GIS

S. No.	Topics	Chapters
1	Introduction	Fundamental concepts of Remote Sensing – Electromagnetic Spectrum, Energies available for sensing, Interaction of EMR with the atmosphere and terrain features
		. Mineral and Rock spectra. Application of energy bands for Geological studies
2	Imaging systems and sensors	Sensors in space today- Radiometric, Spectral and Spatial resolutions
		Selection of spectral and spatial resolutions for different geological themes
		Identification of the satellite data product, product codes, browsing of quality, product availability and procurement procedure
3	Elements of remote sensing and data interpretation	Fundamentals of image interpretation and geological applications-Tone, Texture, Drainage patterns and anomalies, colour, size and Object to background relationship
		Applications of geomorphology. Lithological and structural interpretation from satellite data
4	Digital image processing	Objective of Digital Image Processing, Georectification, Image mosaicing
		Image enhancement: Single band enhancement - Contrast stretching – Linear contrast stretching, Multiple linear stretching, Logarithmic or functional stretching, Gaussian stretching, Histogram equalization stretching and Density slicing
		Application of stretching techniques for geological interpretation and for anomaly zone extraction from airborne radiometric images; Edge enhancement – Anisotropic Kerenels (Linear edge), Gradiant image (1st Derivative), Laplacian image (2nd Derivative), Image smoothening
		Application of different edge enhancements to radiometric images; multiple Image Enhancement - Addition and substration of Images, Principle component Transformation, Image ratioing.
		Application of these transformations for Geological and radiometric interpretation; Spectral and spatial resolution merging – different methods, and its application to geological studies

S. No.	Topics	Chapters
5	Digital Image classification	Supervised classification, unsupervised classification, Application of classification for geological studies
6	Geographical Information Systems (GIS)	Introduction to GIS, Basic map concepts and Data layer generation, Topology building and Attribute Table generation
		Getting spatial data into GIS and making spatial data usable
		Getting attribute table in GIS and making it Linked and usable
		Defining real world coordinate system and Map projections to multi-coverage database
		Performing GIS analysis – Spatial operation, generating buffers, manipulating spatial features, polygon overlay and Tabular analysis
7	Geo-modelling	Introduction, principles of various modelling techniques in mineral exploration; concepts of mathematical modelling
		Vector and Raster geographical information system
		Geological, geophysical and geochemical data used in modelling
		Presentation of case study- nature of data, grid file generation, interpolation algorithms, validation of surface fitting, mathematical equations of trend surface, estimation of parameters of surface equations, goodness of fit, preparation of residual maps for variables and uranium accumulation trend analysis
8	Lab	Handling data products: different sensors and scale; procedure of browsing and selecting data; Interpretation of satellite data based on elements of Remote sensing - sedimentary, Igneous and Metamorphic terrain; Interpretation of structural features.
		Digital Image Processing: Georectification and Mosaicing; contrast stretching, edge enhancement, multiple image enhancements, Merging images, and image classification, using both satellite and radiometric data.
		GIS: working on ERDAS DIPS and ArcGIS for spatial data creation; defining real world coordinate system and Map projections; working on ArcGIS for some GIS analysis; Map Presentation
9	Reference	1. Remote Sensing and Image Interpretation - Thomas M, Lillesand and Ralph, W. 2. Remote Sensing Application for Mineral Exploration - Ed.William L. Smith 3. Remote Sensing data Book – 1999 - Gareth Rees 4. Remote Sensing for Geologists – a Guide to image interpretation - Gary L. Prost (2001) 5. Remote Sensing for Earth Sciences. Ed - Andrew 6. Remote Sensing Geology - Ravi P. Gupta

Course No.: 202

Subject: Exploration for Beach sands

S. No.	Topics	Chapters
1	Placers and the placer environments	Classifying the environments,
		Environmental change, the placer geological time-scale,
		Types of placer minerals
2	Placer sediments and sedimentation	Energy balance, Process-response elements, Sedimentary processes - Mechanical agents of weathering, Chemical agents of weathering, Biological agents of weathering, susceptibility of minerals to change, resistance of minerals to change, Erosion;
		Properties of sediments- Particle size, Particle shape, Particle density;
		Characteristic properties of placer minerals
		Sedimentation - flow of solids through fluids-sediment transportation and settling, Transitional marine sedimentation.
3	Placers and their formation:	Provenances and related minerals, Time related provenances, Tectonically related provenances, Regional aspects of provenance and placer mineral distribution ,Connecting provenance with minerals characteristics;
		Placer formation- Continental placers, Transitional placers, marine placers
		Transitional (Beach) Placers
		Beach terminology, beach morphology, common HMs on the beaches
4	Exploration and prospecting	The placer exploration model- Programme logistics, Exploration tools, Remote sensing and satellite imagery, aerial photography, geophysical and geo-chemical methods
		Prospecting – Reconnaissance, close testing, drilling methods,sampling,analytical methods
5	Placer valuation:	Classification of ore reserves and resources - geometrical and geo-statistical methods - cut-off grade, blending, dilution, feasibility studies
6	Placer mining and placer mineral processing:	Mining methods- Mechanical mining - wet and dry methods – dredging, ecological consideration; Mineral processing: Gravity concentration, magnetic and electro static separation
7	Economic value of placer	

S. No.	Topics	Chapters
	resources – world scenario	

Course No.: 202

Subject: Rare metals and Rare Earths

S. No.	Topics	Chapters
1		Introduction to Rare Metal & Rare Earth minerals and their significance in Modern Technology
		Geochemistry and mineralogy of RM RE minerals
		Geological characteristics of Rare Metal bearing granites, pegmatites ,carbontites and alkaline rocks
		Potential Rare Metal bearing of pegmatite belts of India and world scenario
		Rare metal bearing carbonatite-alkaline rock complexes of India and World scenario
		Geologic characteristics and genetic problems associated with development of granite hosted deposits of Tantalum and niobium
		Exploration Techniques for rare metals minerals
		Geochemical methods in exploration of Rare Metals and their ore reserve estimation
		Gravity Technique for Recovery of Rare Metals
	References	1. Alluvial Mining by Eoin H. Macdonald (1983), Chapman and Hall, London and New York. pp. 508 2. Macdonald, E.H. (1973) Manual of Beach Mining Practice, Exploration and Evaluation, 2nd Edition, Canberra 3. Techniques in Mineral Exploration by J.H.Reedman(1979) pp515 4. Cerny Peter 1992 Rare element granitic pegmatites part-I, Anatomy and internal evolution of pegmatite deposits, Geoscience Canada, vol 18, no.2 5. Heinrich, E.W. 1958 Economic geology of the rare earth elements. Canadian mining journal, 1979 6. Henderson, P. 1984 Rare earth element geochemistry 7. Moller, P. 1986 Rare earth mineral deposits – Lanthanides, tantalum and niobium. Proceedings of a workshop, Berlin. Springer-Verlag 8. Cermy, P. 1989. Characteristics of pegmatite deposits of Tantalum. In Lanthanides, Tantalum-Niobium spl. Publication

S. No.	Topics	Chapters
		vol.7, pp271-299 9. Ginsburg, A.I., Trimofeyer, I.N., and others 1979. Principles of geology of granitic pegmatites, Nedra, Moscow. 10. Ginsburg, A.I. 1984. The geological condition of the location and the formation of granitic pegmatites, proceedings of 27th international geological congress, vol. 15. 11. Teertstra, K.K., Cermy, P. and Howthrone, F.C. 1998. Rubidium feldspars in granitic pegmatites, vol. 36, part-Canadian Mineralogist

Course No.:203

Subject: Inversion methods in Geophysics and signal processing

S. No.	Topics	Chapters
1	Inversion techniques	Fundamental concepts, Inverses with discrete and continuous models
		Inverse methods based length, generalized matrix,
		inverses and maximum likelihood methods
		Non-uniqueness, applications of vector space, resolving kernels
		singular value decomposition, non-linear inverse problems
		Optimization techniques and algorithms, Marquardt algorithm, Parametric, generalized and constrained inversion procedures
		Backus-Gilbert Inverse problem, Applications of inverse theory to geophysics
2	Signal Processing	Signal processing in geophysics, Periodic function, Even and odd functions; Delta function Step function, Analog to Digital conversion; Integral transforms, Fourier transform, Discrete Fourier transform, Fast Fourier transform; Hilbert transform, Hankel transform, Walsh transform, Laplace transform, Z transform; Impulse response, Transfer function, Digital filtering; Convolution, Deconvolution; Auto correlation , Cross correlation; Sampling and reconstruction, Statistical Signal processing; Auto regression, Moving average. Auto recursive moving average filters; Weiner least square method for designing shaping and spiking filters, Butter worth filter, Applications in geophysics
3	References:	1. W. Menke, 1989, Geophysical Data Analysis: Discrete Inverse Theory, Academic Press. 2. J.A. Scales, M.L. Smith and S. Trietel, 2001, Introductory Geophysical Inverse Theory, Samizdat Press. 3. D. Gubbibns, 2004, Tgime Series Analysis and Inverse Theory for Geophysicists, Cambridge University Press. 4. E.A. Robinsonand S. Trietel, 1980. Geophysical Signal Analysis. Prentice Hall, New Jersey

S. No.	Topics	Chapters
		5. Ronald N. Bracewell, 1999, the Fourier Transform and Its Applications, Mcgraw-Hill. 6. John F. Clearbout, 1985, Fundamentals of Geophysical Data Processing With Applications To Petroleum Prospecting. Blackwell Scientific Publications 7. P.S.Naidu & M.P.Mathew, Advances in Exploration Geophysics 5: Analysis of Geophysical Fields. A Digital Signal Processing Approach..Elsevier. Amsterdam 8. M.Bath, Spectral Analysis in Geophysics. Elsevier. Amsterdam

Course No.: 204

Subject: Ore Reserve Estimation

. No.	Topics	Chapters
1	Ore Reserve Estimations	An overview and outline, Exploration and Data Collection (Resource database) - Survey information, Geological data,
		Geological model, Density factor, Sampling issues
		Analytical procedures, Digital databases and validation, Audits of the resource database
		Geological interpretation and Geological modeling
		Role of geological interpretation
		Interpretative techniques, Geological interpretation and modeling for mineral resource estimation
		Ore reserve estimation- Area of Influence methods, Estimation for flat lying deposits
		Uniform area of influence method
		Variable area of influence method
		Polygonal method
		Triangular method
		Cross-section method
		Isopach method and General outline method;
		Estimation method for steeply dipping deposits;
		Inverse distance method
		Geostatistical methods

. No.	Topics	Chapters
		Variography, Variography and data validation, Optimization of sampling grid and Domaining, Semivariogram, Kriging techniques (linear and nonlinear); Conditional simulation
		Mineral sands – Evaluation, resource estimation and reporting
		Reserve categories: Measured/indicated/Inferred, RAR/EAI/EAII/Speculative
		Feasibility studies: Environmental issues and Ore reserve estimation
	Tutorials	Calculation of ore reserves by different methods
	References:	1. Edwards, A.C., (Ed) (2001). Mineral Rersource and Ore reserve estimation – The AusIMM Guide to Good Practice (Monograph 23). Published by The Australiasian Institute of Mining and Mettallurgy, Carlton Victoria Australia. 2. International Atomic Energy Agency (1985). Methods for the estimation of Uranium ore reserve, An instruction Manual. Technical Reports series no.255.

Course No.: 205

Subject: Gravity and magnetic methods

S. No.	Topics	Chapters
1	Gravity method	Earth's gravitational field , Gravitational potential, Potential field equations, Derivatives of potential
		Poisson's equation Geoid
		Figure of Earth, Isostacy, ,Geodetic measurements Density estimations from field data
		Absolute and relative measurement s of gravity
		Theory and principle of gravimeter, zero length spring, Super conducting gravimeter, Calibration of gravimeter, Field procedure, Reduction of gravity data, Free Air, Bouguer and Isostatic anomalies,
		Gravity anomalies due to regular bodies- Sphere, vertical and horizontal cylinders, sheet, step/fault and bodies of arbitrary shape, Simple interpretation methods using thumb rules, characteristic curves, curve matching , excess mass estimation, location of mass centre, over burden effects, maximum-depth rules.
2	Magnetic method	Geomagnetic field, Magnetic field of external and internal origin,
		Van Allen radiation belts, diurnal variation, magnetic storms, Dipole-nondipole fields and their origin, Secular variation
		Magnetic petro physics
		Factors affecting magnetization of rocks and magnetic minerals, magnetism of igneous , metamorphic and sedimentary

S. No.	Topics	Chapters
		rocks
		magnetic signatures in different ore environments
		Remnant magnetization
		Magnetic character of continental and oceanic crusts, reversals of magnetic field, sea floor spreading and plate tectonics
		Theory and principles of magnetometers -Flux gate, Proton precision, Optical pumping and SQUID. Gradiometers
		Measurement of remanence and magnetic susceptibility
3	Processing of gravity and magnetic data	Regional-residual separation, graphical method, Polynomial fitting, Spectral analysis, Average depth estimates
		Smoothing and enhancement techniques, wavelength filtering, matched filtering,
		Werner Deconvolution, Euler depth estimates, Upward and downward continuation, derivatives, reduction to pole for magnetic data, analytical signal, susceptibility mapping, direct and inverse methods of interpretation.
4	Lab	Computation of gravity and magnetic anomalies due to two dimensional and three dimensional regular shaped bodies
		Study of variation of magnetic anomaly with magnetic latitude, azimuth and dip of the body
		Application of spectral analysis for interpretation of field data
		Computation of radially averaged spectrum
		Average depth estimates, upward, downward continuation of data
		Regional-residual separation
		Computation of vertical derivatives,
		Reduction to pole for magnetic data
		Computation of analytical signal
		Euler depth estimates
		Inversion of gravity and magnetic anomalies,
		Estimation of anomalous mass from gravity data,
		Modelling of gravity anomaly over a outcropping sedimentary basin
	References	1. M.B. Dobrin and C.H. Savit, 1988. Introduction to Geophysical Prospecting, Mcgraw Hill. 2. L.L. Nettlton, 1976, Gravity And Magnetic In Oil Prospecting , Mcgraw Hill 3. W.M. Telford, L.P. Geldart and R.E. Sheriff, 1990, Applied Geophysics, Cambridge University Press. 4. I.V. Radhakrishna Murthy, 1998, Gravity and Magnetic Interpretation in Exploration Geophysics, Geological Society of

S. No.	Topics	Chapters
		India, Bangalore. 5. B.S.R. Rao And I.V. Radhakrishna Murthy, 1978, Gravity And Magnetic Methods Of Prospecting, Arnold-Henniman Pub. Co. 6. D.S. Parasnis, 1979, Principles of Applied Geophysics, Chapman and Hall. 7. B.Bhattacharya, 1965, Two Dimensional Harmonic Analysis as a Tool for Magnetic Interpretation. Geophysics Vol. 30, Pp 829-857. 8. Paterson, N.R. And Reeves, C.V. Geophysics 1985 Applications of Gravity and Magnetic Surveys: The State Of The Art in 1985. Geophysics, Vol 50 Pp 2558-94,

Course No.: 206

Subject: Petro-graphic techniques in uranium exploration

S. No.	Topics	Chapters
1	Optics and Mineralogy	Electromagnetic spectrum, light, double refraction; Polarised light microscopy,
2	Transmitted light microscopy	Minerals in plane polarized light – shape and cleavage, relief, colour, pleochroism/diachroism, opacity, vibration direction, birefringence
		Minerals in cross polarized light – anisotropism, interference colors, extinction angle, twinning, mineral identification; Interference figures – significance; sign of elongation
		Unitarian optics – determining optic sign with gypsum plate, quartz wedge
		Biaxial optics – determining optic sign with optic axis figure and acute bisectrix figure, determining 2V/Mallards method
		Becke's lines, oblique illumination method for determining relief, determination of plagioclase compositions using the Michel Levy method;
		Modal analysis, norm calculation
3	Reflected light microscopy:Properties to be studied under	Colour, bireflectance and reflection pleochroism, anisotropism, internal reflections
		Structural and morphological characters – crystal form and habit, cleavage and parting, twinning. Mineral identification
		Qualitative methods –; Colour – quantitative measurement of colour, reflectance, microindentation hardness, standard measure of Vicker's hardness, Knoop's hardness, standards, factors affecting microindentation hardness values for minerals;

S. No.	Topics	Chapters
	reflected light	polishing hardness, scratch hardness; paragenesis
4	Petrography	Petrography, petrology, petrogenesis
		Igneous petrology – rock classification-plutonic and volcanic rocks, textures, alkaline rocks and carbonatites
		Sedimentary petrology – clastic rocks, classification and origin, provenance of accessory minerals in sandstones, significance of glauconite, tectonics and sandstone compositions, climate and sandstones, diagenesis of sandstones, cementation, sandstone interpretation guide
		Chemical and biochemical sedimentary rocks – carbonate mineralogy, classification
		Tectonic setting
		Texture as an indicator of energy levels
		Metamorphic petrology – definition, grade, types, classification, nomenclature, textures and metamorphic settings.
5	Radioactive, Rare earth element and rare metal bearing minerals	. Uranium mineralogy, different stages of formation of uranium minerals, occurrence of radioactive minerals in different rock types
		Thorium: Mineralogical expression of radioactivity
		Types of radioactive minerals/phases, location and identification of radioactive minerals, optical properties of radioactive minerals – colour, reflectance, bireflectance, reflection pleochroiism, anisotropism and isotropism, internal reflection, micro indentation hardness
		primary uranium minerals, complex oxides of uranium and thorium
6	Presentation and preservation of data and assessment	Entry in registers, database, slide cataloging, photomicrography and report writing
7	Lab Petromineralogical techniques	
		Preparation of polished slab, polished thin section -advantages, araldite mount (cold setting), Bakelite mount, preparation of wafers for fluid inclusion studies
		Determination of specific gravity
		staining techniques – feldspars and carbonates

S. No.	Topics	Chapters
		Density separation of mineral grains – coarser than 200 mesh sieves and finer than 200 mess sieves; unconsolidated sediments,
		Identification of minerals, special techniques for radioactive minerals – chromogram test
		CN-85 film autoradiography/SSNTD study, fission tract studies, separation of secondary uranium minerals
8	Parts of the microscope	Objective lenses, ocular lenses, illuminating systems, accessory plates and their uses, monochromators, photometers, stage micrometers, sample holders
		Resolution, numerical aperture calibration of the micrometer, field of view, centering of the objectives
9	Transmitted light microscopy	Minerals in plane polarized light – shape and cleavage, relief, colour, pleochroism/diachroism, opacity, vibration direction, birefringence
		Minerals in cross polarized light – anisotropism, interference colors, extinction angle, twinning, mineral identification
		Interference figures – significance; sign of elongation; Unitarian optics – determining optic sign with gypsum plate, quartz wedge
		Biaxial optics – determining optic sign with optic axis figure and acute bisectrix figure, determining 2V/Mallards method
		Becke's lines, oblique illumination method for determining relief, determination of plagioclase compositions using the Michel Levy method; Modal analysis,
10	Reflected light microscopy	Mineral identification, Kalb's line. Qualitative methods Colour – quantitative measurement of colour, reflectance
		Microindentation hardness, standard measure of Vicker's hardness, Knoop's hardness, standards, factors affecting microindentation hardness values for minerals; polishing hardness, scratch hardness
11	Petrology	Study of thin sections of common igneous, sedimentary and metamorphic rocks
12	Radioactive, Rare earth element and rare metal bearing minerals	Mineralogical expression of radioactivity; types of radioactive minerals/phases, location and identification of radioactive minerals
		Optical properties of radioactive minerals – colour, reflectance, bireflectance, reflection pleochroiism, anisotropism and isotropism, internal reflection, micro indentation hardness
		Primary uranium minerals, complex oxides of uranium and thorium, common accessory radioactive minerals, labile uranium along grain boundaries, secondary uranium minerals
		uranium minerals in igneous, sedimentary and metamorphic environments.
	References	1. Berry, L.G., Mason, Brian 1959. Mineralogy – concepts, descriptions and determinations, W.H.Freeman and

S. No.	Topics	Chapters
		Co.,California 612p. 2. Deer, Howie, Zussman – Rcok forming minerals, vol. 1 to 5. 3. Kerr, F.P. 1959. Optical mineralogy, McGraw-Hill Book company Inc., 441p. 4. Nesse, W.D. 1991. Introduction to optical mineralogy, Oxford University press Inc., New York, 335p. 5. Winchell, A.N. and Winchell, H. 1951. Elements of optical mineralogy – an introduction microscopic petrography, John Wiley & sons Inc., New York, Vol. 1 & 2, 551p. 6. Lecture notes: Internet. Prof. Stephen A. Nelson, Petrology, Tulane University – updated on 12th August, 2008. 7. Cameron, E.N. 1961. Ore microscopy, John Wiley & sons Inc., New York 8. Craig and Vaughan, Ore Microscopy 9. Ramdohr, P 1980. The ore minerals and their intergrowths, 2nd edition, vol. 1 & 2, Pergamon Press, Oxford. 10. Uytenbogaart, W. and Burke, E.A.J.1971. Tables for microscopic identification of ore minerals, Elsevier, Amsterdam, 430p. 11. Frondel, C. 1958. Systematic mineralogy of uranium and thorium, Geol. Sur. Bull. 1064, U.S.Government Printing Office, Washington, D.C., 400p. 12. Heinrich, E.W., 1958. Mineralogy and geology of radioactive raw materials, McGraw Hill Book Company, New York, 654p. 13. Hutchison, C.S. 1973. Laboratory handbook of Petrographic techniques, John Wiley and sons, New York, 527p. 14. Verma, H.M. 1994. Petrographic study of radioactive minerals and the relevance of petrological data to exploration and extraction of uranium, Geotutorials, vol.1, pp1-23, Atomic Minerals Division, Govt. of India, Hyderabad.

Course No. 207

Subject: Electrical and electromagnetic Methods

. S. No.	Topics	Chapters
1	Electrical Methods	Classification of electrical methods, Natural and artificial source methods,
		Conduction in rocks, Electrical properties of rocks and minerals and their measurement
2	Self Potential method-	Origin of self potentials, Electro-filtration, Diffusion, Adsorption, Mineral potential occurrence and stability ,
		Field procedure, equipment, non-polarizable electrodes, Interpretation of anomalies due to simple shaped bodies.

. S. No.	Topics	Chapters
3	Resistivity method-	True and apparent resistivity, Current flow and potential in homogenous and non homogenous media, Potential at a plane interface, Surface potential due to horizontal beds, Effect of anisotropy and topography.
		Geo-electrical parameters- Longitudinal conductance, Transverse resistivity, longitudinal resistivity
		Various configurations and their geometric factors, Comparison of electrode arrays, Principle of reciprocity, Electrode effect, Depth of investigation, Field about a point, Dipole field region, Concept of image in potential theory, analytical continuation of potential fields, numerical methods in potential theory, Resistivity profiling and sounding.
		Typical profiles across contacts, dykes
		Expressions for apparent resistivity over layered earth, Principle of equivalence and suppression, Resistivity transform and linear filter theory, Interpretation of vertical electrical sounding curves. Applications and case histories
4	Induced Polarization method	IP phenomenon, electrochemical theory, over voltage, fixed layer, double layer, Faradaic and non-Faradaic paths, Warburg impedance, equivalent circuits, IP phase angle, mathematical formulation of IP response, Factors affecting IP phenomenon, Time domain, frequency domain and Spectral IP measurements and their equivalence
		Complex resistivity, Cole-Cole model, Discrimination of minerals, Negative IP, Field procedure and equipment, EM and capacity coupling, Computation of theoretical IP curves, IP soundings and interpretation, Magnetic Induced Polarization method, Field procedure and equipment, advantages, Applications and case histories
5	Electromagneti c methods	Classification of electromagnetic methods, Sources for EM waves, EM wave propagation
		Maxwell' s equations, Boundary conditions, wave equation, self and mutual inductance
		Electromagnetic energy and power, Poynting vector
		Diffusion equation and its solution, skin effect and skin depth, Reflection and transmission of electrical and magnetic fields, elliptic polarization
		radiation from dipole, retarded potential, near and far fields, radiation resistance, Field due to a rectangular loop, horizontal wire, horizontal circular coil, vertical straight wire, Phasor diagram, Electric circuit analogy for an EM system
		Negative screening, overburden effect, current channeling and current gathering.
		EM response over bodies with high magnetic permeability.
		EM scale modeling. Cagniard's resistivity
6	Frequency domain EM	Dip angle, Compensator method, Turam method, Horizontal and vertical loop EM methods, Controlled source audio magneto telluric method

. S. No.	Topics	Chapters
	methods-	Frequency and geometric soundings, Very low frequency (VLF) method- VLF station, parameters measured Ground Penetrating Radar method
		Field procedures and equipment
		Processing of Turam data Interpretation of HLEM data and Turam data using standard curves
		Fraser and Hjelt filters, Derivation of Current density cross section from VLF data
7	Time Domain EM methods	Comparison of FDEM and TDEM methods
		Survey configuration, Impulse and Step response measurements, Diffusion time, Transient EM response over confined targets, homogenous half-space, layered earth, thin sheets
		Field procedure and equipment. Interpretation using plate model
		Interpretation of sounding data over layered earth.
8	Natural source EM methods	Magneto-telluric, telluric and AFMAG methods. Source and the frequencies investigated
		Field procedure and equipment. Interpretation of the MT soundings. Applications and case histories
	Lab	Construction of two, three and multilayered VES curves, Interpretation of two ,three and multilayered VES curves using auxiliary point charts and master curves, Interpretation of VES curves by direct and inverse methods, Preparation of pseudo-sections, Current density cross sections from VLF data, Interpretation of HLEM data using master curves, Processing of Turam data and interpretation by using characteristic curves Interpretation of TEM profiles using plate mode, interpretation of TEM sounding data using inversion

Course No.: 208
Subject: Mineral process Engineering

S. No.	Topics	Chapters
1	Ore preparation	Significance of mineralogy in ore/mineral beneficiation
		Mineral liberation, locking factor, image analysis, Particle size analysis
		graphical representation of the results, number, mass, surface area, volume distributions as function of particle size
		statistical distributions, Laser particle analyzer
		Crushing and grinding of ores, operating principles, work index of ores, grinding efficiency and various grinding mills, mathematical treatment of grinding operation, design of grinding circuits

S. No.	Topics	Chapters
		Classification of ground ores, various types of classifiers, classifier performance, classifier efficiency
2	Ore processing by physical beneficiation	Principles of physical beneficiation of ores, qualitative and quantitative separation efficiencies, metallurgical accounting methods applicable to ore processing
		Gravity separation using the differences in specific gravities of mineral constituents, flow of particles in fluid medium, free and hindered settling, terminal velocity
		Introduction to various gravity separators, such as jigs, shaking tables, spiral concentrators, FLOATEX separators
		Electrostatic and high tension separation, the operating principle and applications in processing of atomic and strategic minerals, Froth flotation, basic principles, significance of surface properties in determining the floatability of heavier-than-water minerals, flotation equipment
		Magnetic separation, Principles of operation, magnetic separators Case studies with respect to processing of ores of atomic and strategic minerals such as those of uranium, beach sand minerals (thorium and zirconium), niobium-tantalum, tin, tungsten, molybdenum, cobalt etc
		Fine particles processing, challenges and techniques of separation, introduction to commercially available fine particle processing machines/techniques such as multi-gravity separator (MGS), Knelson concentrators, column flotation and other novel methods
3	Ore processing by chemical and bio-processing methods, hydro-metallurgical operations	Principles of leaching, acid and alkaline leaching, atmospheric and pressure leaching, factors affecting leaching behaviour
		Solid-liquid separation, various types of filters, filtration efficiency
		Hydrometallurgical unit operations, ion exchange, solvent extraction, principles of ion exchange and solvent extraction, process equipment to carry out these operations,
		Recovery of metals from the concentrated/purified solutions including precipitation
		Bio-processing of minerals, bacterial leaching, Case studies of flow sheets for processing uranium ores including those of Jaduguda, Narwapahar, Turamdih, Tummalapalle and Gogi
		Uranium recovery from secondary sources like phosphate ores, copper plant tailings and monazite
		Pilot Plant studies, scale-up and design of industrial size uranium recovery plants and project planning, management and execution
		Material and energy balancing. Process engineering, synthesis and flow sheet design.
4	Tailing processing, effluent treatment and disposal	Dewatering operations, thickening and drying and material handling.
		Significance of tailings and effluent processing in uranium ore processing Tailings neutralization, mine backfilling, tailings pond, fixing of deleterious heavy metal ions and radioactive ions, Bioremediation and impact analysis.

S. No.	Topics	Chapters
5	Lab	Size reduction of ores in laboratory ball and rod grinding mills. Screen analysis of ground ore, data presentation, by graphical methods using standard models and interpretation of data
		Settling characteristic for mineral particles in ground ore slurries and determination of parameters for dewatering of slurries
		Determination of Bonds Work Index in Ball mill, estimation of power requirement and sizing a mill for specific design specification
		Gravity separation of heavy minerals using spirals, jigs, shaking table, estimation of valuable mineral content, calculation of recovery and grade
		Magnetic separation of heavy mineral concentrates from beach sands on low and high intensity magnetic separators
		Froth Flotation of sulfide minerals, generation of kinetic curve of flotation determination of optimum grade and recovery from the graphical plots. Agitation chemical leaching of uranium ores by acid / alkaline leaching methods and computation of leachability.
6	References	1. Mineral Processing Technology, B.A.Wills, Pergamon Press, New York. 2. Introduction to Mineral Processing, Kelly and Spottiswood. 3. Chemical Engineering, Coulson and Richardson, Pergamon Press. 4. Mineral Comminution Circuits, T.Napier Munn, Univ. Of Queensland Press. 5. Hydrometallurgy, S.Venkatachallam. 6. Laboratory Experiments in Mineral Engineering, S.Venkatachallam and S.N.Degaleesan, Oxford & IBH. 7. Mineral Bio-processing, Smith and Misra, TMS. 8. Extractive Metallurgy of Uranium, R.C.Merrit. 9. Uranium Ore Processing, John W.Clegg and Dennis D.Foley, Addison-Wesley. 10. Significance of mineralogy in the development of flowsheet for processing uranium ores. Technical Reports Series. 196, IAEA, 1980. 11. Current practices for management and confinement of uranium mill tailings, Technical Report Series 335, IAEA, 1992.

Course No.: 209
Subject: Airborne geophysical methods

S. No.	Topics	Chapters
1	Introduction	Procedures for obtaining needed licenses for flying in an area
2	Survey	Survey design, and fixation of survey parameters- flight height, flight line spacing and direction, and selection of suitable

S. No.	Topics	Chapters
	designing and implementation	geophysical methods.
3	Airborne survey instruments	Magnetometer, Gravimeter, Electromagnetic system, Gamma Ray Spectrometer and their working principles.
4	Navigation aids-	DGPS, Radio-altimeter and Barometer. Types of platforms. Precautionary measures in flying – weak link mechanism, airworthiness of equipment.
5	Data acquisition	Selection of base frequency, pulse duration in case of EM methods, Sampling interval, format of output data. Types of noise in different sets of data. Quality control, data validation. Calibration procedures.
6	Processing of data	Application of attenuation coefficients, stripping coefficients, gridding, interpolation procedures, contouring
7	Presentation of data	Profiles, contour maps, images, ratio maps, conductivity –depth sections, DTM. Qualitative interpretation- Characterization of gravity and magnetic anomalies and delineation of lineaments, identification of structures
		Delineation of zones of anomalous distribution of radio-elements and identification of alteration zones. Marking positions of conductors and their extent.
8	Quantitative interpretation	Depth estimates using radially averaged spectrum of gravity and magnetic anomalies, Euler depth estimates. Forward and inverse modeling of different sets of data using available software. Modeling of conductors using plate model. Integration of various geophysical data sets and surface geological data in order to refine geological maps.
9	Tutorials	Quality control and validation of various data sets, Processing of radiometric, gravity and magnetic data, after applying the needed corrections, Presentation of data in the form of profiles, contour maps, images using available software. Qualitative interpretation to identify various litho-units and structural features. Computation of derivatives, analytical signal, Quantitative estimates using radially averaged spectrum, Euler depth estimates. Delineation of alteration zones, younger intrusive from processed radiometric data. Forward and inverse modeling of gravity, magnetic and electromagnetic data using available software. Preparation of a refined geological map after integrating various data sets.
	References	1. M.B. Dobrin and C.H. Savit, 1988. Introduction To Geophysical Prospecting, Mcgraw Hill. 2. L.L. Nettlton, 1976, Gravity And Magnetic In Oil Prospecting , Mcgraw Hill 3. W.M. Telford, L.P. Geldart and R.E. Sheriff, 1990, Applied Geophysics, Cambridge University Press. 4. I.V. Radhakrishna Murthy, 1998, Gravity and Magnetic Interpretation In Exploration Geophysics, Geological Society Of

S. No.	Topics	Chapters
		India, Bangalore. 5. B.S.R. Rao And I.V. Radhakrishnal Murthy, 1978, Gravity And Magnetic Methods Of Prospecting, Arnold-Henniman Pub. Co. 6. Parasnis, D.S. 1997, Principles Of Applied Geophysics. Chapman & Hall 7. Proceedings of Exploration 97: Fourth Decennial Conferrence on Mineral Exploration. Toronto 1997 Ed. A.G. Gubin 8. Proceedings of Exploration 07: Fifth Decennial Conferrence on Mineral Exploration. Toronto 2007 Ed. B. Milkcreit 9. Proceedings of International Conference on Airborne Electromagnetics, Sydney. Exploration Geophysics Vol 29 No. 1 & 2 1998 10. Electromagnetic Methods In Applied Geophysics. Applications Ed. Misac N Nabighian, Society Of Exploration Geophysicists 1992 11. Guidelines for Radioelement Mapping Using Gamma Ray Spectrometry Data. International Atomic Energy Agency, Technical Report July 2003.

Course No.: 210

Subject: Analytical techniques in geosciences

S. No.	Topics	Chapters
1	DC Arc spectroscopy	Dispersion of light - Basic operating principle, Dispersion devices used for spectral analysis, Prism and grating, Linear dispersion, Fundamental principles of prism dispersion, Deviation angle, Snellins – Descartes law, Prism dispersion , instrument main components, Littrow and Cornu prisms
		Optical spectra - classification of spectra, structure of line spectra, Instrumentation, Overall arrangement, Arc and spark discharge, Electrodes
		Sample preparation - General aspects, Sampling and preparation of non conducting solid substances, Spectroscopic buffer
		Behavior of elements in an arc discharge
		Simultaneous multi element analysis, Method development, Major and minor element analysis, Trace element analysis, Photo plate detection
		Measurement of the intensity of spectral lines, Straightening of the characteristic curve, Determination of the density of spectral lines, Semi quantitative/ quantitative reconnaissance analysis
	Lab	Sample preparation-weighing-filling of standards and samples in electrodes; arcing; photo plate

S. No.	Topics	Chapters
		development-computation-reporting
2	X-Ray Diffraction	Principles and methods of X-ray diffraction, Preparation of different types of geological samples for XRD studies
		Use of search-match methods for identification of primary and secondary uranium and associated minerals
		Use of search-match methods for identification of rare metal and rare earth and related minerals
		Use of search-match methods for identification of iso-structural, metamict and clay minerals
		XRD techniques for determination of unit cell parameters of atomic minerals
	Lab	Sample preparation-sample diffraction-data output-search and match method-study of diffractogram-identification of minerals-reporting
3	Electron Microprobe (EMP)	X-ray generation by electron bombardment of a sample, the detection of x-rays by WD Spectrometers, qualitative microanalysis
		Standards-based quantitative WDS microanalysis, detection limits, precision and Accuracy, methods for assessment of data quality
		technique of electro microprobe Analysis, imaging, qualitative and quantitative data acquisition, Processing & documentation
	Lab	Sample preparation and operation of EPMA Instrument for both qualitative and quantitative microanalysis.
4	X-ray fluorescence Analysis (XRF)	Qualitative and quantitative rock analyses; Standards-based quantitative WDS XRF analysis; detection limits, precision and Accuracy
		methods for assessment of data quality
		technique of XRF [WDS & EDS] Analysis, qualitative and quantitative data acquisition, data Processing and documentation.
	Lab	Sample preparation and operation of WDS XRF Instrument for both qualitative and quantitative analyses of major and minor elements, in major rock types
5	Chemical Analysis	Introduction to chemical analysis/characterization of geological materials
		Whole rock analysis - Major, minor, trace and ultra trace analysis; Sample types
		Conventional and Modern instrumental analytical techniques
		Sample preparation - Solid sampling, Solution methods for rocks, soils, water, minerals and concentrates, HF & other mineral acid dissolutions(open & closed), Fusions & fluxes
		Field measurements - pH, conductivity, TDS, Eh and Titrimetry for anions, ferrous etc
		Optical emission techniques - Flame Emission - theory, instrumentation, merits, limitations & applications

S. No.	Topics	Chapters
		Fluorimetry - Laser & Pellet methods, theory, instrumentation, merits, limitations & applications
		Atomic Absorption Spectrometry - Flame Hydride Generation and Electro thermal - theory, instrumentation, merits, limitations & applications
		UV-Visible Spectrophotometry - theory, instrumentation, merits, limitations & applications
		ICP-AES - theory, instrumentation, merits, limitations & applications
		ICP-MS - theory, instrumentation, merits, limitations & applications
		Data Quality Assurance - Errors - types, minimization
		figures of merit like accuracy, precision; standard reference materials, statistical criteria for accuracy, precision.
	Lab	Sample solution preparation for Whole rock analysis, beach minerals, niobate-tantalate
		Determination of uranium in water samples by laser fluorimetry using Scintrex analyzer and solid samples by pellet fluorimetry
		Determination of Na, K by flame photometry and Si, Ti, P by Spectrophotometer
		Determination of Fe, Mn, Al, Cu, Co etc. by FAAS
		Determination of rare earths etc. by ICP-AES; Analysis of hydro-geochemical samples for major cations & anions
6	Geochronology and Isotope Geochemistry	K-Ar system, Rb-Sr system, Sm-Nd System, U-Th-Pb System, Zircon Dating, U-Decay Series Dating, Other Decay Systems
		Analytical Methodology Radiogenic Isotope Geochemistry
		Radiogenic Isotope Geochemistry of the Mantle, Isotopic Evolution of the Mantle and models, Isotope Geochemistry of the Continental Crust
		Isotope Geochemistry of Subduction Zone
		Magmas Stable Isotope Geochemistry
		Stable Isotope Theory - Equilibrium Fractionations, Kinetic Fractionation and the Hydrologic Cycle Isotope Fractionation in the Biosphere
		Stable Isotope Applications - at High Temperatures, Oxygen Isotopes as An Indicator of Assimilation
		High Temperature Applications in Subduction zones, Hydrothermal Activity, Metamorphism, and Ore Deposits
	Lab	Sampling and sample preparation; Sample dissolution techniques and ion exchange separation for Rb/Sr, Sm/Nd, U and Pb
		Isotopic analysis using TIMS; Stable Isotope (C,S and O) analysis using IRMS

S. No.	Topics	Chapters
	References	1. The Powder Method in X-Ray Crystallography by Leonid V. Azaroff and Martin J. Buerger, McGraw-Hill Book Company, Inc., New York, U.S.A. 2. X-Ray Diffraction Methods by E.W. Nuffield, John Wiley & Sons, Inc., New York, U.S.A. 3. Elements of X-Ray Diffraction by B.D. Cullity, Addison-Wesley Publishing Company, Inc., Massachusetts, U.S.A. 4. X-Rays in Theory and Experiments by H. Compton & S.K. Allison, D. Van Nostrand Company, Inc., New Jersey, U.S.A. 5. X-Ray Diffraction Procedures by H.P. Klug & L.F. Alexander, John Wiley & Sons, New York, U.S.A.. 6. Mika, J., and Torok, T (1974): Analytical emission spectroscopy. London Butter worths. pp 529 7. Torok, T., Mika J., and Gegus, E., (1978): Emission spetrochemical analysis., Adam Hilger, London pp. 692. 8. Willard, H.H., Merritt, L.L., Dean, J.A. (1965): Instrumental methods of analysis, affiliated East West press pvt. ltd. 4th edition pp 784 9. Brode,. W.R. (1958) Chemical spectroscopy. Johnwiley & Sons pp. 677 10. ASTM committee E-2 (1982) Methods for emission spectro chemical analysis pp.1098 11. Winefordner, J.D., (1972) Trace analysis, spectroscopic methods for elements. Johnwiley & Sons pp 484.Pott, P.J.- A handbook of silicate rock analysis, “arc and spark source optical emission spectrometry”, chapter-6 . Blackie – pp.198-212. 12. Goldstein, J., Newbury, D., Joy, D., Lyman, C., Echlin, P., Lifshin, E., Sawyer, L. and Michael, J., 2003. Scanning Electron Microscopy and X-Ray Microanalysis 3rd Ed. Kluwer Academic/Plenum Publishers. 13. Reed, S.J.B., 2005. Electron Microprobe Analysis and Scanning Electron Microscopy in Geology 2nd Edition. Cambridge University Press. 14. Faure, Gunter and Mensing, Teresa. Isotopes: Principles and applications, 3rd edition. John Wiley. 15. Dickin, Alan P. Radiogenic Isotope Geology, Cambridge university press, 1997 16. Faure, G and Powell, J.L. Strontium Isotope Geology, Springer Verlag, 1972. 17. DePaolo, Donald, J. Neodymium Isotope Geochemistry, Springer Verlag, 1988 18. Aggarwal, S.K. and Jain, H.C. (Eds.) Introduction to mass spectrometry, 1997 19. Hoefs, J. Stable Isotope Geochemistry, 4th edition, Springer Verlag

Course No.:
Subject: Borehole Logging methods

S. No.	Topics	Chapters
1.		Objective, Basic concepts- Archie's equation, Humble's equation, borehole conditions, Principles, operational procedures, equipment, applications of various well logging techniques
		Self-Potential Logging.- Sources for S.P. Use of Self Potential Logs for Oil exploration Shale base line, Sand base line Interpretation of SP logs Use of Self Potential Logs for mineral exploration
		Single point resistance log
		Resistivity Logging - Normal resistivity logging Lateral resistivity logging Microlog resistivity logging Focussed –current logging Induction logging
		Interpretation of logs
		Sonic Logging -Elastic waves in boreholes Estimation of porosity. I.P. Logging
		Nuclear Logging Nuclear Processes Gamma Ray Logging Neutron Logging, Pulsed neutron logging. Magnetic Susceptibility Log
		Nuclear Magnetic-Resonance Log. Borehole gravity log. CalliperLog
		Qualitative and quantitative interpretation of well logs. Determination of reservoir parameters. Delineation of lithology and fractures from logs
		Saline water-fresh water interface from log data. Applications. Field examples.
2.	Lab	Computation of normal and lateral log responses. Identification and delineation of sub-surface formations from well log data. Calculation of formation factor, porosity, permeability, resistivity, fluid saturation, correlation of rock units. Saline water-fresh water interface rom log data.
3.	References	1. O.Serra, 2003. Well Logging And Geology, Technip, Paris 2. O. Serra, 1984. Fundamentals of Well Log Interpretation, Elsevier. 3. R.M. Bateman, 1985, Open Hole Log Analysis And Formation Evaluation, Reidel, Dordrect. 4. G. Asquith and C. Gibson, 1982. Basic Well Log Analysis for Geologists, Academic Press, London.

Course No.: 212
Subject: Nuclear Reactor: Theory, Types and Nuclear Fuel Cycle

S. No.	Topics	Chapters
1	Introduction	The need for nuclear energy, power scenario in India, Atomic Energy establishments in India and programmes of DAE.
2	Nuclear reactor theory and types of reactors	Scientific fundamentals of fission and fusion processes and resultant release of energy
		Interaction of sub-atomic particles and ionization radiations with matter
		Nuclear structure and functions of the reactor systems
		Various types of reactors
		Moderator and coolant
		Typical reactor control system
		Steady and dynamic behavior of reactors
		Requirements of safety systems in nuclear power plants
2	Nuclear Fuel Cycle	Nuclear fuel cycle options for PHWR, BWR, PWR and FBR: Nuclear materials, Nuclear fuel cycle in India, specifications of fuel
		Mining, processing, enrichment, manufacturing, usage and burning of fuel
		Quality control aspects
		Storage and safe transportation of spent fuel bundles
		Nuclear fuel enrichment; fuel reprocessing ; generation and management of radioactive wastes
3	Environmental issues	Need for environmental protection
		Indian legislation and controls related to environment, environmental impact assessment clearances related to setting up of a nuclear power plant and its operation
		Environment survey requirements
	References	1. P.D. Wilson (Editor) 1996, The Nuclear Fuel Cycle from Ore to Wastes, Oxford University Press. 2. C.K. Gupta (1989) Materials in Nuclear Energy Applications, volume 1 & 2, CRC Press, Inc. USA. 3. D. Bhaskar Rao (Editor) 2001, Nuclear Materials Issues and Concerns, Volume 1 & 2, Discovery Publishing House, New Delhi. 4. Lawrence Berkeley National Laboratory, university of California, Geological Problems in Radioactive Waste isolation; A World Wide Review (Proc. 28th Int. Geological Congr. Washington, DC, 1989), Lawrence Berkeley Natl Lab. Berkeley, CA (1991). 5. International Atomic Energy Agency, Radioactive Waste Management: An IAEA Source Book, IAEA, Vienna (1992).

S. No.	Topics	Chapters
		6. International Atomic Energy Agency, Report on Radioactive Waste Disposal, Technical Reports Series procedures, Preparation of MT master curves , Detectability and resolution studies in electrical and EM methods. References: 1. Dobrin, M.B 1984, An Introduction To Geophysical Prospecting. Mcgraw Hill, New Delhi. 2. Telford W.M., Geldart L.P., Sheriff, R.E. And Keys D.A. 1976, Applied Geophysics By Oxford And LBH Publishing Co. Pvt., Ltd., New Delhi,. 3. Parasnis, D.S. 1997, Principles of Applied Geophysics. Chapman & Hall. 4. Sumner, 1976, J.S Principles Of Induced Polarisation For Geophysical Exploration.. Elsevier. 5. Philip Kearey, 2007, An Introduction To Geophysical Exploration. 6. Michael Brooks, Ian Hill Blackwell. 7. Electromagnetic Methods in Applied Geophysics. Applications Ed. Misac N Nabighian, Society Of Exploration Geophysicists 1997 8. Proceedings of International Conference On Airborne Electromagnetics, Sydney. Exploration Geophysics Vol 29 No. 1 & 2 1998 9. Proceedings of Exploration 97: Fourth Decennial Conferrence On Mineral Exploration. Toronto 1997 Ed. A.G. Gubin 10. Proceedings Of Exploration 07: Fifth Decennial Conferrence On Mineral Exploration. Toronto 2007 Ed. B. Milkcreit 11. Appliciations Of Transient Electromagnetic Techniques Technical Note Tn 7 Geonics Limited, Canada 1980 12. Overvoltage Research and Geophysical Applications. Ed J.R. Wait. Pergamon 1959

Course No.: 101 & 201
Subject: Basic Mathematics for Geoscientists I and II

S. No.	Topics	Chapters
1	Basic mathematical concepts	Concepts of a Set, Functions and Relation
		Graphs of Functions,
		Trigonometric Functions, Basic Trigonometry
		Hyperbolic Functions and summation of Trigonometric series

S. No.	Topics	Chapters
		De Movire’s Theorem
		Mathematical Induction
		Quadratic Equations
		Permutations and Combinations,
		Binomial Theorem
		Concept of a Sequence, Series
		Exponential, Logarithmic and Power series
		Convergence, Divergence tests
		Equations of Lines and Circles in 2-Dimensional Geometry and Basics of 3-D Geometry Spheres, Cones, Cylinders
2	Calculus	General, Limits and Continuity
		Differentiation- Basic concepts
		Curve stretching, Maxima and Minima
		Exponential functions and Exponential models
		Differentiation of Trigonometric
		Logarithmic and Exponential Functions
		Integration- Basic Concepts
		Indefinite and Definite Integrals ,Area and integration, Numerical Integration
		Ordinary differential equations- First Order Equations,
		Homogeneous and Non homogeneous equations
		Multiple Integrals
		Functions of several variables
		Double integral, Limits at infinity and Improper Integrals
3	Matrices	Concept of Matrix, matrix operations, determinant,
		Inverse of a Matrix
		Orthogonal Hermition, skew-Hermition and unitary matrices,
		rank Solution of simultaneous equations, quadratic forms
		Linear dependence and independence of vectors

S. No.	Topics	Chapters
		Linear and orthogonal transformations
		Eigen values and Eigen vectors
		properties of Eigen values, Caley-Hamilton theorem
4	Numerical methods	Solution of non-linear algebraic and transcendental equations
		Newton-Raphson, iterative, false position and bisection method
		Generalized Newton's method for multiple roots
		Numerical intergration by Taylor series
		Finite difference operators and their relations
		Factorial notation of a polynomial, data smoothing
		Newton-Gregory and Lagrange's interpolation formulae
		Inverse interpolation by Lagranges and interactive methods
		Numerical differentiation and integration – trapezoidal
		Simpson and Weddle rules, Gaussian quadrature formula
		Matrix and system of linear equation- Pivoting, Triangular factorisation, eigen value problem solving
5	Statistical concepts	Concept of frequency distribution, moments, skewness and kurtosis
		Probability- various approaches of probability- classical, frequency, statistical, subjective and axiomatic, theorems on probability, conditional probability, Independence
		Bayes theorem random variable – discrete and continuous
		Distribution functions and their properties
		Central tendency, probability mean and density function
		Mathematical expectation / moment generating function and its properties
		Probability distribution,Bernoulli's, Binomial
		Poisson and Gaussian distribution Theory of least squares and curve fitting
		Regression Analysis Variance, SD,Covariance
		Correlation – regression lines, regression coefficients Test of significance, normal test, t-test, Chi-square test and f-test
		Filters and smoothening functions
		Moving Averages, Kriging

S. No.	Topics	Chapters
		Trend surfaces Distribution of points, Contouring, Splines, Semi variograms Discriminant functions, Cluster analysis, Eigen values and Eigen vector methods
		Methods of Factor analysis – Prinicpal component analysis

Course No.: 106

Subject: Surveying, Drilling and Mining

S. No.	Topics	Chapters
1	Surveying	Types of surveys and applicability
		Principles and methods of surveying & mapping
		Surveying Equipment – Compass, The Transit, Optical Distance Measuring
		Modern surveying electronic equipments - Digital levels, Digital theodolites, EDMs and Total stations
		Principles, working and applications
		Survey Methods - Co-ordinate methods, Bearings, Traversing and Trilateration (Topo)
		Detail Survey, Orientation and position, Determination of True bearing, Horizontal and vertical control, Accuracy standards;
		Positioning – Introduction, Differential positioning,
		GPS instruments, Global Positioning Augmentation Systems; Errors in measurements – Blunders, Systematic errors, Random errors, Most probable value, Average error, Standard deviation
		Analysis and adjustment of measurements
		Distribution, Adjustment of errors by Approximate method and Least squire method
		Coordinate System in Geodesy - Geocentric Cartesian Coordinates, Topocentric Cartesian or local geodetic Cartesian Coordinates, Geodetic Coordinates, Planimetric Cartesian coordinate
		Datums - Horizontal datums - Everest spheroid, WGS – 84, datum transformation; Vertical datums - Mean Sea Level, Geoid, EGM 96
		Projection – Polyconic projection, Traverse Mercator projection (TM Projection), Universal Transverse Mercator Projection
	Tutorials	Adjustment of instrument errors by approximate method and Least square method. Datum transformation exercises.
2.	Drilling	History of Drilling; Methods of soil sampling - Auger, Drive sampling;
		Rock Drilling – Percussive, Attritive, Rotary Cutting, Shearing etc.,

S. No.	Topics	Chapters
		Rotary reverse circulating, Rotary with down hole motors, Cable tool method;
		Diamond Drilling - Diamond quality, types of diamond bits, natural and synthetic diamonds, Rotary core drilling equipment, Drilling standards, circulating media, Drilling fluid properties
		Controlled Directional Drilling - Deviation in drilling, Measurement of deviation and control, Tools for directional drilling, Downhole motors
		Various types of drills in use in AMD
	References:	1.Drilling Technology by C.P. Chugh 2.Drilling Technology Part 1 & 2 by British Drilling Association 3.Thomas, L.J. An Introduction to Mining, Methuen, Brisbane, 1978. 4.Sinha, R.K. and Sharma, N.L. An Introduction to Mineral Economics, Wiley Eastern, 1993. 5.Chatterjee, K.K. An Introduction to Mineral Economics, Wiley Eastern, 1993.
3.	Mining	Introduction to Mining
		Mining Terminologies
		Types of mining
		Techniques in Open Cast mining
		Techniques in Underground Mining
		Stages of mine development
		Blasting technique
		Economic feasibility studies andMining, milling and waste disposal etc.

BARC TRAINING SCHOOL

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SYLLABUS OC: 2019-20

CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (CHEMICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Computational fluid Dynamics and Heat Transfer	CEM:E 21:CM-40	40	5	150
2	Basic Process Instrumentation and Control	CEM:CC03-M - 20	20	3	75
3	Process Dynamics and Control	CEM:E31 E29:50	40	5	150
4	Advanced Mass Transfer, Solvent Extraction and Equipment Design	CEM-04:E32 AC03:C 45	45	6	200
5	Process Modeling, Simulation and Optimization	CEM-5:E 33:C20	20	3	75
6	Advanced Chemical Reaction Engineering	CEM:E 30:C-25	25	3	100
Core Total			**190**	**25**	**750**

ELECTIVES (CHEMICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Electrical Engineering Practices in Process Industries	CElect:FC09:E -20	20	2	75
3	Energy Conservation and Demand side Management	CElect:AC07-CMI-20	20	2	75
4	#Vacuum Technology/ Statistics for Engineers/ Corrosion Engineering/ Design of Experiments for Chemical Engineers	CElect :M-13 :New-C-20 CElect 10:New M C:20 CElect : C	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**520**	**62**	**2100**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (1/150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2725**

ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (ELECTRICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Applied process Instrumentation	CEM :E 50:CEEI-45	45	6	200
2	Programmable Logic Controllers and Applications	CEM:EEI-40	30	4	125
3	Electrical Engineering Practices-I	AC13:E-30	35	5	125
4	Electrical Engineering Practices-II	EEP-II: E:20	30	4	100
5	Networking Communications	CEM-9:E61: Etrn-I-20	20	3	75
6	Modern Electronic Control of AC and DC Drives	CEM:JNTU:30	25	3	125
Core Total			**185**	**25**	**750**

ELECTIVES (CHEMICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Electrical Engineering Practices in Process Industries	CElect:FC09:E -20	20	2	75
3	Energy Conservation and Demand side Management	CElect:AC07-CMI-20	20	2	75
4	Industrial Instrumentation and Human Machine Interface	CElect 17:E581 E:50:I-30	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**515**	**62**	**2100**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce **(2/150);** Practical **(1/150);** Project **(12/200);** Internal Assessment (125)	15	625

Grand Total	**77**	**2725**

ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (ELECTRONICS)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Applied process Instrumentation	CEM :E 50:CEEI-45	45	6	200
2	Programmable Logic Controllers and Applications	CEM:EEI-40	30	4	125
3	Embedded and Computer based System Design	CEM:E 54:Electrn-40	40	5	150
4	Digital Signal, Image Processing & Machine Vision	CEM :NEW	30	4	100
5	Networking Communications	CEM-9:E61: Etrn-I-20	20	3	75
6	Modern Electronic Control of AC and DC Drives	CEM:JNTU:30	25	3	125
Core Total			**190**	**25**	**775**

ELECTIVES (ELECTRONICS)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Mechatronics / Robotics	CElect AC14:EEMI :20 CElect:MI-14:New-EC:20	20	2	75
3	Modern Control Systems	CElect:E52A-EC -20	20	2	75
4	Industrial Instrumentation and Human Machine Interface	CElect 17:E581 E:50:I-30	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**520**	**62**	**2125**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (1/150); Project (12/200); Internal Assessment (125)	15	625
Grand Total	**77**	**2750**

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (MECHANICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Computational fluid Dynamics and Heat Transfer	CEM:E 2l:CM-40	40	5	200
2	Basic Process Instrumentation and Control	CEM:CC03-M - 20	20	3	125
3	Pressure Vessel and Piping Design	CEM-13:E 20 CC08:M-30	30	4	150
4	Engineering Design and Finite Element Methods	CEM:AC09	45	6	100
5	Computer Aided Design and Manufacturing	CEM-14: M-35	35	3	75
6	Vibrations	C EM :E26: M:20	20	3	125
Core Total			**190**	**25**	**775**

ELECTIVES (MECHANICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Mechatronics	CElect AC:14:EEMI :20	20	2	75
3	Welding and Quality Assurance of Welds	C-Elect :CC06-M-20	20	2	75
4	#Vacuum Technology / Manufacturing and Industrial Engineering/ Design of High Temperature Components / Statistics for Engineers	CElect :M-13 :New-C-20 C-Elect-JNTU,M -20 CElect 11:New Mech-20 CElect 10:New M C:20	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total		**520**	**62**	**2125**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (11150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2750**

QUALITY ASSURANCE ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (QUALITY ASSURANCE)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Statistical Quality Control for QA	CEM:QA-01	30	4	100
2	NDT and QC of Nuclear Fuel and Structural components	CEM:QA-02	40	5	150
3	Design of PHWR Fuel and Structurals	CEM:QA-03	30	4	100
4	Engineering Design and Finite Element Methods	CEM:AC09	45	6	200
5	Materials Characterization and Applications	CEM:EN713	35	3	100
6	Basic process instrumentation and control	CEM:CC03-M - 20	20	3	100
Core Total			**190**	**25**	**750**

ELECTIVES (QUALITY ASSURANCE)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Corrosion Engineering	CElect : C	20	2	75
3	Image Processing and Machine vision	CElect:EN-710	20	2	75
4	# Data Base Management System and Web Technology / Advanced Computational Techniques	CElect:EN-705 CElect:EN-701	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**520**	**62**	**2125**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (11150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2750**

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Project Work	**Code:** P-NFC-BARC-01
Discipline: Chemical, Electrical, Mechanical and Quality Assurance	**No. of Lectures: 175**

Following Placement in various DAE Units, the Trainee Scientific Officers will carry out project work at their respective places of posting under the guidance of their Reporting officers, on a well-defined project/problem for a period of 7-8 weeks. The Project work will commence immediately after the Placement Committee meeting leading to the placement of TSOs in various DAE Units. The TSOs shall submit a project report at the end of the project duly certified by the project guide.

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General Lectures

1) Series of Invited Lectures by Eminent Speakers on various programmes of DAE (about 4-6 talks to be arranged during the year)

2) Lectures on

   a) Public Speaking & Presentation Techniques (2 Hrs)
   b) Administrative Procedures (2 Hrs)
   c) Vigilance & Service Conduct Rules (2Hrs)
   d) Financial & Accounts Procedures (2 Hrs)
   e) Purchase Procedures (2 Hrs)
   f) Contract/Works Procedures (2 Hrs)
   g) Role of Official Language In Central Government Offices (2Hrs)
   h) Fire Safety (2 Hrs)
   i) Security (2 Hrs)

Nuclear Engg. Module

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Syllabus

Subject: Engineering Mathematics	**Code: E01 E02-CMEI-30**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 30**

Part – A

Overview of arithmetic errors in computations
Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
Linear systems solutions by direct methods, iterative methods and acceleration techniques.
Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
Linear systems: Eigen values.
Non -Linear systems: Newton-Rapson & Successive Approximation methods
Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

Part - B

Finite Difference Approximation in 1-D and 2-D
Solution of steady and unsteady heat conduction equations
Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
Response Surface Method 2K+1, factorial design, 3k factorial design
Monte Carlo Method
Artificial Intelligence and Genetic Algorithm
Artificial Neural Network
Gram-Schmidtt Orthogonalization
Transformation of matrix
Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.

Reference Books

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.

Contd....

9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.
19. Ramana,B.V., "Engineering Mathematics", McGraw Hill, 2006
20. Desai& Abel, " Introduction to the finite Element Method: QA numerical Method for Engineering Analysis", CBS, 2002
21. Grewal, B.S. and Grewal, J.S., "Higher Engineering Mathematics" , 39th Edition, Khanna Publications, 2005
22. George F Simmon & John S Robertson, "Differential Equations with Applications and Historical Notes", 2nd Edition, Tata McGraw Hill, 2003

BARC Training School
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Syllabus

Subject: Nuclear and Reactor Physics	**Code: NE 2-E07 -CMEI-45**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 35**

NUCLEAR AND REACTOR PHYSICS (35)

1. **Properties of Nuclei:**
    - Binding energy-formula and interpretation, nuclear forces, nuclear structure.
2. **Fission process:**
    - Fission rate and reactor power
    - Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
    - Fissile, fertile and fissionable materials
    - Fission product activity after shut down –decay heat.
3. **Interaction of Neutrons with Matter**
    - Production of neutrons
4. **Concept of microscopic cross section:**
    - Inelastic and elastic scattering
5. **Variation of cross-section with energy**
    - Fast, resonance and thermal ranges
    - 1/v law of neuron cross-section
    - Resonance absorption, Doppler effect.
    - Eta vs E curve conversion & breeding concept
    - Thorium utilization
6. **Diffusion of Neutrons**
    - Fick's law and its validity
    - Steady state neutron diffusion equation
    - Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.
7. **Chain Reaction**
    - Four Factor formula
    - Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
    - Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,
8. **Slowing Down Process**
    - Neutron slowing down
    - Slowing down power/ moderating ratio of moderators
    - Slowing down with spatial migration
    - Fermi age concepts, migration length
    - Multi zone reactors
    - Ideas of reflectors/blankets, reflector savings, form factor.

Contd…

9. Heterogeneous Reactors

- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

10. Reactor Kinetics

- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

11. Core Burn Up

- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

12. Neutron Poisons

- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

13. Reactivity Coefficients

- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Reference Books:

1. S Glasstone and M C Edlund, "Elements of Nuclear Reactor Theory", Van Nostrand, 1952.
2. K S Ram, "Basic Nuclear Engineering", Wiley Eastern, 1977.
3. J R Lamarsh, "Introduction to Nuclear Reactor Theory", Addison Wesley, 1960.
4. S Glasstone and S Sesonske, "Nuclear Reactor Engineering", Van Nostrand, 1963.
5. A M Weinberg and E P Wigner, "Physical Theory of Neutron Chain Reactors", Chicago University Press, 1958.
6. H S Isbin, "Introductory Nuclear Reactor Theory", Reinhold Publishing Corp., NY, 1963.
7. P P Zweifel, "Reactor Physics", McGraw Hill, NY, 1973.
8. R V Meghreblian and D K Holmes, "Reactor Analysis", McGraw Hill, 1960
9. Suresh Garg, Feroz Ahmed & L. S. Kothari, "Physics of Nuclear Reactors", Tata McGraw-Hill,1986.
10. Weston M. Stacy, "Nuclear Reactor Physics", John Wiley & Sons, Inc.
11. Ronald Allen Knife, "Nuclear Energy Technology – Theory and Practice of commercial Nuclear Power", Hemisphere Publishing Corporation.
12. Cohen Bernald, "Concepts of Nuclear Physics", McGraw Hill, 2002
13. Kaplan Irving, "Nuclear Physics", 2nd Edition, Narosa Publications, 2002

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Reactor Engineering & Radiation Shielding	**Code: NE 03-E 13-CMEI -30**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 30**

Introduction to reactor system & Indian Nuclear power programme; station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems, classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR, AGR, HTGR, AHWR etc,.), Fast reactors; Research reactors (CIRUS, DHRUVA etc.) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.

Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems. Heat flow & temperature distribution in plate & solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example. **(10Hours)**

Brief description of various types of fuel; metallic (DHRUVA, CIRUS) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; heat and mass balance in a BWR; boiling height in a BWR core; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pr, temp) in various reactors.

Nuclear Fuel Cycle:
Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
Global options of fuel cycles; Issues related to Resources, Long-lived radioactive waste, Proliferation, and Advanced Technologies.
Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle, Thorium utilization; Indian capabilities in: managing nuclear waste, long lived radio active waste and fuel cycle technologies.
Advanced fuel cycles; Role of ADS. **(10 Hours)**

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Radiation Shielding

Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors. **(10 hours)**

Reference Books:

1. Introduction to Nuclear Reactor Theory - J.R. Lamarsh, Wasley Reading Mass.
2. The Technology of Reactor Safety, Vol. 1 & 2 - T.J. Thompson & J.G Backerley, Eds., M.I.T. Press.-Cambridge, Mass.
3. Nuclear Reactor Engineering - S. Glasstone & A. Sesonske, D. Van Nostrand Co. Princeton, New Jersey.
4. Engineering Compendium on Shielding - Vol.1, II & III- R.G. Jaeger, Editor-in-chief, Sponsored by International Atomic Energy, Vienna.
5. Reactor Shielding Design Manual - Theodore Rockwell III.
6. Indian Nuclear Society(INS), "Nuclear Technology Challenges in 21st Century:12th Annual Conference of INSAC-2001", INS Publications, 2001
7. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor Design Basics", 4th Edition, Vol.1, CBS, 1998
8. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor System Engineering", 4th Edition, Vol.2, CBS, 1998

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Health Physics, Chemical Plant Safety And Environmental Engineering	Code: NEM - FC02, E06, CC09-CMEEI-25
Discipline: Mechanical, Chemical, Electrical Electronics and Instrumentation Engineering	**No. of Lectures: 30**

Health Physics (8 Lectures)
Radiation Sources, Quantities & Units: Natural & Technologically enhanced radiation sources, Radiometric quantities, Interaction coefficients, Dosimetry, Radioactivity, Exposure-dose relationship. Calculation of dose from alpha, beta, gamma & neutron sources.

Fundamentals of Radiation Protection: Objectives of radiation protection, ICRP system of dose limitation, radiation protection standards, annual limit of intake, derived air concentration. Exposure and absorbed dose, equivalent dose, effective dose and their units (old & new), Limits of intake for radio nuclides including radon, accidental & emergency exposure, Atomic Energy Act, Radiation Protection Rules, Safety organization, Regulatory aspects of radiation protection.

Non- stochastic or immediate effects: Acute radiation sickness - LD 50 / 60, radiation effect on gonads, blood & blood, storming organs, lung, thyroid & skin.
Stochastic or Delayed effects: Cancer, life shortening linearity of dose effect:
Effects on embryo & foetus, genetic effects, doubling dose. Human data for calculating risk coefficients.

Operational Radiation Protection: Modes of exposure, Exposure control.
1.External: time, distance & shielding
2.Internal: containment, ventilation, plastic suits, respirators. Design of hot laboratories, zoning of areas, personal control, medical control, concept of controlled area, supervised area, radiation protection procedures, special work permit, barrier rubber stations.
Radiation Protection Monitoring: Work place monitoring for external radiation levels, air born contamination, surface & personnel contamination, monitoring instruments, collection of air & swipe samples & their counting, Individual monitoring of external exposure - TLD, film badge, monitoring for internal exposure - whole body counting, bioassay, dose records, collective dose equivalents. Radiation emergency; onsite and offsite procedure of handling emergencies, early phase, intermediates, late phase and counter measure.

Industrial Safety (8 Lectures)
Introduction: Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques
Hazards due to physical agents: UV and IR radiation, Lasers, Microwave radiation; noise, heat
Chemicals hazards: Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals
Evaluation: Instrumental methods, air sampling methods, liquid effluent monitoring
Occupational exposure limits: Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50
Handling, storage and control: Engineering control measures and safety features, Safety management techniques such as safety audit, Personal/ administrative control, and Medical control
Fire and explosion hazards: Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits, USNFPA Classification of Flammable/combustible liquids: flammable gases; Engineering safety for prevention of fire and explosion, Hazard area classification, selection of equipment, detection and extinguishing systems

Contd….

Hazard identification, assessment and control: Hazard identification: Concept of risk and Risk management; Formal methods of hazard identification and assessment: Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies, Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation. Specific hazards in HWPs and various facilities of NFC. Area classifications for hazardous chemicals, types of protection & Protective equipments. Safety work permit system

Management of major hazard Installations: (6 Lectures) Plant Layout and Engineering Design Considerations, Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic. Releases, Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment, Emergency Planning Guidelines, Development of On-site & off site emergency preparedness plans

Health and safety regulatory aspects: Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate. EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

Environmental Engineering & Environment Protection: (8 Lectures)
PRINCIPLES: Population, economic growth, industrialization, urbanization and energy-use, as causes of environmental pollution. Application of environmental principles (technical and non-technical) to: water resource management, water and wastewater treatment, air pollution control, solid waste management, environmental impact assessment, and environmental ethics. Thermal pollution, noise pollution, greenhouse effect, acid precipitation, ozone depletion, air toxics, and ground-level ozone and fine particulates (photochemical smog). Sustainable development, life cycle analysis, and principles of environmental quality objectives, standards and guidelines.

Environment Impact assessment, various effluents generated from HWPs & NFC and their treatment methods strategies, Limiting concentration of pollutants and pollution control measures. MSDS, toxic releases; Emission & dispersion

Reference Books:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.
10. Source Book of Atomic Energy - Gtasstone
11. Introduction to Atomic & Nuclear Physics H. Semat & J.R. Atbright
12. Introductory Nuclear Physics - D. Haliday
13. Introduction to Nuclear Physics & Chemistry G.G.Harvey
14. Nuclear Physics - 1.Kaptan
15. Nuclear Radiation Detection - W.J. Price
16. Perspectives of Modern Physics - A. Beisser.
17. Radiation Detection & Measurement - G.F.KNOLL.
18. Principles of Instrumental Analysis (2nd Ed.) - D.A. Skoog & D.M. West
19. Atomic and Nuclear Physics - K. Gopalakrishnan.
20. Goel P.K., "Advances in Industrial wastewater Treatment", ABD Publishers, 2005
21. Arvind, Goel P.K., "Industrial Environment & Pollution", ABD Publications, 2003
22. Masters, Gilbert M, "Introduction to Environmental Engineering & Science", 2nd Edition, Prentice Hall of India

BARC Training School
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Syllabus

Subject: Nuclear Power Plant Engineering	**Code: NE 05 -CMEI-30**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 30**

a) PHWRs (12 Lectures)

Description of schematic of NPP; siting requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building; Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting. Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.

Reactivity control mechanisms - Zone control / Regulating rods, Absorber rods and shim rods; Shut down System.

Fuel Transfer System.

Auxiliary systems - Ventilation, Annular gas, Process water & Fire water systems.

Secondary System - Description of flow sheet and major components, Comparison of operating conditions, Thermal Cycles and Major Components of thermal and nuclear units.

Power Plant Control and Instrumentation: Reactor Power control (neutronic and thermal signals), Coolant and Steam pressure control, Integration with grid for base load operation. Control and protection channels with typical examples.

Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system. Brief description of systems components like Bus bar, Switchyard, Circuit Breakers, Switchgear, Bus duct, Generator, Transformer, Cables and their selection, Layout and Scaling.

Nuclear Power Plant Safety: Design principles for providing nuclear safety :-Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

Safety Evaluation and Safety Criteria Description of Deterministic and Probabilistic approaches. Safety Monitoring of Operating Plants- IAEA Classification, NUSS Codes. Safety systems, Description of Safety Systems (shutdown system, ECCS, Containment and Engineered Safety Description of features) Exclusion Zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.

Description of a typical Design Basis Accident Scenario - build up event tree to describe sequential role of safety features. Broad description of TMI, Chernobyl accident, NAPS fire incident.

Advanced reactor concepts with passive safety features.

Nuclear Architecture: Design of integrated layout of Equipment, Piping, Electrical/ Instrumentation Cables etc. to provide Operation and Maintenance Convenience (to minimize man rem and meet safety objectives), Non propagation of incidents/ accidents.

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b) PWRs / BWRs (8 lectures)

Pressurized Water Reactors : Reactor pressure vessel and internals, reactor core and fuel, methods of reactivity control, reactor coolant system & equipments, pressurizer, Engineered Safety features, reactor auxiliary systems including turbine & generator.

Boiling Water Reactors; Introduction, reactor vessel and internals, neutron monitoring, reactor coolant recirculation systems including secondary steam, reactor protection system, turbine generator.

c) Fast Breeder Reactors (10 Lectures)

INTRODUCTION: Breeding, definition & reactions; Breeders as an Inexhaustible Energy Source; Fast reactors as breeders: Classification of power reactors; Characteristics & types of fast reactors: Comparison of some characteristics of fast and thermal reactors; Role of Fast Reactors in Indian Nuclear Power Programme.

Fuel: Fuel pin diameter, number of fuel pins per sub-assembly, reactivity worth of sub-assembly, Sub-assembly outlet temperature.

Shielding Principles: Special features of sodium cooled reactor shielding, reactor shielding, shield for activation products, shielding for fuel management.

Thermal analysis: Sodium heat transfer coefficient (empirical relation), calculation of temperature of fuel pin, hot spot analysis (brief outline).

Coolant for fast reactor: General requirements for fast reactors coolant; Comparison of various coolants & choice of sodium as coolant; Properties of sodium: Physical & chemical; Methods of sodium purification & purity control: Cold & hot traps; Oxide measuring & indicating devices.

Reference Books

1. WakiL M.EL, "Nuclear Power Engineering", McGraw - Hill.
2. Strosal and Vapet., "Power Plant Engineering & Economics".
3. Lews E.E., "Nuclear Power Reactor Safety", Wiley Inter Science
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von- Nostrand, 1981.
5. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors, Pergamon Press.
6. Yevick J.G., "Fast Reactor Technology", Plant Design, H.I.T, Press.
7. John R Lamarsh, "Introduction to Nuclear Engineering", Addison Wesley, 1975
8. Rajan Babu V, "Fast breeder Reactor"
9. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor Design Basics", 4th Edition, Vol.1, CBS, 1998
10. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor System Engineering", 4th Edition, Vol.2, CBS, 1998

BARC Training School
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Syllabus

Subject: Material Science In Nuclear Engineering	Code: NE 06 -CMEI-25
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	No. of Lectures: 25

Shri. Chittaranjan Das

Properties of Engineering Materials: (21 Lectures)
Metals, alloys, ceramics, metal cladding semiconductors, polymers, and composites. Mechanical properties and their evaluation as per ASTM or equivalent standards. Stress-strain diagram, Principle stresses, Biaxial stresses, creep, fatigue and fracture toughness. Material testing for tensile strength, hardness, fracture, creep, fatigue wear.
Material Processing: Metal forming, casting, cutting and joining: ASTM standards, quality control during processing.
Metallurgy of Steels: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, Austenitic and Martensitic S.S. Selection of Steel for hydrogen services, different types of corrosion aspects in heavy water plants (Ammonia based & Sulfide based); their protection method and the selection of structural material. Selection of steel for high temperature and radiation environment, Welding and heat treatment. Powder Metallurgy for fuel fabrication

Shri. R. Tewari

Nuclear Materials: Fabrication, properties and application of nuclear materials like Zircoloy, Zr-Nb alloys, Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and application.
Decontamination, radiolysis, specification for chemistry parameters in process systems of BWRs & PHWRs.

Shri. Kamalesh Chan.

Corrosion Engineering: Corrosion, activation of corrosion products.
Chemical properties: Oxidation, corrosion, gaseous corrosion, stress corrosion, corrosion prevention, chemical degradation.
Basic Corrosion principles, types of corrosion & their mechanism and prevention; Crevice corrosion, SCC, IGSCC and other under deposit corrosion, Electro- chemical corrosion and erosion corrosion, cathodic protection of pipelines and vessels; Corrosion in chemical process industries and their prevention methods.

Smt. K.S. Lakshmi

Non Destructive testing: (4 Lectures)
Covering basic aspects of various types of NDT Techniques like UT, Radiography, Edycurrent, Magnetic Particle testing, Dye penetrant testing & Visual Inspection Methods.

Reference Books

1. "Introduction to Materials Science for Engineers, James Shackelford
2. "Physical Metallurgy Principles & Practice", V. Raghavan
3. "Introduction to Solids", L.V.Azaroff
4. "Structure and Properties of Materials, Wultff Series, Wiley Eastern, New Delhi
5. 'Materials in Nuclear Application'-C.K.Gupta
6. Carter G F and Paul D E G, " Material science and engineering", Published by ASM, 1991
7. Baldev Raj et al, Practical Nondestructive Testing", 2nd Edition, Narosa, 2005
8. Fontana, Mars G, "Corrosion engineering" 3rd Edition, McGraw hill, 1987
9. Uhlig, Herbert H and Revie R Wniston, "Corrosion and Corrosion Control- An Introduction to Corrosion Science Engineering", 3rd Edition, John Wiley, 1984

BARC Training School
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Syllabus

Subject: Nuclear Fuel Cycle And Water Chemistry	**Code: - NE 7-FC07 FC08-CMEI-50**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Hours: 45**

Nuclear Fuel Cycle: (19 Hours) General description for different types of reactors. Front end and back end processes. Three stage Nuclear Power Programme of DAE.
Basic considerations of Fuel Design. Types of Nuclear Fuels, Research/Power Reactors Fuels, Thermal/ Fast Reactor Fuels. Metallic, ceramic fuels, cermet and dispersion fuels, Advantages/ disadvantages. Cladding Materials, zirconium alloys,stainless steels, aluminum and alloys.
Manufacturing processes for Uranium. Uranium ore mining and milling, Production of Uranium metal, alloying of U, Fuel for CIRUS & Dhruva; their properties and fabrication methods, methods of fuel plate fabrication. Uranium oxide powder preparation, compaction, sintering. Problems with U Fuel, Oxide Fuels, Mixed Oxide and Carbide fuels, properties of Pu Fuels, U & Pu Carbide fuel plate fabrication, FBTR fuel pin fabrication method,
Manufacturing processes for production of nuclear grade zirconium
Production of nuclear grade Zirconium Oxide, Iodide Process and Kroll process for production of sponge. Thermal decomposition, electrolysis etc., Specification of Zr-Sponge in Nuclear reactor applications. Melting Practices: Arc Melting, plasma melting and Electron beam melting methods for producing zirconium alloy ingots.

Fabrication: Cold working & hot working, Forging, rolling, extrusion, pilgering, tube drawing, rod fabrication, wire drawing and metal joining (Resistance welding, TIG welding and EB welding), Heat treatment of Zirconium alloys; Vacuum annealing & Stress relieving, Pickling & finishing of zirconium alloys. Manufacture of Fuel Tubes, Coolant Tubes, Calandria Tubes and other structurals
Irradiation effects in fuel and cladding materials. Pellet Clad Interaction & Stress Corrosion Cracking. Delayed hydride cracking, Performance of pressure tubes Advanced Fuels, Canflex, Dupic, thorium utilisation

Heavy Water Production (8 Hours)
Heavy Water: Properties and importance of Heavy Water in Nuclear Power Generation, scenario of D2O requirement, Unique features of deuterium separation, details of various methods of production, distillation and electrolysis processes of D2O and their comparison. Chemical exchange processes: H2S - H2O, NH3-H2 processes, description of sulphide process, separation factor, flow sheet, utilities, effluent treatment, special components.
Ammonia - H2, mono-thermal and bi-thermal processes description, flow sheet, effluents, NH3 – H2O front end process, salient features of equipments like ejector tray towers, etc. Ammonia-Hydrogen Front end process

Reprocessing of spent Nuclear Fuels. **(4 Hours)** Introduction to radiochemistry, difference between conventional & radiochemical plant, process and equipment limitations, criticality, safety and other hazards, ventilation and shielding. Spent fuel storage, decontamination, solvent extraction, Purex process, Reprocessing of thorium based fuels.

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Nuclear Waste management: (4 Hours) Sources, Characteristics and classification of radioactive waste, general philosophy of radioactive waste management. Methods of treatment for low, intermediate and high level solid, liquid and gaseous wastes with examples. Conditioning of radioactive waste, cementation, bituminisation and vitrification methods. Storage for primary/secondary solid waste and ultimate disposal.

Aspects of Heavy Water and its Analytical Chemistry (6 Hours)
Fundamentals of analytical chemistry, IR, UV, Neutron scattering, atomic absorption spectrophotometry, GC, GLC, HPLC, Mass spectrum.
Specific analytical instruments used in process & mineral plants, Measurements of impurities in gas / liquid like CO, CO2 , SO2, H2S, NH3 etc.
Measurement of SPM in stack, ambient air etc.
Online measurement of O2, sulfides (for H2S), pH etc.
Water source and Impurities, External treatment: Aeration, chlorination, clarification, filtration, precipitation softening processes, Ion exchange and DM water production
Boiler water systems & treatment
Cooling water systems & treatment
Industrial waste water treatment

Isotope separation Process (4 Hours)
Equilibrium and non Equilibrium Processes,
Thermodynamic minimum work for separation
Value function separative work
Cascade theory, Ideal cascade and squared of cascade.
Various reversible separations processes
Isotopic separation systems

Reference Books
Fundamentals of Analytical chemistry- Douglas, A.S.; Donald, M. W., Fourth edition
BETZ handbook of Industrial Water conditioning, eighth edition, 1980
Chemical engineer's Handbook- Perry J.H. and Green, Seventh edition
Nuclear Reactor Engg – Reactor Design basics 4th edition, Vol.1
Nuclear Reactor Engg – Reactor Systems Engg 4th edition Vol.II
By Glasstone, Samuel , Pub: Sesonske, Alexander, Pub: CBS, New Delhi
Nuclear Radiation Detectors by Kapoor S.S. & Ram Murthy, V.S. Pub: New Age, New Delhi
Advances in Industrial waster water treatment by P.K. Geoel Pub: Jaipur
Essentials of Nuclear chemistry 4th edition by H.J. Arnikar Pub: New Age, New Delhi
Technology of Zirconium by Miller.
Villani , Stelio, " Isotopic separation (An ANS Monograph)", American Nuclear Society, 1976
Skog , Douglas A et al, " Principles of Instrumental Analysis "5th Edition , Harcourt Asia , 2001

BARC Training School

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Syllabus

Subject: Advanced Chemical Reaction Engineering	**Code: CEM:E 30:C-25**
Discipline: Chemical Engineering	**No. of Lectures: 25**

Review of basic concepts of reaction engineering

Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.

Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations

Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.

Reactor design: counter-current moving bed reactors, fluidized bed reactors.

Advanced topics in reaction engineering- three phase reactors, integral reactor-separators, complex systems.

Examples from nuclear chemical engineering.

Reference Books:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.

2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.

3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.

4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.

5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

6. Hartland, Stanley, "Counter-current Extraction: An Introduction to Design & Operation of Counter-current Extractors", Pergamon Press, 1970

7. Smith Robin, "Chemical process Design, MGH (New York), 1995

8. H. Scott Fogler, " Elements of Chemical Reaction Engineering" 4th Edition, Pearson, 2006

Core Engg. Module

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Syllabus

Subject: Advanced Mass Transfer, Equipment Design and Solvent Extraction	Code: CEM-04:E32 AC03:C 45
Discipline: Chemical Engineering	**No. of Lectures: 45**

Theories of mass transfer: 15 Hrs

Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fiber extractors. Adsorption and ion exchange equipment. Membrane separation and other advanced mass transfer processes. Process intensification approaches.

Mass Transfer Equipment Design: 10 Hrs

Different types of mass transfer equipment for gas liquid operations. Selection criteria for tray v/s packed columns. Design of cross flow and multiple d/c type sieve trays, Ejector Trays Hydro dynamics of trays & packed columns, Structured & random packings Performance evaluation of plate & packed column, spray, packed & tray columns trickle bed reactors.

Solvent extraction: 20 Hrs

Introduction to liquid-liquid extraction: Molecular and eddy diffusion, inter phase mass transfer, Lewis-Whitman theory calculation of No. of stages for cross flow and counter current flow, selection of solvent. Three component system. One pair partially soluble, two pairs partially soluble Binodal solubility curve, Representation in equilateral triangular coordinates, interpretation of equilibrium curves, extraction in multi component systems, use of "pinching " in extraction & scrubbing operation.

Dispersion & Coalescence: axial and radial dispersion, Factors influencing dispersion, Primary and secondary break ,types of impellers, dispersion in spray columns, sieve plate column packed column and in agitated systems. Factors affecting coalescence, coalescence in spray column, packed column in settlers.

Equipment for solvent extraction: Selection criteria for contractors, classification of contractors, contractors effectiveness, spray columns, packed columns, sieve tray, pulsed sieve plate column, mixer-settlers, centrifuge.

Contd...

Design of mixer settlers: Design from 1st principles, Batch and continuous equipment, (Design of batch mixer settler), Principles of scale up of designs, mixer and scale up hydrodynamic balance and location of aqueous ,mixed and organic parts.

Chemistry of Uranium Extraction: Different solvents, Mechanism of Uranium extraction, diluents, third phase formation, Phase or diluents modifiers.

Extraction processes in Nuclear industry: Ore concentration, DDPA process, DEHPA, AMEX process,TBP-UO_2 $(NO_3)_2$ refining ,PUREX process, Thorex Process, TBP-$Zr(NO_3)_4$ process

Reference Books:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)
8. Treybal, R.E., "Mass Transfer Operation" 3rd Edition, Tata McGraw Hill, 2005
9. J.M.Coulson et al, "Coulson & Richardson's Chemical engineering- Fluid Flow, Heat Transfer & Mass Transfer" 6th Edition, Vol.1, Oxford Univ. 2007
10. Hartland, Stanley, "Counter-current Extraction: An Introduction to Design & Operation of Counter-current Extractors", Pergamon Press, 1970
11. Joshi M.V., "Process Equipment Design" McMillan, New delhi, 1976
12. Perry Edmond S.Ed. et al, "Separation & Purification Methods", Marcel Dekker, New York, 1974

BARC Training School
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Syllabus

Subject: Basic Process Instrumentation and Control	Code: CEM:CC03-M - 20
Discipline:Mechanical, Chemical & QA Engineering	No. of Lectures: 20

Instrument terminology, symbols & performance:
Instrument terminology: Accuracy, Precision, Resolution, Repeatability, Reproducibility, Drift, Dead band, Flow sheet symbols, Instrument performance, Standard unit of measurements, P&I diagrams.

Measurements: **Flow measurement**:
Mechanical type flow meters: Orifice meter, Venture meter, Pitot tube, Elbow meters.
Variable area flow meters, Magnetic flow meters, Turbine flow meters, Ultrasonic flow meters

Level measurements:
Level gauges, floats, Differential pressure type level detectors, Displacer type level detectors, Conductivity type, Capacitance type, Ultrasonic type, Radiation type

Temperature measurement: Filled-bulb and glass type thermometers, Bimetallic type, Resistance temperature detectors, Thermocouples, Pyrometers

Pressure measurement:
Bourdon & helical type pressure sensors, Bellow type pressure sensors, Diaphragm type, Differential transmitters, Manometers,Vacuum sensors.

Panel display instruments: Indicators, Recorders, Controllers
Signal transmission methods & Annunciations.

Automatic control theory: Control basics, Control modes, Closed loop response, Feed back & feed forward control, Tuning of PID controllers.
Final control elements: Control valve sizing, Control valve types, Actuators, Accessories & positioners

Control & Instrumentation, Sensors and Transmitters
Final control elements. Control valves, actuators, and positioners Controllers Automatic controllers

Distributed Digital Control System
(a) Signal conditioning, (b) Data acquisition system (c) PC based instrumentation (d)Organisation of distributed control system; (e) Control software and qualification aspects (f) Data processing and SCADA.

Contd….

Reference Books:

1. Fundamentals of Temperature. Pressure and Flow Measurements – Benedict
2. Measurement Engineering – Stein P.K. Pub-fished by Stein Engineering Services
3. Mechanical Measurements – T.G. Backwith and N. Leins Suck, Addison Wesley
4. instrument Technology, Vols. 1 to 5, - E.B. Jones, Butterworth and London
5. Experimental Methods for Engineering – J.P. Holman, McGraw Hill
6. Measurement in Applied Physics – A.A. Burr K.J. Dean, Chapman and Hall
7. Mechanical and Industrial Measurements – R.K. Jain, Khanna Publishers, NewDelhi.
8. Instrumentation for Scientific Research – Kurt S. Lion, McGraw Hill
9. Industrial Instrumentation Fundamentals – A.E. Fribance, Tata McGraw Hill
10. Measurement system, Application and Design, Ernest D. Deophhlin, McGraw Hill
11. Process control – P. Harrict, Tata McGraw Hill
12. Automatic Process Control – Donald P. Beckman, Wiley Eastern Ltd., New Delhi
13. Industrial Instrumentation – Donald P. Beck-Man, Wiley Eastern Ltd. New Delhi
14. Fluid Meters – Their Theory & Application Edited by H.S. Bean, ASME Publication
15. Principles and Practice of Flow meter Engineering – L.K. Spink, Published by the Foxboro Company.
16. Manual on the use of Thermocouples in Temperature Measurement, ASSE Publication
17. Process Instruments and Control Handbook Edit-by D.M. Considine McGraw Hill
18. Handbok on Applied Instrumentation : Edited by D.M. Considine McGraw Hill and S.D. ROSS McGraw Hill
19. D.Patranabis, "Principles of Process Control" McGraw Hill, 2007
20. Harriott, Peter, "Process Control", TataMc Graw Hill, New Delhi, 1998
21. Seborg, Dale. E, "Process Dynamics & Control" 2nd Edition, Wiley, Singapore, 2005

BARC Training School
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Syllabus

Subject: Computational Fluid Dynamics and Heat Transfer	Code: CEM:E 21:CM-40
Discipline: Mechanical and Chemical Engineering	**No. of Lectures: 40**

Basics of Fluid Flow, Heat Transfer and Numerical Analysis: 15 Hrs
Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
Classification of Partial Differential Equations (PDEs)
Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
Temporal integration: explicit, implicit scheme
Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
Discretization of convection-diffusion problem: exponential scheme, power-law scheme

Laminar Boundary Layer and Forced Convective Heat:
Formulation of differential equation for hydrodynamic and thermal boundary layer
Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
Convective heat transfer for internal and external flows
Low and high Prandtl number limits and different thermal boundary conditions
Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer:
Reynolds decomposition for turbulence ; Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder ; Calculation of friction factor and drag coefficient ; Analytical and semi-analytical correlations for calculating heat transfer coefficients ; Analogy between heat and momentum transfer ;Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models,Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

Natural Convection :
Basic Equations of natural convection : Boussinesq approximation : Derivation of Dimensionless groups from basic equations : Analytical approximations : Numerical solution of approximate equations

Contd....

Numerical Solution of Complete Fluid Flow and Energy Equation : 6 Hrs
Formulations of governing equations used in numerical simulation:
Streamfunction-temperature formulation
Streamfunction-vorticity-temperature formulation
Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
Primitive-Variable (P-V-T) formulation
Pressure velocity coupling for incompressible flow:
Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
Simple grid generation techniques for structured grid:
Elliptic, parabolic and hyperbolic equation method
Grid adaptation
Domain decompositions in CFD and heat transfer
SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer : 10 Hrs
Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Heat Transfer With Phase Change : 9 Hrs
Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model); Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation) ; Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.Critical Flow: Models for single – phase and two-phase critical flow.

Contd….

Reference Books:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag
23.John D Anderson, " Computational Fluid Dynamics: The Basics with Application"
24. Bernard, Jng C.J., " handbook of Fluid flow Metering", The Trade & Technical press, 1988
25. Kern, Donald Q, "Process Heat Transfer", Tata McGraw Hill, 2000
26. Mc Adam, W H, "Heat Transmission", McGraw Hill, 1954
27. " Fundamentals of Two-phase Heat Transfer", Chapter 10
28. j.H.Ferziger & Milovan Peric, "Computation Methods for Fluid Dynamics" John Wiley Sons, 2006
29. J.M.Coulson et al, "Coulson & Richardson's Chemical Engineering-Fluid Flow, Heat Transfer & Mass transfer", 6th Edition, Vol.1, Oxford Univ., 2007
30. Sengupta Tapan K, "Fundamentals of Computational fluid Dynamics", New Delhi, Elsevier, 2006

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Process Dynamics, Analysis and Control	Code: CEM:E31 E29:50
Discipline: Chemical Engineering	No. of Lectures: 40

Review of Basic Control: 40 Hrs

Dynamic models, Transfer function Transient analysis - Rouths criteria etc., Stability, Frequency analysis - Nyquist criteria with examples using MATLAB etc., Discrete models, z-transforms, Sampled data control, Introduction to state space control, State feed back, Pole placement, Controllability, Observability, Stochastic Processes, Kalman filtering. Process identification from plant data; SISO with PID control, Inadequacies; Cascade, feed forward, dead time compensation; Introduction to adaptive control, non-linear control; Poorly defined system, and fuzzy control. Multivariable systems, Model predictive control: internal model control, Dynamic matrix control, multivariable control, and optimal control. Introduction to Fault Detection and Diagnosis. The assignments include problem solving with simulation software.

Reference Books:

1. W.L. Luyben, Process Modeling Simulation and Control for Chemical Engineers, McGraw Hill, 1990.
2. D. Burghes and A. Graham, Introduction to Control Theory including Optimal Control, John Willey & Sons,
3. Stephanopoulos, Advanced Process Control
4. Coughanowr and Koppel
5. K. Ogata, Modern Control Systems, Prentice Hall (India)
6. K.S. Astrom and B. Wittenmark, Computer Control Systems, Prentice Hall (India)
7. Douglas Considine, Handbook of Process Instrumentation and Control,
8. E. O. Doebline, Instrumentation and Measurements

BARC Training School
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Syllabus

Subject: Process Modeling, Simulation and Optimization	Code: CEM-5:E 33:C-20
Discipline: Chemical Engineering	**No. of Lectures: 20**

Process Simulation: 10 Hrs
Introduction to process modeling, simulation and optimization. Deterministic versus stochastic models. Dynamic and steady state models.
Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
Approaches to Plant Simulation: Sequential modular; Equation oriented; Simultaneous modular
Steady-State Sequential Modular Simulators:
Concepts of partitioning, tearing and nesting as applied to flow sheets: Methods of representation of plant topology; recycle detection and calculation ordering algorithms; recycle convergent methods.

Steady State Equation Oriented Simulators:
Strategies for formulation of plant models; sparse systems and Solution procedures; Solution methods for simultaneous modular approach; General Approaches For Non-Linear Systems; Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eign-value method. Examples of solving non-linear systems; Commercial Simulators ;Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization: 10 Hrs
Classification of optimization problems, necessary and sufficiency conditions for optimum; Search procedures for unconstrained optimization problems; Non-linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator; Case Study: Simulation and modeling of heavy water cascade, use of lumping and de-lumping strategies, application on Optimisation techniques. Decomposition of complex topology, rate base model versus equilibrium base model for tower internals, evaluation of transport co-efficients using mass transfer with reaction models, use of analogies for evaluation of interface co-efficient introduction, Recent Developments: Multi-objective optimization, Plant optimization by Genetic Algorithms and Neural Network.

Reference Books:
1) Process Modeling, Simulation And Control for Chemical Engrs. 2nd Edition: Luyben William L, Publisher: McGraw-Hill, New York .
2) Optimization of Chemical Processes ; Edgar, Himmelblau & Lasdon

BARC Training School
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Syllabus

Subject: Applied Process Instrumentation and Control	Code: CEM :E 50:CEEI-45
Discipline: Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 45**

Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: **15 Hrs**
Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annular, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices, venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flow meter; Ultrasonic flow meters- transit time, Doppler type, Clamp on type ultrasonic flow meters, Coriolis and thermal mass flow meters. Applications and limitations of various flow meters. Two phase flow measurements.

Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermo well, thermo well installation aspects. Surface temperature measurement techniques; Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

Pressure: 15 Hrs
Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.>Analytical Instrumentation: Conductivity, pH, ORP and Turbidity measurement.
Automatic Control Theory: Control busses, Control Modes, closed looping response, PID controllers, feed back & feed-forward control, timing of PID controllers. Auto tuning and self adaptive controls. Operational amplifiers and its applications.

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Instrumentation Field Busses: HIRE Foundation Field Bus, profi bus, mod bus, TCP/IP, Industrial Ethernet, device net & CAN

Introduction of Advance Sensor Technology: Wireless sensors.
Basics of Pneumatics : Instrument Air Quality, Air requirement, Flaper nozzle mechanism, signal booster.
Other Measurements: Relative humidity; viscosity and density measurement

Introduction to Neural Network and Fuzzy Logic : 5 Hrs

Control valves: 10 Hrs

Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve range ability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings; P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

Reference Books:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Murthy, D.V.S ,"Transducers and Instrumentation ", Prentice Hall, 1995
13. Liptak, Bela G.Ed, "Instrumentation Engineers Hand Book: Process Measuring & Analysis", 3rd Ed., Buter Lurth
14. Nakra, B.C & Choudhary K.K. "Instrumentation, Measurements" ,Tata Mc Graw Hill, 2004
15. ECK Man, D.P. " Industrial Instrumentation Measurements" , CBS, 2004
16. Anderson, Norman A, "Instrument for Process Control", 3rd Ed., CRC Press, 2005

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Electrical Engineering Practices- I	Code: CEM:AC13:E -30
Discipline: Electrical Engineering	**No. of Lectures: 30**

1. **EHV Switchyard Design**: Switching schemes; clearance; Comparison between types of switchyards; Brief introduction to equipments in switchyard and their functions; Lighting arrestors and insulation co-ordination; Lightning protection, Maintenance of Switch yards, Selection of instrument transformers for measurement and protection.
2. **Selection Of Transformers**: Types & classifications; Special design features; Accessories; Specifications and testing; Voltage regulation calculations, Maintenance, Transformer oil, requirements, specifications and maintenance.
3. **Motor & Their Applications**: Types of motors; System requirements; Performance requirements, Drives, Selection of starters, Installation and maintenance, Insulation classes and maintenance.
4. **Station Auxiliary Systems**: Class 1, II , III and IV systems classifications.
5. **Introduction to DG Sets, Ups & Batteries**: DG sets: Engine, auxiliaries, Generator, Electrical equipment, brush-less and static excitation systems and introduction to SCADA
6. **UPS:** Types, different configurations, selection.
7. **Batteries**: types, selection criteria, charging methods, Testing methods
8. **Cabling, Lighting & Grounding**: Cabling: Types, sizing, laying and de-rating factors, terminations, fault location Grounding systems; Bus ducts.
9. **Selection of MV & LV Switchgear:** Types ; specifications and testing MCCs; Distribution boards; ELCB, Internal protection, Maintenance.
10. **Electrical Equipment**: Requirement In Hazardous Areas: Specific requirements for safety related electrical equipments & systems in Chemical Industries. Fire wall, barrier and stops.
11. **Electrical Control Circuits**: Symbols, development of control circuit, Single-line/schematic diagram Latest Trends In Electrical Engineering
12. **Protection**: Line protection; generator protection; Transformer protection; Motor protection.

Reference Books:

Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey, Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey
Source book of Electronic circuits by Markus John, Pub: McGraw Hill, New York
Electrical control for machines 3rd edition, by Rexford, Kenneth B, Pub: Delmer
Elec Engg materials by A.J. Dekker, Prentice Hall, New Jersey
Basic Elec. Engg 2nd edition by D.P. Kothari & I.J. Nagrath Pub: Tata McGraw Hill, New York

BARC Training School
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Syllabus

Subject: Electrical Engineering Practices - II	Code: CEM: EEP-II: E:20
Discipline: Electrical Engineering	**No. of Lectures: 20**

Electric Drive: Advantages of electric drive; Factors governing selection of motors; Nature of electric supply; Nature of the drive: Individual drive, group drive: Nature of load: Starting torque, behavior of load with respect to speed, high inertia loads, Electrical characteristics of motors: Starting Characteristics, running characteristics, speed control, braking characteristics

Size and rating of motors: Sizing calculation, Duty cycle of motor, continuous, intermittent, over load capacity and pull out torque: Mechanical considerations: Type of enclosure, type of bearings, transmission of drive, noise level Cost: Capital cost, running cost.

Electric Heating: Advantages of electric heating Methods of heating Resistance heating; direct resistance heating; indirect resistance heating; types of heating elements, selection of heating elements, requirements of a good heating material, causes of failure of heating elements, temperature control resistance furnaces, introduction to design of heating element. Introduction to refractory materials for furnaces.

Illumination Engg: Fundamentals of radiation, visible range of light, colour temperature, Eye end vision. Laws of illumination and units. Various light sources: incandescent and discharge lamps. Illumination system: Luminnaire, Ballast and starters. Colour and glare, Interior and exterior lighting applications and controls. Lighting calculation and design. DC Power surfaces for industrial applications

Electric Arc Furnaces: Definition and Characteristics of arc, power supply and control of arc furnace.

Plasma furnaces: Definition and characteristics of plasma, start plasma, power supply and control of plasma furnace.

Electron beam melting: Introduction, generation of electron beam, power supply and control of electron beam

High frequency heating Induction heating: skin effect, aspects of power supply Di-electric heating, Introduction, advantages

Electric Welding: Electric arc welding, Electric resistance welding, Electron beam welding

Contd....

Electrolytic Processes: Laws of electrolysis, electroplating,
Earthing & lightening protection-effect of current to human body.

Introduction to power quality:

Perspective on power quality--Categories and origin of power quality--
Power system harmonics--Non linear loads--
Effect of power quality on industrial loads--
Motor issues--Electro magnetic interaction--
VFD issues

Reference Books:

Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey,
Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J
Prentice Hall, New Jersey
Source book of Electronic circuits by Markus John, Pub: McGraw Hill, New York
Electrical control for machines 3rd edition, by Rexford, Kenneth B, Pub: Delmer
Useful IS Codes for Electrical Engrs.

a) Code of practice of earthing : IS 3043:1987
b) Chart and treatment of electric shock : SP 31:1986
c) Guide on effects of current passing through human body: IS 8437 (Part 1 & 2)
d) Three phase induction motor: IS 325
e) Power transformers : IS 2026 (Part 1 to 5)
f) Code of practice of industrial lighting : IS 6665
g) Code of practice for interior illumination : IS 3646 (Part 1 to 3)

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Syllabus

Subject: Modern Electronic Control of AC and DC Drives	Code: CEM:JNTU:30
Discipline: Electrical Engineering, Electronics Engineering and Instrumentation Engineering	**No. of Lectures: 25**

A. Power Control of DC Drives

UNIT-I Three phase naturally commutated bridge circuit as a rectifier or as an inverter Three phase controlled bridge rectifier with passive load impedance, resistive load and ideal supply – Highly inductive load and ideal supply for load side and supply side quantities, shunt capacitor compensation, three phase controlled bridge rectifier inverter.

UNIT – II Phase controlled DC Motor drives
Three phase controlled converter, control circuit– Two quadrant, Three phase converter controlled DC motor drive – DC motor and load, converter

UNIT – III Current and Speed controlled DC Motor drives
Current and speed controllers – current and speed feedback – Harmonics and associated problems – sixth harmonics torque.

UNIT – IV Chopper controlled DC motor drives
Principle of operation of the chopper – Four- quadrant chopper circuit – Chopper for inversion – Chopper with other power devices – model of the chopper – input to the chopper – rating of the devices – Pulsating torque.

UNIT – V Closed loop operation of DC motor drives
Speed controlled drive system – current control loop – pulse width modulated current controller – hysterisis current controller

B. Power Control of A.C. Drives

UNIT I Introduction to AC Drives
Introduction to motor drives – Torque production – Equivalent circuit analysis – Speed-Torque Characteristics with Variable voltage operation, Variable frequency operation, constant v/f operation – Variable stator current operation – Induction motor characteristics in constant torque and field weakening regions

UNIT II Control of Induction motor drives at Stator side
Scalar control – Voltage fed inverter control – Open loop volts/Hz control – speed control slip regulation – speed control with torque and flux control – current controlled voltage fed inverter drive – current-fed inverter control – Independent current and frequency control – Speed and flux control in Current-Fed inverter drive – Volts/Hz control of Current-fed inverter drive – Efficiency optimization control by flux program

Contd...

UNIT III Vector control of Induction Motor Drives

Principles of Vector control – Vector control methods – Direct method of vector control – Indirect method of vector control – Adaptive control principles

Techniques of motor drive configuration.

Reference Books:

1. Power Electronics and motor control – Shepherd, Hulley, Liang – II Edition, Cambridge University Press
2. Electric motor drives modeling, Analysis and control – R.Krishnan – I Edition, Prentice Hall India
3. Power Electronic circuits, Devices and Applications – M.H.Rashid – PHI – I Edition – 1995
4. Fundamentals of Electric Drives – G.K. Dubey- Narosa Publications -1995
5. Power Semiconductor drives – S.B.Dewan and A.Straughen - 1975
6. Electric Motor Drives Pearson Modeling, Analysis & Control – R.Krishnan – Publications – 1st edition – 2002
7. Modern Power Electronics and AC Drives – B.K.Bose – Pearson Publications – 1st edition
8. Power Electronic control of AC Motors – MD Murphy & FG Turn Bull Pergman Press(For Chapters II, III, V) – 1st edition
9. Power Electronics and AC Drives – B.K.Bose – Prentice Hall, Eagle wood diffs New Jersey(for chapters I, II, IV) – 1st edition
10. Power Electronic circuits, Devices and Applications – M.H.Rashid – PHI - 1995
11. Fundamentals of Electrical Drives – G.K.Dubey – Narora publications - 1995 (For Chapter II)
12. Power Electronics and Variable frequency drives – B.K.Bose – IEEE Press – Standard publications -1st edition – 2002
13. Sen P.C., " Power Electronics", Tata McGraw Hill, 1988

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Networking Communications	**Code: CEM-9:E61: Etrn-I-20**
Discipline: Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 20**

Data Communication Topics: Basic Concepts, V.24 and V.35 standards, Dial up modems, xDSL technology, Techniques of Flow Control, Error Control, Switching, Multiplexing, and Routing. (4)

Digital Networks: ISDN BRA, ISDN PRA, Introduction to Frame Relay and ATM. (2)

Topologies: OSI Layer Model

Link Layer Communication: Types of Local Area Networks, Types of Ethernet, Ethernet frame structure, CSMA/CD, Hubs, Switches, Wireless LAN, Point-to-point Protocol. (3)

Internetworking: Repeater, Bridge, Router, Spanning tree Algorithm, Tunneling, Packet Fragmentation. (3)

TCP/IP: IP packet format, IP Addressing, Subnets, Introduction to CIDR and DHCP, IPv6,TCPsegment format,TCP Call Control. (3)

IP Routing: IP Routing Algorithm, ARP, and ICMP. IP Routing Protocols: RIP, OSPF, and BGP. Domain Name System. (2)

Network Application and Security: Half/full Association, Client Server and peer-to-peer working, Unix socket programming, E-mail, http, concepts of firewall and proxies, Encryption, Digital signatures. (3)

Reference Books:

1. Data and Computer Networks: William Stalling. Prentice Hall of India
2. Internetworking with TCP/IP – D.E Comer, Vol. I. Prentice Hall of India
3. Unit Network Programming – W.R Stevens. Prentice Hall of India.
4. Practical Data Communications: Roger L. Freeman. John Wiley and Sons
5. Basandra, Suresh K, "Local Area Networking", Galgotia, 1995
6. A.S.Tanenbaum, "Computer networks", 4th Edition, Pearson, 2003
7. B.A.Forouzan etal, "Data Communications & Networking", Tata McGraw Hill, 2001

BARC Training School
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Syllabus

Subject: Programmable Logic Controllers and Applications	Code: CEM:EEI-40
Discipline: Electronics, Electrical and Instrumentation Engineering	**No. of Lectures: 30includes Practical Demos**

20 Hrs

Unit 1: PLC Basics: PLC system, *VO* modules and interfacing, CPU processor, programming equipment, programming formats, construction of PLC ladder diagrams, devices connected to *VO* modules.

Unit 2: PLC Programming: Input instructions, outputs, operational procedures, programming examples using contacts and coils. Drill press operation.

Unit 3: Digital logic gates, programming in the Boolean algebra system, conversion examples. Ladder diagrams for process control: Ladder diagrams & sequence listings, ladder diagram construction and flow chart for spray process system.

Unit 4: PLC Registers: Characteristics of Registers, module addressing, holding registers, input registers, output registers.

Unit 5: Sensors as input devices to PLC- Various types of proximity sensors: Inductive, capacitive, photo electric, magnetic, laser, UV and ultra sonic sensors. Brief discussion on other input devices like pressure switch, flow switch etc.

20 Hrs

Unit 6: PLC Functions: Timer functions & Industrial applications, counters, counter function industrial applications, Arithmetic functions, Number comparison functions, number conversion functions.

Unit 7: Data Handling functions: SKIP, Master control Relay, Jump, Move, FIFO, FAL, ONS, CLR & Sweep functions and their applications.

Unit 8: Bit Pattern and changing a bit shift register, sequence functions and applications, controlling of two axis & three axis Robots with PLC, Matrix functions.

Unit 9: Analog PLC operation: Analog modules & systems, Analog signal processing, multi bit data processing, analog output application examples, pm principles, position indicator with pm control, pm modules, pm

Unit 10: Introduction to CNC controls

Reference Books:

1. Programmable Logic Controllers - Principle and Applications by John W. Webb & Ronald A. Reiss, , Fifth Edition, PHI

2. Progranunable Logic Controllers - Programming Method and Applications by JR. Hackworth & F.D Hackworth Jr. - Pearson, 2004.

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Syllabus

Subject: Digital Signal Processing and Machine Vision	Code :CEM : New
Discipline: Electronics and Instrumentation Engineering	**No. of Lectures :30**

Digital Signal Processing:

Introduction : Basic elements of a digital signal processing system, Fourier series and fourier transform, Z-transform, convolution, correlation, sampling theory, aliasing anti-aliasing filter, quantization noise and signal reconstruction. (4 Hrs)

Discrete Fourier Transform(DFT) : Interpretation of DFT, Properties of DFT, DFT of real signals, convolution and correlation using DFT (2 Hrs)

Fast Fourier Transform (FFT) : Efficient computation of DFT, Inverse FFT algorithm, Use in linear filtering and correlation. (2 Hrs)

Design of Digital Filters : IIR & FIR filters, design techniques and realization. (2 Hrs)

Overview of DSP Processors : Harvard architecture, pipelining, general purpose, fixed point and floating point processors. (2 Hrs)

DSP Applications : in Nuclear and other fields (2 Hrs)

Image Processing:

Fundamentals of Image Processing : Image acquisition, Image model, sampling, quantization, relationship between pixels, distance measures, connectivity, Histogram : definition, decision of contract basing on histogram, image stretching, sliding, histogram equalization. (4 Hrs)

Image transforms, Image enhancement by spatial domain methods and frequency domain methods (1Hrs)

Applications of digital image processing. (1 Hrs)

Machine Vision:

- Image Model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflection, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, boundary representation, Mathematical Morphology ;
- Intermediate Vision: Line, Circle, Elipse and Polygon detection, Hough Transform for detection, Corner detection, Generalized Hough Transform;
- High level Vision: Scene interpretation;

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- Texture - Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & Pattern classes, Classifiers in general, Distance Metric, Classification and recognition, various methods of recognition & interpretation, Template matching and area correlation, matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

Reference:

1. Johnny R Johnson, Introduction to digital signal processing, Prentice-Hall of India, 2000
2. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice-Hall of India, 1995
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice-Hall of India, 1988 .
4. Fundamentals of Digital Image Processing – A.K. Jain, Prentice Hall of India.
5. Digital Image Processing – R.C. Gonzalez & R.E. Woods.
6. Refel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
7. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis and Machine Vision, Vikas Publishing House, 2003.
8. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc.2004.
9. Davies E.R., Machine Vision Theory Algorithms Practicaltities, Academic Press.
10. D.A. Forsyth & J.Ponce, Computer Vision A Modern Approach, Prentice Hall, 2003.
11. Horn B.K.P., Robot Vision, The MIT press, 1987.
12. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
13. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Embedded and Computer Based Systems Design	Code: CEM:E 54:Electrn-40
Discipline: Electronics Engineering	**No. of Lectures: 40**

Microprocessor Based Hardware Design: 14 Hrs
Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Microcontrollers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
Industry Standard Bus Systems: ISA, PCI, VME, PXI: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, and testability.
Embedded computer system design example.

Computer Communication and Networks: 7 Hrs
Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables,hub,switch,routers etc.)
Fault Tolerant and Distributed Architectures : Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues; Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

Real-Time System Design: 15 Hrs
Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.
Overview of LINUX and Embedded NT.

Introduction to VLSI Design: 4Hrs

Reference Books:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, And 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Microcontroller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices

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4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill
17. Hofacker, W., "Microcomputer Hardware handbook", 1982
18. Leventhal, Lance A, "Introduction to Microprocessor: Software, Hardware programming", Prentice Hall, 1986
19. Basandra Suresh K, "Local Area Networks", Galgotia, 1995
20. James F Kurose & Keith W.Ross, " Computer Networking: Atop Down Approach Featuring the Internet" 2nd Edition, Pearson, 2003

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Computer Aided Design and Manufacturing	Code: CEM-14: M-35
Discipline: Mechanical Engineering	**No. of Lectures: 35**

Introduction to CAD & CAM: 35 Hrs

Extensive definition of CE - CE design methodologies - Organizing for CE - CE tool box collaborative product development. IT support - Solid modeling - Product data management -Collaborative product commerce - Artificial Intelligence- Expert systems - Software hardware co-design. Life-cycle design of products - opportunity for manufacturing enterprises - modality of Concurrent Engineering Design - Automated analysis idealization control - Concurrent engineering in optimal structural design - Real time constraints. Manufacturing competitiveness - Checking the design process - conceptual design mechanism – Qualitative physical approach - An intelligent design for manufacturing system - JIT system - low inventory - modular - Modeling and reasoning for computer based assembly planning - Design of Automated manufacturing Lathe Machining, Milling Machining, EDM Wire Cut, Turret Punch Press, Absolute & Incremental Prog., Canned Cycle, Tool Selection, G / M code programming, CNC maintenance & macro programming, Generative machining. FEA, Mechanisms and Sheet Metal, CNC Technology, Robotics. Life Cycle semi realization - design for economics - evaluation of design for manufacturing cost concurrent mechanical design - decomposition in concurrent design - negotiation in concurrent engineering design studies - product realization taxonomy - plan for Project Management on new product development – bottleneck technology development.

Modeling : 3D Solid Modeling, Surface Modeling, Advance Surfacing, Assembly & Animation, Drafting & Detailing. Model Generation, Loading & Solution, Post Processing, Structural Analysis, Thermal Analysis using I-deas code for 2-D and 3-D cases using ANSYS.

Reference Books:

1) Proceedings of the 4th International Conference on CAD, CAM, Robotics & Factories by Indian Istitute of New Delhi : Edited by Juneja B L : Pub: Tata Mc Grew Hill, New Delhi, Vol. I, II, III

BARC Training School
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Syllabus

Subject: Engineering design and FEM	Code: CEM:AC09,
Discipline: Mechanical & Quality Assurance Engineering	No. of Lectures: 45

Introduction (2 lectures):

Failure modes of pressure vessels and heat exchangers: yielding,Tensile instability,creep effects,fatigue,flow induced vibration, uckling,etc. Type of stress, significance of stress, theories of failure, stress intensities, ASME Sec.VIII Div. I and ASME Sec.111 omparisons

Theories of failure, Stress invariants and yield surfaces (3 lectures):

Mohr's circle, state of stress and invariants (2 D and 3 D) Hydrostatic state (dilatational) and distortional (Pure shear) state. Vonmises failure theory based on second invariant of distortional stress tensor and based on distortional energy theory; Tresca theory and comparison with Vonmises theory. Yield surfaces of Vonmises theory and Tresca theory in 3 - D with respect to O1, O2 and O3 axes.

Collapse load assuming elastic perfectly plastic material (3 lectures)

Long thick cylindrical shell under internal pressure. Pressure at I which yielding starts, pressure at which interface radius is p and collapse pressure (full section yielding) by Vonmises and Tresca theories. Limiting moment or collapse moment of beams of various cross sections (Rectangular, circular) and reduce shape factor. Collapse moment of a straight pipe (Treating as a beam) and deduce shape factor for pipe section.

Design aspects of cylindrical pressure vessel (3 lectures)

Major design options: Vertical, horizontal, choosing length and diameter of a vessel, support options (Lug! Bracket Vs skirt support), choice of closures. Formulae for thickness as per Sec. VIII, Div. I and numerical problem. Background to external pressure charts, effect of ovality / imperfection and plasticity, factor of safety for cylinders and factor of safety for sphere under external pressures. Sizing of stiffening ring. Flange design as per code: Bolt design and flange thickness calculation.

Heat exchangers: (3 lectures):

Shell and tube plate types heat exchangers. Tubesheet
thickness as per TEMA, Sec VIII Div 1 and see III (including concept of equivalent solid plate and modified elastic constants). Effect of axial rigidity of tubes in tubesheet thickness. Methods of joining tube to tubesheets. (rolled/expansion joints and welded joints); Pullout load. (strength of tube to tubesheet joint) Accomodating differential expansion among tubes and shells: Bend tube, U tube and Bellows. Buckling strength of tube and FIV of tubes (FIV mechanisms: Vortex shedding (lock-in), Fluid elastic instability and a acoustic resonance.

Stress and Strain concentration factors (Ka and K €) - 3 lectures:

Importance of local strain (peak strain) variation - fatigue damage rules (Coffin Mansion and Cumulative fatigue damage). Stress concentrations (i) elliptical holes in the center of a

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large plate subjected to uniaxial load (ii) circular hole in a plate subjected to uniaxial/biaxialloading (iii) circular hole in a cylindrical shell subjected to pressure loading. Stress and strain uncertain due to a small hole in an infinite plate subjected to hydrostatic in plane loading (based on thick shell formula for external pressure) and based on component stress and equivalent stress. (Elastic factors) and plastic stress and strain concentration factors. Approximate methods to obtain local plastic strain at point of interest: Nueber's rule and Molshy-Glinka rule. (Analytical equations and graphical representation and comparisons); Introduction to simplified elastic plastic analysis as per ASME.

Fracture Mechanics, Non ductile failure and Hydrostatic test (3 lectures):

Introduction to fracture mechanics, stress Intensification factors, fracture toughness, Paris' Law, concept of plastic domain at crack tip, J - integral, JIC, Transition temperature, (RTNDT), Methods to prevent brittle fracture, Integrity assessment diagram, appendix: G of ASME, Sec III Div 1, Maximum postulated defect, allowable pressure as a function of (T -RTNDT) and Hydrostatic test temperature.

Introduction to FEM and Modelling: 25hrs:

Historical Background - Weighted Residual Methods - Basic Concepts of FEM - Variational Formulation of B.V.P - Ritz Method - Finite Element Modeling - Element Equations – Linear and Quadratic Shape functions - Bar, Beam Elements - Applications to Heat Transfer. Basic Boundary Value Problems in 2 Dimentions - Triangular, quadrilateral, higher order elements - Poissons and Laplace Equations - Weak Formulation - Elements Matrices and Vectors - Application to Solid mechanics, Heat transfer, Fluid Mechanics. Natural Co-ordinate System - Lagrangian Interpolation Polynomials - Iso- parametric Elements - Formulation - Numerical Intergration - 1D -2D Triangular elements – rectangular elements - Illustrative Examples. Introduction to Theory of Elasticity - Plane Stress - Plane Strain and Axisymmetric Formulation - Principle of virtual work - Element matrices using energy approach. Dynamic Analysis - Equation of Motion - Mass Matrices - Free Vibration analysis - Natural frequencies of Longitudinal - Transverse and torsional vibration - Introduction to transient field problems. Non linear analysis. Use of software - h & p elements - special element formulation.

References Books:

1. O.C. Zienkiewicz., & R.L. Taylor., "The Finite Element Method", VoL.1 and Vot.2, McGraw-Hill, 4th Edition, 1991.
2. R.D. Cook., D.S. Malkus., & M.E.Plesha., "Concepts and Applications of Finite Element Analysis", John Wiley and Sons, 3rd Edition, 1989.
3. C.S.Desai & J.F.Abet., "Introduction to Finite Element Method", Affiliated East West Press Pvt. Ltd., 1972.
4. Larry J. Segerlind., "Applied Finite Element Analysis", John Wiley & Sons, 2nd Edition, 1984.
5. K.I.Rate., "Finite Element Procedures in Engineering Analysis", Prentice-Hall of India, Pvt. Ltd., NewDelhi,1990.
6. Mendleson A, 'Plasticity 'theory and Application'
7. Harvey J.F 'Pressure Vessel Design' CBS Publication
8. Process Equipment Design by 'Brownell and Young'
9. ASME Pressure Vessel and Boiler code Sec VIII Div 1., Div II, Div 111,Sec III Div1 (Including appendices)
10. Reddy, J.N., “Introduction to Finite Element Method”, 2nd Edition, tata McGraw Hill, 2003
11. Rao Singiresu S., “ The Finite Element Method in Engineering” 4th edition, Butterworths, 2005.

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Pressure Vessel and Piping Design	Code: CEM-13:E 20 CC08:M-30
Discipline: Mechanical Engineering	No. of Lectures: 30

20 Hrs

Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference among Sec. VIII Div.1, Div.2. and Div.3
Difference between metallic pressure vessel and FRP pressure vessels

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Piping Design & Engg :10 Hrs

Fundamentals of piping, pipe sizing and their economics, selection of pipe diameter, Pipe design pressure and input parameter.
Selection of pipe materials, Galvanizing of pipes, piping lining techniques & uses
Pipe classification, piping specification, and pipe schedule, ratings
Pipes and pipe fittings, branch connection criteria
Evaluation of bill of materials in piping & estimation
Pipe flexibility analysis, Expansion loops, Bellows
Pipe stress analysis
Pipe safety in two-phase flow and other flow induced vibrations
Valves
Insulation & painting of pipe lines, costing of piping schemes
Pipe supporting arrangements
Spring hangers, spring boxes, Pipe jointing, C.I. pipe caulking, Threaded piping, Construction welding of piping, Isometric drawings preparation & reading, Piping GA drawing preparation & reading, Inch-dia, Inch-M concept, Rack piping philosophy, under ground piping, coating-wrapping of underground pipe line, Holiday detection of coating & wrapping.

Reference Books:

1 Harvey J.F., "Pressure Vessel Design", CBS Publication
2 Brownell L.E., and Young E.D., "Process Equipment Design" Wiley Eastern Ltd., India
3 :ASME" Pressure Vessel and BoilerCode", Sec. VIII, Div. I and Div. II, 1985
4 "American StandardCode for Pressure Piping", - B31.1, 1972
5 "American Standard Code for Pressure Piping", - Petroleum, Refinery Piping, B31.1, 1972
6 "Standard of Tubular Exchanger Manufactures Association", 7th Edition, 1988.
7 Chemical engineer's Handbook- Perry J.H. and Green, Seventh edition
8 Plant design and economics for Chemical engineers- Peters and Timmerhaus, 2nd edition., McGraw-Hill, New York, 1968

BARC Training School
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Syllabus

Subject: Vibrations	**Code: C EM :E26: M:20**
Discipline: Mechanical Engineering	**No. of Lectures: 20**

Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.

Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.

Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N

Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinery.

Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required, vibrations with special reference to vibrations of reciprocating systems.

Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, a periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

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Reference Books:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.
16. S.Kraham Kelly, "Fundamentals of Mechanical Vibrations", 2nd Edition, McGraw Hill, 2000 (CD is available)
17. Victor Wowk, "Machine Vibration: Alignment", McGraw Hill, 2000

BARC Training School
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Syllabus

Subject: Design aspects of Nuclear Fuel and Structurals	Code: CEM:QA-03
Discipline: Quality Assurance Engineering	**No. of Lectures: 30**

Fuel Bundle Design Approach (10 hrs) :
Design basis, Applicable codes, Material selection, Bundle design and analysis, Physics calculation, Radial flux depression across the bundle, Axial flux peaking, Engineering of the fuel bundle assembly, Pellet design, Dimensional requirements, Surface finish, UO2 chemical composition, UO2 density, Oxygen to Uranium ratio, UO2 microstructure and visual standard, Sheath (clad) design, Collapse behavior of sheath, Mechanical properties, Corrosion, Hydriding, Manufacturing process, Graphite coating, End plug design, Fuel bundle assembly design, End plate design, Bearing pad, Bearing spacer and Spacers design, Fuel bundle packing, Design analysis of fuel assembly, Thermo-mechanical analysis, Temperature distribution, Fission gas, Fuel thermal expansion, Stresses and strains in sheath, Sub channel analysis, CHF estimation, Stress analysis, Fuel bundle assembly, Analysis of end plate, Bundle droop, Fuel sheath collapse, Power ramp analysis, Fuel temperature during spent fuel transfer, Built-in safety features, Testing requirements and Type testing

PHWR Fuel Bundle operation (8 hrs):
Environmental condition, Primary coolant system requirements, Coolant channel / Linear tube region requirements, Fuel movement in Fuel handling system, Normal operation, Operational transients, Fuel thermal power, Fuel bundle power envelopes, Duty envelopes, Bundle power operating limit envelope derived from design, Linear heat ratings (LHR) and ∫Kdt (Integral Kdt), Fuel burnup, Fuel residence time in the reactor, Power ramps, Fueling machine compressive loads on fuel bundle, Refueling impact load on bundle, Defueling, Fuel bundle decay heat, Shutdown refueling, Fuel bundle operation during upset condition, Abnormal thermal power, Abnormal fueling machine loads, Sheath overheating, Sheath over-straining.

Pressure Tube Operation and design approach (8 hrs):
Operating Environment for fuel Channel, Material Selection for Pressure tube, manufacturing process for pressure tubes, degradation and failures modes for pressure tube like irradiation diametric and axial Creep, Growth, corrosion, Delayed Hydride Cracking, Design approaches based on degradation and failure mechanisms, Leak before Break (LBB) criteria, mitigation irradiation changes in the pressure tube, interaction of pressure tube with fuel bundle during operation.

Calenderia tube and Garter Spring (4 hrs):
Operating Environment, Material Selection for calandria tube and garter spring, manufacturing process, Failures modes, PC-CT contact, irradiation induced changes, Design approach, mitigation irradiation changes, corrosion mechanisms, interaction of pressure tube with Calanderia tube and Garter Spring.

Reference:

1. Corrosion of Zirconium Alloys in Nuclear Power Plants, IAEA-TECDOC-684, January, 1993
2. Assessment and Management of Ageing of Major Nuclear Power Plant components Important to Safety: Candu Pressure Tubes, IAEA-TECDOC-1037
3. Materials in Nuclear Energy Applications, Volume-I & II, C.K.Gupta, 1989
4. Nuclear Reactor Engineering, Samuel Galsstone
5. Thermo Physical Properties Data Base of Materials for Light Water Reactors and Heavy Water Reactors, IAEA-TECDOC-1496,2006
6. Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies-Operational Behavior, IAEA Nuclear Energy Series No.NFT-4.3, 2012
7. Advanded Fuel Pellet Materials and Fuel Rod Design for Water Cooled Reactor, IAEA-TECDOC-1654, 2010
8. Handbook of Nuclear Engineering, Volume-I, Dan Gabriel, 2010
9. Status of Fast Research Reactor and Technology Development, IAEA-TECDOC-1691, 2013

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Materials characterization and Applications	**Code: CEM:EN713,**
Discipline: Quality Assurance Engineering	**No. of Lectures: 25**

Microscopy Techniques (10 hrs)

Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Importance lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, Sample preparation, Etching of samples and Etchants for various materials. Quantitative analysis using optical microscopy (Grain Size, Inclusion Analysis-Size and Distribution etc.) , Interpretation of Micrograph for defects.

Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.

Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast,. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice, and Ewald sphere construction, indexing of selected area diffraction patterns, High resolution electron microscopy.

Scanning electron microscopy : interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and focus Other modes of operation, Application in failure analysis, fracture surfaces etc.

Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, field ion microscopes.

X-Ray Diffraction and Applications (10 hrs)

Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production, and detection of x-rays. Intensity of diffracted beams - scattering by an electron by an atom, by a unit cell, structure-factor calculations; factors to be considered in calculating the intensities.
Experimental methods in x-ray analysis; Laue methods, power photographs diffractometer and spectrometer measurements.

Applications: orientation of single crystal, crystal structure of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline aggregates, crystal size crystal perfection, crystal orientations:

Analytical Techniques: (5 hrs)

Methodologies of Chemical Characterization of Nuclear Materials by Wet chemical and instrumental methods. Introduction on principles of spectroscopic techniques Analysis of Uranium based materials produced at NFC for metallic impurities by spectroscopic techniques Analysis of Zirconium based materials produced at NFC for metallic impurities by spectroscopic techniques Analysis of steel based materials produced at NFC for metallic impurities by spectroscopic techniques

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Introduction on principles of wet chemical methods, Analysis of Uranium based raw materials and process intermediates by wet chemical methods, Analysis of Zirconium based raw materials and process intermediates by wet chemical methods, Analysis of steels by wet chemical methods

Introduction to Gas Analyzers, Analysis of Uranium based materials produced at NFC for non-metallic impurities by Gas Analyzers, Analysis of Uranium based materials produced at NFC for non-metallic impurities by Gas Analyzers, Analysis of zirconium based materials produced at NFC for non-metallic impurities by Gas Analyzers, Analysis of steels for non-metallic impurities by Gas Analyzers

Reference:

1. Physical Metallurgy Principles and Practice, V.Raghavan, III Edition
2. Transmission Electron Microscopy by David B.Williams, C.Barry Carter
3. Electron Microscopy and Analysis, Peter J.Goodhew, John Humphreys, Richand Beanland
4. Introduction to Optical Microscopy, Jerome Mertz
5. Metallography Principles and Practice, Vander Voort
6. Vogel's Quantitative chemical analysis: J. Mendham, R.C. Denney, M. J. K. Thomas, David. J. Barnes, (2009), 6th edition, Pearson.
7. Vogel's Text book of Qualitative inorganic analysis (2013), G. Svehla, B. Sivasankar, 7th edition, Pearson.
8. Principles of instrument Analysis(2014), 6th Edition, Douglas A. Skoog, F. James Holler, Stanely R. Crouch, 6th edition, Cengage
9. Skoog and West's fundamental of analytical chemistry(2012), F. James Holler, Stanely R. Crouch, 9th edition, Cengage
10. Analytical chemistry, Qualitative analysis; F.P Treadwell, William. T. Hall, S.B , Volume 1, John Wiley and sons; London
11. Chemical Analysis, Modern Instrument methods and Techniques; Francis Rouessac and Annick Rouessac; University of Le Mans, France, 2nd edition,; John Wiley and Sons, London
12. Modern Analytical Chemistry (2000), David Harvey; McGraw Hill Publication;
13. Analytical chemistry of zirconium and hafnium, Anil K. Mukherji, (1970), 1st edition, Pergaman press
14. Determination of Gaseous elements in Metals, Chemical Analysis (1974), P.J.Elving and I.M
15. Analysis of Non-Metals in Metals- Proceedings of International Conference Berlin (West), June 10-13, 1980; Editor Gunther Kraft, Walter de Gruyter.

BARC Training School

NFC, Hyderabad

Syllabus

Subject: NDT and QC of Nuclear Fuel and structural components	**Code: CEM:QA-02**
Discipline: Quality Assurance Engineering	**No. of Lectures: 40**

NDT Techniques for Inspection of Materials: (28 hrs)

Ultrasonic testing (UT) : Principle and propagation of ultrasound, Properties of Ultrasound, Types of Transducers, Ultrasonic Testing Methods, UT Techniques, Calibration of Equipment, Instrument Control, Method for Evaluating Discontinuities, UT Procedures for casting, forging, tubes, bars and welds, Limitation, Code Requirement, Acceptance Criteria for Weld Metals.
Eddy current testing (ECT) : Physical Principles, Electricity, Magnetism, Electromagnetic Induction, Factors effecting Induction, ECT probes, Practical Characteristics of Probes, Design of Probes, Instrumentation of ECT equipment, Testing Procedures, Reference Standards, Applications, Presentation of Results
Radiography (RT) : Type of Industrial Radiation sources and Application, Radiographic Exposure Factors and Technique, GAMA Ray and X-Ray Equipment, Type of film and Screens, Image Quality Indicators Section, Radiographic Techniques, Film Processing, Viewing of Radiographs, Radiograph Interpretation, RT Procedure Qualification, RT Procedures for welds, RT Acceptable Level of Welds and radiation safety Codes.
Leak testing : Theory and Principle of Leak Testing, Equipment, Techniques and Calibration, Interpretation and Evaluation of Results, Leak Testing Procedures, Leak Testing Specifications.
Visual testing and Liquid Penetrant testing (LPT): Overview, Physics of light, Light Sources, Optical Aids, Measuring/Inspection Equipment, Surface Condition, Interpretation of Results and Evaluation. Principle of LPT, Equipment, LPT Procedures, Materials, Evaluation of Indication, Application of LPT, Hazards Precautions, Code Requirements.
Magnetic Particle Testing (MPT) : Principle of MPT, Type of Magnetization, Type of Magnetizing Current, MPT Equipment, Method of De-Magnetization, MPT, MPT, MPT Procedures, Evaluation of Indications.
Applicable Codes and Standards for NDT

Quality Checks during Fabrication of Tubes, Components, Fuel and Structurals (5 hrs)

Fuel Fabrication: Qualification of machine, material and men, Quality checks during PHWR fuel fabrication, viz Powder, pellet and Fuel bundles, Quality checks during BWR fuel fabrication, Quality checks for Fast reactor fuel and components.
Zircaloy Tubes and Components: Process Qualification, Types of Defects and Origin, Testing Procedures, Inspection of Ingot, Billets, Blanks, Dimansional and visual Inspection of Tubes,
Pressure Tubes and calandria Tubes: Process Qualification, Types of Defects and Origin, Testing Procedures, Inspection of Ingot, Billets and blanks. Specifications, relevance and final Inspection of tubes, Report Generation and Documentation.

Contd...

Introduction to Metrology (5 hrs):

Drawing symbols and methods of measurement, Linear metrology instruments viz. vernier caliper, vernier height gauge, micrometers, bore gauges etc., Measurement of straightness, flatness, squareness, parallelism, roundness, surface finish, Taper measurement, angle measurement, radius measurement, end squareness measurement, Introduction to CMM and non contact measurement system, Documentation

Advanced NDT Techniques (2 hrs)

Acoustic Emission, Infrared Thermography etc

References:

1. General dynamics (NDT techniques), ASNT Level-III Study Guide,
2. Handbook on NDT, Volumes 1 to 10, III and IV Editions, ASTM & ASME Hand Books
3. Practical Non-destructive testing, Baldev Raj et al, 1997
4. Practical radiography-Baldev Raj, B.Venktraman, 2004
5. Non-destructive testing of Welds-Baldev Raj, T.Jayakumar, 1999
6. Practical Eddy Current Testing, BPC Rao, 2007
7. Eddy Current Testing, Theory & Practice, ASNT reference Manual 1995
8. General Dynamics, Non-destructive Testing, General Dynamics, IV Edition
9. ASNT Level-III Study Guide, Electromagnetic Testing, Radiography, Ultrasonic Testing, Visual Testing
10. Acoustic Emission Testing, Leak Testing, Materials and Processes for NDT Technology, III Edition.

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Syllabus

Subject: Statistical Quality Control for QA	Code: CEM:QA-01
Discipline: Quality Assurance Engineering	**No. of Lectures: 30**

Introduction and Planning for Quality (3 hrs)

Concepts of quality, Inspection , Quality control , Quality Assurance, Total Quality Management, Cost of quality. Quality Policy, Quality plans, Quality control Instructions, Quality Audit and Surveillance.Factors Effecting Quality, Tools for quality improvement viz. Pareto Analysis, Cause and Effect Diagram, Failure Mode & Effect Analysis, SQC tools and Six sigma. Report generation and documentation

Descriptive statistics (5 hrs)

Sample, population, parameter, qualitative and quantitative characteristics etc., summarization of data; frequency distributions; histograms; visual methods of representation of data; measures of central tendency and dispersion; Skewness and Kurtosis; regression and correlation.

Probability Theory (2 hrs)

Classical definition of probability, conditional probability, independence, random variables, expectation, Hypergeometric, Binominal, Poisson and Normal distributions.

Inference (6 hrs)

Sampling distributions : Chi-square, t and F. Estimation of parameters; point and interval estimates standard error of estimates. Tests on proportions, means and standard deviations, simple non-parametric tests, introduction to analysis of variance.

SQC Techniques (6 hrs)

Theory Control Charts Concepts of quality and meaning of control, basic philosophy and principle of rational subgrouping. Different types of control charts (Xbar-R, np, p and c-charts). Specification and process capability. Economic centering of the process; Setting approval, statistical concepts of fits and tolerances. Modification of Control Charts - Group control charts, sloping control charts, modified control charts, median and midrange charts, narrow limit gauging, Control Chart to eccentricity, Cumulative sum charts, Master control charts.

Contd…

Acceptance Sampling (5 hrs)

Sampling Vs. 100 percent inspection, basic concepts of sampling inspection, conflicting interests of producer and customer, attributes inspection, producer's and consumer's risk, AQL, LTPD, OC curves, AOQL, ATI, Single, Double, Multiple and Sequential sampling plans. Published sampling plans –, MIL-STD 105D, IS-2500 (PartI), variables inspection plans, MIL-STD 414, IS-2500 (Part-II), Hamilton Lot-Plot Method.

Industrial Experimentation (3 hrs)

Principles of experimentation: randomization, replication, local control. Introduction to factorial experiments and Orthogonal Array Designs.

References :

1. Montgomery, Douglas C (2013). Introduction to Statistical Quality Control, 7th edition. John Wiley & Sons (ISBN: 978-1-118-14681-1).
2. Statistical Quality Control, McGraw-Hill Series, Eugene L.Grant, 1996 Edition
3. Juran's QUality Handbook, J.M.Juran & Joseph Defeo, Indian Edition, VI Edition, 2017
4. Juran's Quality Handbook, Joseph Defeo, VII Edition, 2016

Core Electives Module

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Syllabus

Subject: Systems Management : A B C D and E	**Code: C Elect :AC06,AC08, CC10: CEEIM:50**
Discipline: Chemical, Electrical, Electronics & Instrumentation and Mechanical Engineering	**No. of Lectures: 45**

A: Project Management: 10 Hrs
B: Operations Management: 10 Hrs
C: Maintenance Management: 10 Hrs
D: Quality, Environment, Health & Safety Management: 5 Hrs
E: Reliability Engg. : 10 Hrs

A) Project Management AC06 (10 Lectures)
Introduction, terminology, definitions: Differences between Project Management and other functions management: special safety aspects for Nuclear Projects., legal requirements.

Project life cycle – important stages, activities in each flow-chart of clearances/ approvals at each stage: Project conceptualization, pre feasibility, Techno economic feasibility report (TEFR): Detailed Project Report (DPR) – major contents.

Time value of money, Investment Criteria, Economic evaluation methods for Project alternatives/ investments –(ROI, IRR, DCF): cost estimation methods – unit rates, factoring, data capture fran close-out reports : Items of cost in procurement of major equipments (imported) (duties, customs' clearance, receipt, octroi, insurance etc): Site selection for project – quantitative and qualitative aspects numerical problems using Brown – Gibson model for choice.

Organisation structure for projects – Matrix type –adv/limitations, responsibility allocation, team building, HR aspects.

Project scheduling: Gantt charts, Network diagrams, PERT – CPM, Numerical problems, Float, Crashing, Work breakdown structure, time monitoring / contour.

Resource planning, optimization, leveling, monitoring, control through budgets, 'S' curves, Bell curves, histograms, use of milestones, reports, meetings, communication

Use of computer software like MS Project, PRIMAVERA, Capabilities, reports, decision support / monitoring & control tools hands on working of simple projects.

Analysis of failures / delays of earlier projects – reasons, case studies, recommendation to avoid repletion for future.

Presentations by small groups of small typical project including PLC stages, CPM, resources, monitoring / control reports.

Contd....

B) Operations Management CC10 (10 Lectures)

Quality Management System (QMS) as per ISO.9001-2008
Environment Management System (EMS) as per ISO.14001

Principles of Auditing of QMS & EMS
Operations (systems) function in the organization, conversion process, operations management-definition, different views- classical, behavioral and modeling views of management. Frame work of managing operations - planning, organizing and controlling, operations objectives.

Planning: Strategic Planning for Production! Operation, Forecasting in operations, forecasting models, forecasting requirements, constraints setting production targets! capacity planning, materials requirement planning, MRP objectives, MRP system components - Master Production schedule, inventory status, Bill of materials manpower, maintenance spares, scheduling of production targets.

Organizing: Implementation of operations plans, startups, shut down of process systems under normal & abnormal conditions. Operations procedures, Technical specifications, safety manuals, emergency preparedness plans. Monitoring of plant parameters, evaluation of plant performance indicators, plant trips/ failures analysis and feed back, energy & utility consumptions, Inter group coordination for plant maintenance, prioritizing the maintenance activities, safe handling of process system for maintenance safety work permit system & ensuring safety during maintenance, handling emergency conditions.

Controlling: Controlling the conversion process inventory control fundamentals, inventory concepts, multistage inventories, multiechelon inventories, inventory systems, inventory costs, inventory models managing for quality, product quality, quality management system, analysis for improvement, quality costs or pay. (2 Hr)

C) Maintenance Management AC08 (10 Lectures)

Meaning of the term 'Maintenance' - nature of failures of components and systems in different contexts like civil, electrical, electronics (both hardware items and software systems), instrumentation, and mechanical engineering. Objectives of the Maintenance function.

Manufacturing process and production equipment - study of relation between failure rate of a component population and the related component life-time - causes of failures, remedial strategies for different periods of the component life (infant mortality / useful life / wear-out periods).

Concept of availability and related definitions, failure statistics, repair statistics - various terms used in maintenance engineering and their definitions / explanation.

Study of various maintenance techniques — Break Down Maintenance (or Reactive / Unplanned / Run-to-failure / Emergency Maintenance), Preventive Maintenance, Planned Maintenance, Routine Maintenance, Predictive Maintenance (or Condition-Based Maintenance - CBM), Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM), Total Quality Maintenance (TQMain).

Contd...

Spare parts management.

Computerized Maintenance Management Systems (CMMS).

Maintenance organization, fundamentals of maintenance planning, work scheduling, safety in maintenance - work permit system, work flow and control, establishing basic values in maintenance, maintenance audit, performance metrics in the maintenance function - the role of management & leadership.

Organization of the Maintenance Function at NFC.

D: Quality & Environment Management: 5 Hrs

ISO Systems

- **Systems Standards vs product standards**
- **ISO 9000 Family of Standards for Quality Management System**
  Genesis, Purpose, Scope, Quality Management Principles, First release, Revisions, Terms and definitions, clauses of ISO 9001:2008, Customer satisfaction, continual improvement, Documentation requirements, Policy Manual, Control of documents, Control of records, Responsibility, authority and Communication, Management review, Human resources, product realization, Design & Development, Purchasing, Control of Production, Validation of processes, Identification & traceability, Monitoring & measurement, Calibration, Analysis of data, Corrective and preventive actions etc.

- **ISO 14000 family of Standards for Environmental Management System**
  Ozone depletion, Global warming due to Green House Gases, Pollution, Social responsibility, Sustainable development, Statutory requirements Public hearing, Environmental policy, conservation of resources; control of discharges to air, land and water bodies; Environmental aspects, evaluation of impact of environmental aspects, Environmental objectives, Management programs for prevention of pollution, Emergency preparedness and response, Environmental monitoring, Management review of environmental performance, Continual improvement of environmental performance etc.

- **OHSAS 18001:2007 Specification for Occupational Health & Safety Management System:**
  Statutory requirements, Hazards, Evaluation of risk associated with hazards, Safety indices, Incidents, Accidents, Near Misses, Loss prevention, designing for safety, PPEs, Management programs for minimizing risk, Safety training, Mock drills and Emergency handling

- 3rd party certification of the Management Systems of an organization as per the international standards (ISO 9001, 14001, 18001 etc...)
  Internal audits, external audits, certification, validity of certificate, need and benefits of certification.

Contd....

E: Reliability Engg: 10 Hrs

Reliability mathematics: Probability, Distribution functions, some discrete and continuous distributions in Reliability, Definitions of Reliability, Availability, Life characteristic curve, Exponential Law of reliability.
System Reliability: Systems with components in series/parallel, Redundancy techniques, failure Mode & Effect Analysis (FMEA),Boolean methods, Cut-Set Tie Set methods, Fault-Trees and Event Trees, Design for Reliability including Fail Safe concepts, single failure criteria etc.

Probabilistic Risk/Safety Assessment: Risk, PSA of Nuclear Power Plants, identification of initiating Events, dominating IEs.
Reliability Testing: Environmental Testing, confidence interval Estimation, Time Terminated, and failure terminated tests.
Human Reliability Analysis: Human errors, Skill, Rule and Knowledge Based Actions, Human Reliability during Emergency conditions, cognitive errors.
Economics of Reliability Engineering: Manufacturer's cost, consumer cost, life cycle cost, Economic Decision Models.

Reference Books:

1. Reliability Engineering for Nuclear and other High Tech Systems by Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg by Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis by Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design by Parag K. Lala, Prentice Hall, (1985)
6. Reliability for the Technologies by Leonard A. Doty, 2nd edition
7. Environmental Engineering :Peavy. Howard.S – MC Graw Hill, New York
8. Introduction to Environmental Engineering & Science 2nd Edition: Masters Gilbert M – Printice Hall of India, New Delhi
9. Industry Environment & Pollution: P K Goel & Arvind Kumar – ABD Publishers, Jaipur
10. ISO-9001 – 2008 standard
11. ISO-14001 – 2004 standard
12. OHSAS-18001-2007 standard
13. Production & Operations Management
14. Essentials of Mgt – An international perspectives 7th edition Harold, Koontz Tata McGraw Hills, New York
15. Practical Project Management: Ghattas. R G and Mckee Sanda L – Pearson Singapore
16. Project Management with CPM & PERT. 2nd Edition: Moder Joseph J & Philips Cecil R – Van Nostrand, Newyork
17. Project Management Vol-1, 2, 3, 4, 5: ICFAI – The Indian Institute of Chartered Financial Analysis of India
18. Project Planning Scheduling and Control: Hands on Projects in on time and Budget: 3rd Edition: James P Lewis – MGH, New York
19. Project Planning Scheduling and Control: Hands on Guide to Bringing Projects in on Time and on Budget - James P Lewis – MGH, New York
20. Rase Howard F & Barroe M H, "Project Engineering of Process plants", John Wiley, 1968
21. S.N. Chary, "Production & Operation Management", Tata McGraw Hill, 2009
22. Richard B Chase et al, "Operations management for Competitive Advantage", 11th Edition, Tata McGraw Hill, 2009
23. Maintenance Engineering Handbook, by Keith Mobley & others, McGraw Hill Education, 8th edition (2014)
24. Handbook of Maintenance Management and Engineering, by Mohamed-Ben-Daya & others, Springer, 2009.

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Syllabus

Subject: Electrical Engineering Practices in Process Industries	Code: CElect:FC09:E -20
Discipline: Chemical Engineering	**No. of Lectures: 20**

Fundamentals of electricity: DC/AC , Concepts of Active, reactive & apparent power Power factor & methods to improve the system power factor, Electricity tariff, Maximum demand, average demand, Load and capacity factor
Power Supplies: Classification of power supplies (Class I,II,III,IV) – batteries and their types, battery chargers, invertors & uninterrupted power supply system, diesel generator, protection to be given to batteries, UPS and DG sets.
Electrical Machines : Transformers, losses in Transformers, efficiency, Induction & Synchronous Motors, Technical Specifications, Characteristics Operations & Maintenance, Motor Starters calculation of percentage loading of motors, Motor efficiency calculations, factors affecting performance of motors,
Variable Speed AC drives: Need & selection, advantages
Industrial Electrical Heating Systems: Types of furnaces, Selection of heating elements, Thermal Insulation & System heat losses.
Classification of electrical equipment in hazardous areas, properties of hazardous gases, selection and installation of electrical equipment in hazardous areas, standards applicable for electrical equipment in hazardous areas.

Circuit Brakers : Types and applications
Safety Aspects: Electrical Shock ---- Various definitions-Let Go Current, Touch Voltage, Time current curves/zones for AC and DC currents, Effect of frequency, Resistance of the human body
Likely effects of current flow through human body, Risk of electric shock from various sources such as batteries, domestic mains, industrial mains, power distribution system and lightning, protection against electric shock, Methods of earthing, Earth grid, Soil resistance, Use of ELCBs on appliances.

Cables & Cables Trays: Types of cables, Power & Control Cables, PVC, HRPVC & XLPE cables, FRLS cables (their properties), Fire survival cables.

Reference Books:
Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
Contd……
Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey, Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey
Source book of Electronic circuits by Markus John, Pub: McGraw Hill, New York
Electrical control for machines 3rd edition, by Rexford, Kenneth B, Pub: Delmer
Elec Engg materials by A.J. Dekker, Prentice Hall, New Jersey
Basic Elec. Engg 2nd edition by D.P. Kothari & I.J. Nagrath Pub: Tata McGraw Hill, New York S.Rao, "Testing, Commissioning, Operation & Maintenance of Electrical Equipment", Khanna Publishers, 2008

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Syllabus

Subject: Energy Conservation and Demand Side Management	**Code: CElect:AC07-CMI-20**
Discipline: Chemical and Electrical Engineering	**No. of Lectures: 20**

Energy Scenario: Primary energy sources, commercial energy production in the world and in India, energy needs of growing economy, long term energy scenario, energy security, energy conservation & its importance, Global environmental concerns, UN Framework convention on climate change (UNFCC), sustainable development, Kyoto Protocol, Clean Development Mechanism (CDM), Energy Conservation Act – 2001 and its features.

Thermodynamic Analysis: Concept of energy, energy analysis, min. energy requirements, energy flow diagram/sankey diagram, Bench marking of energy consumption in the chemical process units...etc. Energy Economics, energy saving and cost involved, evaluation through pay back period, cost-to–benefit ratio.

Energy Conservation Techniques:
Energy efficiency in thermal utilities:- Boilers, steam distribution system, Furnaces, insulation & refractories, cogeneration, waste heat recovery, heat exchanger Networking, Energy saving potential & identification.

Energy Efficiency in Electrical utilities: Electric load management & maximum demand control, power factor improvement, distribution & transformer losses, energy efficient motors. Losses in compressed air system, Refrigeration system, pumping systems, cooling towers, lighting system. Energy efficient technologies – max. demand controllers, automatic Power factor controllers, energy efficient motors, variable speed drives, and energy efficient transformers.
Energy Audit: Purpose of Energy Audit, steps involved in energy audit, measurement of important parameters, collection of data & analysis, preparation of audit reports, energy index calculation, recommendation.

Reference Books:
1)Energy Auditing made simple by P.Balasubramanyam: Aug 2004 : Bala Consultancy Services
2) Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
3) Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
4) Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey, Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
5) Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey

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Syllabus

Subject: Vacuum Technology	**Code: CElect :M-13 :New-C-20**
Discipline: Chemical and Mechanical Engineering	**No. of Lectures: 20**

1. INTRODUCTION TO VACUUM

Basic terms and concepts in vacuum, Units used Pressure ranges in vacuum and their characterization.

2. VACUUM PHYSICS

Gas laws and models. Continuum theory. Kinetic gas theory. Types of flow and conductance.

3. VACUUM GENERATION & IMPORTANCE OF SEQUENCE OF OPERATION

Classification of pumps based on the operating Principle. Compression pumps. Water ring pumps, steam ejector pump, mechanical rotary pumps (rotary vane and rotary piston), diffusion pumps, mechanical booster pump, oil vapor booster pump, turbo molecular pumps, seals for vacuum pumps. Condensation and getter type pumps. Cryopumps, sputter ion pumps, sorption pumps.

4. VACUUM MEASUREMENT

Fundamentals of low-pressure measurement. Classifications of different gauges. Hydrostatic gauges. McLeod gauge, bourdon tube, capsule gauge and u-tube manometer. Thermal energy gauges. Thermocouple and pirani gauges. Electrical energy gauges
Hot cathode and ionization gauge, cold cathode ionization (penning gauge)

5. CONSIDERATIONS IN SYSTEM DESIGN

Calculations of conductance values. Gas and vapor load. Matching pump combination.

6. LEAK DETECTION OF SYSTEMS & MEASUREMENT

Leak location by rough methods.Penetrant dye, spark tester etc. Leak location by over pressure methods. Bubble methods, halide torch etc.
Leak location by vacuum methods. Discharge tube, mass spectrometer etc.

7. APPLICATIONS

Low-pressure applications (e.g. mechanical handling based on rubber suction pads)
Low molecular density applications (e.g. removal of impurities during chemical processes) Vacuum metallurgy. Decrease in energy transfer applications (e.g. thermal insulation, electrical insulation) Large mean free path applications (e.g. electron tubes, nuclear physics)

8. QUALIFICATION OF VACUUM SYSTEMS

9. INTER LOCKS & SAFETY IN VACUUM SYSTEMS

10. VACUUM CASE STUDIES

Reference Books:

1) Guide to the measurement of Pressure and Vacuum : The Institute of Measurement and Control, London
2) Introduction to Vacuum Technology by Dr. K G Bhushan under the Indian Vacuum Society
3) A.Chambers et al, "Basic Vacuum Technology", 2nd Edition, Oversees Press, 2005

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Syllabus

Subject: Statistics for Engineers	**Code: C.Elect 10:New M C:20**
Discipline: Chemical and Mechanical Engineering	**No. of Lectures: 20**

1. Treatment of data – Graphical methods: Stem – and – Leaf, Box plots, etc. Descriptive methods: Sample mean, median, mode, variance, percentiles
2. Basic probability: Counting, basic laws, and elementary theorems; independent events
3. Discrete random variables and distributions – Binomial , hyper geometric, poisson, mean and variance, poisson process
4. Continuous random variables and distributions – normal , normal approximation to binomial, gamma exponential , probability plots
5. Random sampling and sampling distributions : "t" distribution, chi square and "F" distributions
6. Estimation: Confidence intervals, sample size determination, prediction and tolerance levels
7. Tests of hypothesis for one and two means, sample sizes, paired sample tests
8. Simple linear regression: Curve fitting, Linear correlation, and models
9. Control charts : X- bar , R and "p" charts

Reference books:

1. Probability and statistics for engineers and scientists (7^{th} edition by Walpole , Myers and Ye-2002)
2. Minitab software

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Subject: Industrial Instrumentation Practices and Human Machine Interface	**Code: CElect 17:E51 E50:I-30**
Discipline: Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 20**

Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems. Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices. Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design-relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.

PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. OPC Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Contd....

Overview of plant automation. (1 lecture)
Design of HMI, Soft Console versus Conventional control panels (1 lecture)
Guidelines for design of HMI displays (1 lecture)
Case study of a commercially available Professional HMI package. (10 lectures)
Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
Practical (2 lectures)

Reference Books:

1. Biomedical Instrumentation and Measurements : Cronwell Leslic - Prentice Hall, New Jersy
2. Tranducers and Instrumentation: Murthy DVS – Prentice Hall, New Delhi
3. Instruments Engineers Handbook: Process Measurement: Liptak, Belag –Chilton Books
4. Instruments Engineers Handbook: Process Measurement & Analysis: Liptak, Belag Butter Worths
5. Instruments Engineers Handbook Vol - II: Process Control - Liptak, Belag –Chilton Books
6. Process / Industrial Instruments & Control Hand Book : Considne DM – MGH, New York
7. Considine, D A, "Process Instruments and Controls Handbook", McGraw Hill, 1957
8. A.D.Helfric & W.D.Cooper, "Modern Electronic Instrumentation and Measurement Techniques"

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Syllabus

Subject: Mechatronics	**Code: CElect. AC14:EEMI :20**
Discipline: Electrical, Electronics, Mechanical and Inst Engineering	**No. of Lectures: 20**

Pneumatic control engineering: - Introduction, compressed air line installation, Pneumatic equipment like cylinders, seals, control valves and accessories. Graphical symbols for energy conversion, control valves, energy transfer and conditioning, actuators, converters, counters and sensors. Classification of cylinders based on operating medium, functions performed; basic construction, mounting style etc., various types of seals, materials, usage. Different type of directional control valves, classifications based on usage, functions and actuation, flow control valves and pressure control valves. Pneumatic circuits, electro-pneumatic circuits, bi-selector systems. Cycle times, Applications of pneumatics and trouble shooting. Standard vendor list.

Hydraulic control engineering: - Introduction, Pump, reservoir, valves and actuators. Selection of pump, tank, Air breather, Baffle plate, pipelines, relief valves, Simple valves, Directional control valves, Flow control valves, special valves, un loading valves, counter balance valves, pressure reducing valves. Filters, selection and location. Hydraulic circuits, basic, regenerative, sequencing and counter balancing circuits. Rotary motion. Hydraulic accessories like accumulator, hydraulic intensifier, pressure switches Pressure gauges and flow meter. Introduction on Hydro pneumatics and electro-hydraulic (servo) systems. Trouble shooting. Standard vendor list

Electrical/electronics control engineering: Introduction and applications of diode, transistor, thyristor, LED's, Opto-isolators, etc. Solenoid valves DC and AC selection of solenoid valves, rating, stepper motors, servo motors, encoders: rotary and linear, transducers, positional sensors.

Cont...

Mechanization: Introduction. Handling: gripping, feeding, Forging, Inserting, positioning, clamping, working, removing, transferring Etc., Orientation: Position control, turning, rotation, division. Feeding, Assembly operations, linear indexing, rotary indexing, Door control. Bulk feed like Conveyors, industrial vehicles, over head equipment's, Containers and supports, Positioning weighing and control equipment.

Introduction to Industrial Robotics: CNC

Reference Books:

1. Mechatronics: Electronics in Products and Processes:Bradeley. DA - Eswar Press, Chennai / Chapman Hall, U K
2. Mechatronics : HMT Ltd – Tata MGH. New Delhi
3. Mechatronics : Electronics Control Systems in Mechanical and Electronical Engg. 3rd Edition : W.Bolton - Pearson

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Subject: Robotics	**Code: Celect:M14:New-EC:20**
Discipline Electrical, Electronics, Inst Engineering	**No. of Lectures: 20**

Pneumatic control engineering: - Introduction, Pneumatic equipment like cylinders, seals, control valves and accessories. Graphical symbols for energy conversion, control valves, energy transfer and conditioning, actuators, converters, counters and sensors. Classification of cylinders based on operating medium, functions performed, basic construction, mounting style etc.,
Different type of directional control valves, classifications based on usage, functions and actuation, flow control valves and pressure control valves.
Pneumatic circuits, electro-pneumatic circuits, bi-selector systems.
Applications of pneumatics and trouble shooting. Standard vendor list.
(2 Lectures)

Hydraulic control engineering: - Introduction
Simple valves, Directional control valves,
Flow control valves, special valves, un loading valves, counter balance valves, pressure reducing valves.
Hydraulic circuits, basic, regenerative, sequencing and counter balancing circuits.
Pressure gauges and flow meter. Introduction on Hydro pneumatics and electro-hydraulic (servo) systems. Trouble shooting. Standard vendor list
(2 Lectures)

Electrical/electronics control engineering:
Solenoid valves DC and AC selection of solenoid valves.
Stepper motors, Servo motors, encoders: rotary and linear, transducers, positional sensors.
(1 Lecture)

Mechanization: Introduction. Handling: gripping, feeding, Forging, Inserting, positioning, clamping, working, removing, transferring Etc., Orientation: Position control, turning, rotation, division. Feeding, Assembly operations, linear indexing, rotary indexing, Door control. Bulk feed like Conveyors, industrial vehicles, over head equipment's, Containers and supports, Positioning weighing and control equipment.
(3 Lectures)

Industrial Robotics: Fundamentals. Classification of Robots. History of Robotics. Advantages and Disadvantages of Robots. Robot Components. Robot Degrees of Freedom. Robot Joints. Robot Coordinates. Robot Reference Frames. Programming Modes. Robot Characteristics. Robot Workspace. Robot Languages. Robot Applications. Social & Safety Issues
(8 Lectures)

Trajectory planning: Path vs. Trajectory. Joint Space vs. Cartesian-Space. Basics of Trajectory Planning. Joint space trajectory planning, Cartesian space trajectories.
(4 Lectures)

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Modern Control Systems	Code: CElect:E52A-EC -20
Discipline: Electronics and Instrumentation Engineering	**No. of Lectures: 20**

State Variables Descriptions Introduction, The concept of State, Elementary Definitions, State space Representations of continuous-time and discrete-time systems, State diagrams, Illustrative examples, Solution of state equation, State transition matrix, Properties of state transition matrix, Computation methods of state transition matrix, relationship between state equations and transfer functions, , Characteristic equations

Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability criteria, Principle of Duality, Controllability and Observability of discrete-time systems

Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR Technique

Reference Books:

1. John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design-Conventional and Modern" , 2nd Edition, McGraw Hill Book Co., 1986
2. Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Wintson, 1984
3. M.Gopal, "Modern Control System Theory", 2nd Edition, Wiley Eastern Ltd., 1993
4. Gene F. Franklin et al, " Feedback Control of Dynamic Systems", 3rd Edition, Addison- Wesley Publishing Co., 1994
5. B.Friedland, " Introduction to State space Methods"
6. K.Ogata, " Modern Control Engineering", Prentice-hall

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Design of High Temperature Components	**Code: CElect 11: New : Mech-20**
Discipline: Mechanical Engineering	**No. of Lectures: 20**

Introduction: Plasticity, Viscoplasticity and mechanism of creep deformation
Deformation & fracture behavior at high temperature (HT), Creep curve, Creep rupture, Life estimation parameters, Low cycle fatigue, creep-fatigue interaction.
Material selection for HT application: Thermal stability, strength, oxidation, carburization etc.
Design codes & standards: ASME codes historical background, loading categories, stress classification,
Sub-section NB & NH: Low & High temperature failure modes and limits, Design and construction rules of RCC-MR, Efficiency diagram and Bree diagram, Life assessment as per CEGB-R5.
NDE & ISI: Surface and volumetric examinations
Models for creep crack initiation and growth
Design by analysis: FEM analysis, stress categorization, time & strain rate dependent stress-strain relations, unified treatment of plastic, creep & thermal strain, theory of viscoplastic flow, elasto-plastic and creep analysis of simple geometries, time stepping algorithm etc.
Life assessment: Remaining life prediction, API 579, inspection & interval determination, integrity of steam pipes, reheat pipes and bends, super heater tubes, gas turbine parts etc.
Reference books :

1) High Temperature Component life assessment. : George A Webster, R A Ainsworth 1994 – Technology & Engg.
2) Creep & Fracture in High Temperature Components. Design & Life assessment issues, : I A Shibli & S R Holdsworth
3) Welding Technology & Design By V M Radhakrishnan

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Syllabus

Subject: Welding and Quality Assurance of welds	Code: C-Elect :CC06-M-20
Discipline: Mechanical Engineering	No. of Lectures: 20

Introduction To Soldering, Brazing & Different Types Of Welding Like: Arc Welding, Gas Welding, Resistance Welding, Thermit Welding, Electron Beam Welding, Plasma Welding, Laser Welding, Explosion Bonding, Ultrasonic Welding.
Manual Metal Arc Welding: TIG/MIG & Submerged Arc Welding
Weld Joint & Geometry: (Lap/Butt/Fillet/Corner Joints: Square Butt, Single-V, Double-V, Single-U, Double-U, J-Joint, Special Joints)
M.S. Electrodes & Filler Wires: (Designation, Codes & Classification, Specifications, Fluxes & Electrode Coating – their effect on weld quality)

S.S. Electrodes: (Designation, Codes & Classification, Specifications, Electrode Coating, their effect on weld quality)
S.S. Welding: (Inter-Pass Temperature, Sensitisation & Inter-Granular Corrosion & its control, Delta Ferrite & its effect on hot cracking & Sigma Phase, Delta Ferrite Measurement – Schafflar / Delong Diagram / Magna Guage / Magnetic Saturation Method, Hard facing, Stelliting, Carburizing, Nitriding

Welding Technology:
Polarities (AC, DC(+), DC(-), Pre Heating & Carbon Equivalent , Inter-Pass Temperature, Post Weld Heat Treatment & Hydrogen Embrittlement, Stress Relieving & Solution Annealing, Distortion Monitoring, Weld Sequencing & Balanced Welding Parameters & their effect on weld quality, Weld Defects - their causes & Acceptance Criteria. Role of flux on weld quality improvement. Welding of dissimilar materials.

ASME Code Section IX
Welding Procedure Specification, Welding Procedure Qualification, Procedure Qualification Record, Welders' Qualification, Welding Machine Specification, Essential & Non Essential Variables, Positions of Welding & Their Importance

Non Destructive Testing of welds:
Radiography & Ultrasonic Examination of butt welds

Destructive tests:
All Weld Tensile Test, Transverse Tensile Test, Bend Tests, Ferrite Test, Corrosion Test, Creep Test, Micro & Macro Examination / Etching Test, Metallography Examination.

Maintenance Welding: Limitations, Difficulties, Selection of Welding Consumables. Cold welding, Powder metal spraying, underwater welding.

Reference Books:

1) Welding Metallurgy: Kou, Sindo : John Wil, New York
2) Practical Non-Destructive Testing – 2nd Edition: Baldev Raj : Narosa
3) Principles of Welding Technology-3rd Edition:Gound LM:Viva Books,New Delhi

BARC Training School
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Syllabus

Subject: Manufacturing And Industrial Engineering	**Code: C-Elect- JNTU, M -20**
Discipline: Mechanical Engineering	**No. of Lectures: 20**

Fundamentals of hot and cold working processes: Forging, extrusion, wire drawing, sheet metal working, punching, blanking, rolling, pilgering, bending, deep drawing.

Machining Processes and Machine Tool Operation: Mechanics of metal cutting, single and multipoint cutting tools, geometry and machining aspects, tool life, machinability, and economics of machining.

Inspection: Limits, fits and tolerances, linear and angular measurements, comparators, gauge design, interferometer, form and finish measurement, measurement of screw threads, alignment and testing methods.

Tool Engineering: Principles of work holding, design of jigs and fixtures, design of press working tools.

Machine Design: Machine development concepts

Advanced Manufacturing Processes: E–Manufacturing, Fundamentals of Nanotechnology, Micro-machining and High Speed Machining.

Reference Books:

1) Sensors and Control Systems in Manufacturing : Soloman, Sabrie – Mc Graw Hill, New York
2) Precision Engineering in Manufacturing : R K Murthy – New Delhi

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Corrosion Engineering	Code: CElect : C
Discipline: Chemical Engineering	No. of Lectures: 20

BASICS OF CORROSION: Electrode processes – free energy, electrode potential, emf series, Pourbaix diagrams and their practical use, Chemical Vs electrochemical mechanisms of corrosion reactions, Introduction to corrosion – Wet and dry corrosion – Theories of corrosion - corrosion rate expressions; Passivity, factors affecting passivity.

(4 h)

CORROSION AND ITS FORMS: General corrosion – atmospheric corrosion, galvanic corrosion, biological corrosion, High temperature corrosion; Localized corrosion– pitting corrosion, crevice corrosion, Intergranular corrosion, de-alloying; Mechanically assisted corrosion – erosion corrosion, cavitation corrosion, fretting corrosion, corrosion fatigue, stress corrosion cracking and hydrogen embitterment.

(5 h)

CORROSION IN REACTOR SYSTEMS: Corrosion in various reactor systems; Effect of high temperature water, cooling water, sea water; nitric acid – effect of flow, environment and metallurgical variables of materials.

(4 h)

PREVENTION AND CONTROL OF CORROSION: Corrosion control by design; Selection of corrosion resistant materials – alloying, coatings and surface treatments; Oxidation resistant materials, control of high temperature corrosion; Cathodic and anodic protection methods; Use of inhibitors-types.

(3 h)

CORROSION MONITORING & INSPECTION: Ccorrosion coupons, Electrical resistance, linear polarization resistance, electrochemical noise analysis; Inspection - liquid penetration inspection, ultrasonic testing, radiography testing, eddy current testing.

(4 h)

BOOKS FOR STUDY AND REFERENCE:

1. Herbert H. Uhlig and R.Winston Revie, "Corrosion and corrosion control", Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, "Corrosion Engineering", Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.
4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

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Syllabus

Subject: Image Processing and Machine Vision	**Code: CElect:EN-710**
Discipline: Quality Assurance	**No. of Lectures: 20**

Image Processing & Machine Vision (20 hrs)

Introduction : Digital image model representation, Image sensor, Digitalizer, Computer, Standard file format;

Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening. Histogram Modification, Colour image processing;

Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;

Boundary extraction and representation;

Morphological operations;

Image Restoration-PSF, Deconvolution, Restoration using inverse filtering. Wiener filtering & maximum entropy-based methods:

Image Compression: Models, Error free compression, Lossy compression, Standards;
Machine Vision:

Imaging model, Scene radiance and image irradiance, Reflectance model of a surface. Lamberitan and specular reflection; Photometrix stereo;

Early Vision : Low level processing for noise suppression, Segmentation by thresholding; Edge detection; representation, Mathematical Morphology;

Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, Generalized Hough Transform;

Contd....

High level vision: Scene interpretation;

Texture - Statistical, Structural and Spectral approaches;

Stereo vision and correspondence problem; Structured light; Optical flow;

Image representation: Invariants;

Unstructured objects: Snakes

Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, classification and recognition; Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
Introduction to image understanding;

Robotic applications of machine vision, Camera calibration.

Reference Books:

1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing. Addison Wesely, 1999.
2. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine, Vision Vikas Publishing House, 2003.
3. William K Pratt, Digital Image Processing, John Wiely & Sons Inc.2004.
4. Davies E.R.Machine Vision Theory Algorithms Practicalities, Academic Press.
5. D.A.Forsyth & J.Ponce, Computer Vision A Modern Approach, Prentice Hall, 2003.
6. Horn B.K.P.,Robot Vision, The MIT Press, 1987;
7. D.Ballard and C.Brown, Computer Vision, Prentice hall, 1982.
8. Wesley E.Snyder & Hairon QI, Machine Vision, Cambridge, 2004.

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Syllabus

Subject: Data Base Management system and Web Technology	Code: CElect:EN-705
Discipline: Quality Assurance	No. of Lectures: 20

Data Base Management System and Web Technology (20 hrs)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to Postgre SQL and MySQL (3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(!)
- Content Management Systems(!)
- Web 2.0 I Semantic Web(2)

Reference Books:

1. Fundamentals of Database Systems Sixth Edition Ramez Elmasri, Shamkant B. Navathe, Addison-Wesley Publication 2010
2. Database Systems: A Practical Approach to Design, Implementation and Management 2014 by Thomas Connolly, Carolyn Begg
3. An Introduction to Database Systems 8th Edition by C.J. Date
4. Web Technologies: A Computer Science Perspective 1st Edition by Jeffrey C. Jackson
5. Web Technologies Paperback 2010 by Uttam K. Roy

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Syllabus

Subject: Advanced Computational Techniques	Code: CElect:EN-701
Discipline: Quality Assurance	No. of Lectures: 20

Advanced Computational Techniques (20)
Programming Language C++

C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.

C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initializers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogonal Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO

Contd….

• Applications using above all methods to DAE related problems.

Parallel Programming

• Introduction to parallel computers, classification, technologies, ratings
• Parallel programming concepts, examples, terms and definitions, parallelism, parallel programming models
• Different examples of parallel programs and parallelization strategies
• Message Passing Interface (MPI), concepts of MPI, MPI Library calls
• MP! Point to Point communication calls
• MPI Collective communication calls

Scientific Visualization

• Geometry Classification - 2D & 3D grids.
• Structured & Unstructured grid development.
• Data storage techniques for ID, 2D & 3D grids.
• Data visualization techniques for scalar & vector data.
• Common pitfalls in programming
• Case Studies

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Syllabus

Practicals on Material Science & Engineering and Corrosion Engg.

Sl. No.	Name of the Experiment
1.	To evaluate the hardness of materials
2.	To evaluate the Tensile properties of materials
3.	Preparation of specimen for Metallography for microstructure evaluation
4.	To detect susceptibility to inter granular attack (associated with the precipitation of chromium carbide)in S.S. samples (Corrosion Test)
5.	Measurement of wall thickness by Ultrasonic test
6.	Familiarisation of Procedure and interpretation of indications in liquid penetrant test principle

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Syllabus

Practicals on Health Physics

Sl.No.	Name of the experiment
1	α – particle counting
2	β- particle counting
3	- particle counting
4	Whole body counting

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Syllabus

List of Experiments to be carried out in Process Control & Instrumentation Lab

Sl.No	Name of the Experiment	Branch
1	**Study of Flow and Level control system** a) Mention different types of instruments/equipments used in the system with their tag nos. specifications and applications b) Write the details of different material used for the system (structure & pipe lines etc).	All
2	**Study of control system (PLC & Control Panel)** a) Control system architecture b) PLC Unit (configuration & specifications) c) Control Panel (Instruments used with specifications)	All
3	Calibration of Control Valve	All
4	Calibration of Level Transmitter	All
5	Calibration of Flow Transmitter	All
6	Calibration of Differential Pressure Transmitter	All
7	Studying the characteristics of Control Valves	All
8	Single tank liquid level control using PID controller	All
9	Calibration checking of RTD/Thermocouple	All
10	Study of Field instruments	All

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List of Experiments on PLC Demo unit

Sl.No	Name of the Experiment
1	Direct On Line (DOL) Starter
2	Star Delta starter
3	Up – Down Counter
4	ON – Delay Timer
5	OFF – Delay Timer
6	Arithmetic Functions
7	Number Comparison Functions
8	Paint Spray process system
9	Speed control of AC Motor through MODBUS Communication
10	Temperature controlling using PID controller of PLC

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Syllabus

List of Experiments to be carried out in Structural Dynamics &Vibration Laboratory

Sl.No	Name of the Experiment
1	Dynamics of a three storied building frame subjected to harmonic base motion
2	Dynamics of a one-storied building frame with planar asymmetry subjected to harmonic base motions.
3	Dynamics of a three storied building frame subjected to periodic (non-harmonic) base motion.
4	Vibration isolation of a secondary system
5	Dynamics of a vibration absorber.
6	Dynamics of a four storied building frame with and without an open ground floor
7	Dynamics of one-span and two-span beams.
8	Earthquake induced waves in rectangular water tanks
9	Dynamics of free-standing rigid bodies under base motions
10	Seismic wave amplification, liquefaction and soil-structure interactions.

BACK TO MAIN

IGCAR

PGD in ENGINEERING SCIENCES
(PROGRAM CODE: ENGG00)

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
ME1	Code Design for Pressure Vessels and Piping	30	4
ME4	High Temperature Design and Inelastic Analysis	25	2
ME6	Computational Fluid Dynamics	30	4
ME8	Finite Element Method	30	4
ME10	Advanced Heat and Mass Transfer	30	4
ME13	Reliability Engineering	20	2
ME14	Manufacturing Technology	40	4
Total		**205**	**24**

SPECIALISED/ELECTIVE COURSES

(Any three of the seven listed courses)

Course Code	Course Name	Hours	credits
ME3	Machine Design	25	2
	Structural Integrity Assessment Methods and NDE	30	4
	Vibration Engineering and condition Monitoring	20	2
ME5	Seismic Design of Nuclear Reactors and Facilities	20	2
	Plant Dynamics	20	2
	Experimental Mechanics	20	2
ME15	Process Control and Instrumentation	20	2

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-001-P	Project	Duration : 9 Weeks	
2.	02ENGG04-001-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

1. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
2. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
3. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
4. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
5. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
6. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
7. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity

2 **Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor

3 **Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors

4 **Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation

5 **Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions

6 **Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization

B BASIC REACTOR PHYSICS-STATIC

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety
Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down
Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
7. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology (NRST)

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flowmeter: Electromagnetic pumps and flowmeter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6.	Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7.	Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Code Design for Pressure Vessel & Piping (ME1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11.	Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India

3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Finite Element Method (ME8) (30 hours)

S.No.	Course content
1.	Introduction to FEM as applied to solid mechanics. Energy principles in structural mechanics and principles of minimum potential energy
2.	Element Shape and Shape Functions: Generalised co-ordinates. General requirements of shape functions; Lagrangian and Hermitian interpolation functions – CO, C1 continuity; Natural coordinate system; Derivation of shape functions for Bar, Beam, Plane, Brick and Plate elements.
3.	Bar Element: Derivation of elemental stiffness matrix and load vector; Transformation from element to global coordinate system; Assembly of Global stiffness matrix and load vector; Solution of typical 2D-plane Truss problems to evaluate Displacements and Member forces/stress; Thermal stress evaluation in Bars/Truss.
4.	Beam Element: Derivation of elemental stiffness matrix and load vector; Solution of simple Beam problems to evaluate Deflections/rotations; BM/SF distribution and determination of stresses, Shear deformation in beams. Curved Beam Element: Derivation of elemental stiffness matrix and load vector; Derivation of stiffness matrix for elbow.
5.	Axisymmetric Thin Shell Element: Strain-displacement and stress-strain relationship; Derivation of stiffness matrix and load vector for 2 noded axisymmetric thin shell element. 2D Plane Elements – 3 Noded Triangular Element: Derivation of elemental stiffness matrix and load vector, Plane Stress/Plane Strain & Axisymmetric elements: Evaluation of Strain/Stress.
6.	2D Isoparametric Element – 4, 8 and 12 noded quadrilateral Element: mapping of parent element to global space; Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of stiffness matrix for plane & axisymmetric elements; Evaluation of strain/stress at Gauss points.
7.	Introduction and Application of 3D Elements: Strain displacement and stress-strain relationship; Tetrahedron, Triangular prism and Hexahedron elements.
8.	Plane Bending Elements: Thin and Thick plate theory; Elements based on Kirchoff's Theory; Elements based on Mindlin Theory; Shear locking and Reduced Integration.
9.	Shell Element: Strain-displacement and stress-strain relationship; Flat plate and curved shell elements; 4 and 8 noded degenerated thick shell Elements, basic assumptions, degree of freedom, shape functions and shear locking.
10.	Incompatible Displacement Model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral element.
11.	Introduction to Nonlinear Problems. Meshing and Errors: Finite Element Modeling and Discritization Criterion, Adaptive meshing, classification of FEM stresses per ASME code, sources of potential error in the finite element solution

Books Suggested:

1.Finite Element Procedures-K.J.Bathe, Prentice Hall, 1996.
2.Concepts and Applications of Finite Element Analysis, R.D.Cook,D.S.Malkus & M.E.Plesha, 4th Ed., Prentice-Hall India, 2003.
3.An introduction to the Finite Element Method-J.N.Reddy, 2nd Ed., McGraw Hill Education (ISE editions)-1993.
4.Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.1, Butterworths-Heinemann,2000.
5. Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.2, Butterworths-Heinemann,2000.

6.The Finite Element Methods: its basics and fundamentals- O.C.Zienkiewicz ,R.L.Taylor &J.Z.Hu, Elsevier,2005.
7.The Finite Element Method: Linear,Static and Dynamic Finite Element analysis-T.J.R.Hughes, Dover Publication,2000.
8.Fundamentals Finite Element Analysis and Applications-M.Ashghar Bhatti, John-Wiley & Sons, NJ,2005.

3. Advanced Heat and Mass Transfer (ME10) (30 hours)

S.No.	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes & Bemoulli equations.
2.	**Laminar Boundary Layer and Forced Convective Heat:** Formulation of differential equation for hydrodynamic and thermal boundary layer. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory. Convective heat transfer for intemal and extemal flows. Low and high Prandtl number limits and different thermal boundary conditions Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method.
3.	**Turbulent Flow and Heat Transfer:** Reynolds decomposition for turbulence**.** Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical. correlations for calculating heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
4.	**Turbulence Modeling:** Eddy diffusivity models: k-£ and k-w) models, RNG based k- £ model. Reynolds stress models: algebraic & differential models. Low Reynolds number models Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
5.	**Natural Convection:** Basic Equations of natural convection. Boussinesq approximation. Derivation of Dimensionless groups from basic equations. Analytical approximations
6.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Moment, porosity, permeability etc.., homogenization method, continuity equation & energy equation, introduction to 2 phase flows & heat transfer in fluid flows.
7.	**Heat Transfer With Phase Change** : Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post dryout heat transfer. Various models available for calculation of heat transfer coefficient.. Critical Flow. Models for single -phase and two-phase critical flow.
8.	**Radiation heat transfer:** Radiation heat transfer. Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Books suggested:

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.

3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

4. Computational Fluid Dynamics (ME6) (30 hours)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme
B.	**Numerical Solution of Complete Fluid Flow and Energy Equation:**
1.	Formulations of governing equations used in numerical simulation:
2.	Stream function-temperature formulation
3.	Stream function-vorticity-temperature formulation
4.	Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5.	Primitive-Variable (P-V-T) formulation
6.	Pressure velocity coupling for incompressible flow.
7.	Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8.	Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9.	Simple grid generation techniques for structured grid:
10.	Elliptic. parabolic and hyperbolic equation method
11.	Grid adaptation
12.	Domain decompositions in CFD and heat transfer
13.	SIP and preconditioned conjugate gradient methods for solution

14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Books suggested:

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

5. Reliability Engineering (ME13) (20 hours)

S.No.	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.\
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY.

6. Manufacturing Technology (ME14) (40 hours)

S.No. Course content

Curriculum for Metal Forming

1. **Uniaxial tensile test**:
   a. Engineering stress, engineering stain, true stress, true strain;
   b. Extraction of plastic stress-plastic strain data from load – elongation data of uniaxial tensile tests; Hollomon type and Voce type constitutive relations;
   c. Tensile instability and significance of strain harkening exponent;
   d. Determination of strain rate sensitivity index and the significance of strain rate sensitivity;
2. Stress matrix and the derivation of the Cauchy relation from the law of conservation of linear momentum; concept of principal stress;
3. Small strain matrix and rotation matrix obtained from the displacement functions;
4. **Elements of the theory of plasticity**:
   a. Decomposition of stress matrix to hydrostatic and deviatoric matrices;
   b. Yield surfaces as a function of the second and third invariants of the deviatoric matrix with von Mises and Tresca criteria being examples; concept of equivalent stess;
   c. Normality flow rule and convexity of the yield surface; concept of equivalent strain

Curriculum for Materials Joining

1. **Welding Processes**
   a. Fusion Welding Processes: Arc Welding Processes like SMAW, GTAW, GMSE, GVSE etc. and Beam welding process like EB welding and Laser Welding
   b. Solid state Welding Process like Friction Welding, Friction Stir Welding, Diffusion bonding, Explosive welding
   c. Resistance Welding Processes
2. **Thermal Cycle during welding**
   a. Weld Thermal Cycle, Dependence of bead shape with welding speed, prediction of weld thermal cycle
3. **Residual Stress and Distortion**
   a. Generation of residual stress, Effect of residual stress on performance, removal of residual stresses, measurement of residual stresses
   b. Origin of Distortion, Control of distortion

7. High Temperature Design & Inelastic Analysis ME4: (25 hours)

S.No. Course content

1. Introduction: Modes of failure, material selection, criteria to assess creep effect, creep law, creep-fatigue interaction, thermal striping
2. Design Practice: Loading category, primary, secondary and peak stress intensity, allowable stress intensity (S_m), assessment of basic wall thickness, strain limits

3. Analysis: strain range under multi axial state of stress, Nuber's rule, triaxiality, elastic followup, fatigue damage, allowable numbers of cycle, creep damage, creep life prediction, creep rupture strength, creep fatigue interaction, ratcheting, efficiency diagrams and creep buckling
4. Fracture mechanics, creep crack growth, introduction to RCC-MR A16
5. In elastic Analysis: General principles for constitutive models, non unified model (plastic + creep), flow rule, creep strain hardening, classified models, viscoplastic material model, non-linear kinematic hardening, isotropic hardening, plastic strain memory, finite element Implementation, automatic time integration

Books Suggested:

1.Creep Analysis – H.Krauss
2.Mechanical Metallurgy-G.E. Dieter
3.Creep in Structures-A.R.S.Ponder and Drkhayhurst
4.Advances in Creep Design-Ed.A.I.Smith and A.M.Nickelson
5.ASME Section3 Subsection NH-1
6.French Design Code-RCCMR-Subsection RB

SPECIALISED/ELECTIVE COURSES

1. Machine Design (25 hours)

S.No.	Course content
1.	Principles of Machine Design: Objectives of machine design, general design rules, design methods, variable loads, Lightening of parts and rational design schemes, Rigidity of structures, Cyclical/Contact/Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs. Introduction to inventive problem solving.
2.	Design and Drawing Practices: Drawing standards, selection of tolerances, fits, and positional tolerances. Introduction to Drawing Practices: (matter from various drafting standards), Introduction to CAD (including introduction to various drafting and solid modelling softwares)
3.	Sealing Methods: Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric `O' rings, mechanical seals, labyrinth, valve packings. Methods of sealing for high and ultra high vacuum.
4.	Special Dimensional Inspection Techniques: Description of special dimensional inspection techniques, gauging techniques including composite and paper gauging, advanced inspection tools including co-ordinate measuring machines and form measuring machines.
5.	Advanced Manufacturing Techniques: Precision machining, super finishing, advanced manufacturing, Micro machining.

Books suggested:

1) Mechanical engineering design (In SI Units) - Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2) Design Of Machine Elements Edition 7 - Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3) Machine Elements in Mechanical Design - Mott (R L), Columbus, Charles E Merril, 1985.
4) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.

5) Mechanical Engineering Design (In SI Units) – Joseph E Shigley & Charles R. Mischke, New Delhi, Tata Mcgraw Hill, 2001.
6) Design of Machine Elements - Ed. 7 – Spoots M F, Shoup T E, New Jersey, Prentice Hall 1998
7) Machine Elements in Mechanical Desgin – Moot R L, Columbus, Charles E Merril, 1985.
8) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.
9) Fundamentals of machine design – Oriov, Mir Publishers, Moscow.
10) Fluid power applications – Anthony Esposito, Pearson education
11) Precision engineering manufacturing – Murthy R.L., New Age International
12) MEMS and Microsystems design and manufacture – Tai-Ram Hsu, Tata McGraw Hill.

2. Structural Integrity Assessment Methods and NDE (ME3) (30 hours)

S.No.	Course content
1.	Fracture Mechanism in Metals
2.	Linear Elastic Fracture Mechanics
3.	Elastic Plastic Fracture Mechanics
4.	Low Cycle Fatigue
5.	Assessment of Creep damage and creep-fatigue interaction
6.	Creep crack growth models
7.	Experimental determination of fatigue and creep curve CTOD, KIC, KIa, J-R curve and C*
8.	Basis of ASME Sec. XI Reference Curve and its use in Pressurised Thermal Shock
9.	CTOD design method
10.	J-Estimation Schemes and J-based failure assessment diagram
11.	Net Section Collapse Criteria and Reference Stress approach
12.	R-6 method and its application
13.	Thermal background of international assessment procedure
14.	RCCMR code/A-16 method and its application
15.	CEGB codes
16.	Application of R-5/R-6 for design of high temperature components
17.	Failure Assessment Diagram of PD-6493 and BS-7910
18.	J-Estimation Schemes and J-based failure assessment diagram
19.	Leak-Before-Break design method
20.	Analysis of numerical techniques/Computational fatigue, Fracture and creep
21.	Probabilistic Fatigue, Fracture and creep
22.	Bench Mark solutions
23.	Manufacturing and process-induced defects that influence structural integrity -
24.	Principles, capabilities and applications of surface examination NDE techniques
25.	Principles, capabilities and applications of volumetric examination NDE techniques
26.	Quality assurance of nuclear components with relevant codes and standards and quality concepts
27.	Structural integrity, in-service inspection and life assessment of nuclear components using NDE
28.	NDE Lab visit and Practicals

Books Suggested:

1. Practical Non-destructive testing- Baldev Raj, Jayakumar.T. and Thavasimuthu. M., Narosa publishing house, New Delhi, 1997
2. Advances in NDE for structural integrity, - Nichols. R.W., Applied Science Publishers, London, 1982.
3. Non destructive Evaluation: A tool in Design, Manufacturing and Service and Francis – Don E.Bray and Roderick K. Stanley, Taylor, CRC Press, New york, 1996.
4. Non-destructive testing, R. Halmshaw, Edward Arnold, 1991.
5. Electrical and Magnetic Methods for Non-destructive testing, - J. Bllitz, Adam Hilger, Bristol, 1997.
6. Ultrasonic testing of materials, - Josef Krautkramer, Herbert Krautkramer, Springer-Verlag. January 1983.

3. Vibration Engineering and Condition Monitoring (20 hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
7.	Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum,

coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

4. Seismic Design of Nuclear Reactors and Facilities (ME5) (20 hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson’s ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
7.	**Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.

Books Suggested:

1. Chopra, A.K., "Dynamics of Structures, Theory and applications to Earthquake Engineering", Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures", New York, McGraw-Hill Book Company.
3. Mariopaz, "Structural Dynamic (Theory and Computation)", CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., "Numerical Methods in Finite Element Analysis", Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, "Engineering Seismology", IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, "Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites". AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design", BIS, New Delhi.

5. Plant Dynamics (20 hours)

S.No.	Course content
1.	**Pressure drop** in fuel Subassembly, friction, local acceleration and elevation pressure drop in wire-wrap. Flow zoning
2.	**Hot spot factors**: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors. Subchannel analysis of fuel subassemblies, mixing parameters, introduction to computer codes.

3. **Event analysis**: General safety features, General Considerations on Design Basis Events, Thermal and Hydraulic Modeling for Analysis, Safety Criteria, Design Criteria for Selection of SCRAM Parameters, Sympathetic Safety Actions, Primary Sodium Flow Halving Time, Maximum Permissible Absorber Rod Speed.
4. **Results of Analysis of Major DBE:** One Primary Sodium Pump Acceleration, Both Primary Sodium Pumps Acceleration, One Secondary Sodium Pump Acceleration, Both Secondary Sodium Pumps Acceleration, Feed water Flow Increase Events, Continuous Withdrawal of One CSR, One Primary Sodium Pump Trip, One Primary Sodium Pump Seizure, Off-Site Power Failure with Emergency Backup for PSP, Primary Pipe Rupture, One Secondary Sodium Pump Trip, One Secondary Sodium Pump Seizure, One Boiler Feed Pump Trip, Loss of Feed Water Flow to Steam Generator, Intermediate Heat Exchanger Sleeve Valve Closure, Loss of Heating in High Pressure Feed water Heaters, Spurious SCRAM. Reactor start-up, BFP Trip and over speeding at full power, Turbine Generator -Trip and subsequent plant operating actions, power setback.
5. **Decay Heat Removal:** Decay Heat Removal through OGDHRS, Decay Heat Removal through SGDHRS, Need for Forced Convection Core Flow, Decay Heat Removal during Station Blackout Situation, Adequacy of SGDHRS Capacity.
6. **Energy Release In Beyond Design Basis Events:** Local Events: Subassembly Accident, Whole Core Events: Pre – disassembly Phase, Disassembly Phase, Mechanical Energy Release / System Response Phase, Analysis of Transient Over Power Accident, Computer Codes, Analysis of Loss of Flow Accident (LOFA), Sodium Void Worth, Consequences of Fuel - Coolant Interaction

Books Suggested:
Material will be provided during the course

6. Experimental Mechanics (20 hours)

S.No.	Course content
1.	Stress & Strain: State of stress, strain, plane stress, plane strain, Thermal stress, Hydrostatic & Deviatoric Component of stress, Elastic stress-strain relationship, Elastic-Plastic strain relations, Von-mises plasticity criteria, plastic flow rule, strain hardening law, perfectly plastic material, Isotropic strain hardening material, kinematic strain hardening, combined strain hardening stress concentration, cyclic stress, Fatigue, Endurance limit, Creep, Larson Miller parameter.
2.	Photo elasticity: Polarisation, polariscope, diffused light and lense polariscope, stress optics law, plane polariscope, circular polariscope, criteria for model material selection, Isochromatic fringe pattern, Iso fringe pattern, scaling model to prototype stress.
3.	3D photo elasticity: locking of model deformations, scaling model and interpretation of the resulting fringe pattern, effective stresses, Birefringent coating, scattered light and its relation to photo elasticity, scattered light polariscope.
4.	Strain measurement methods: strain gage, basic characteristics, types of strain gages, factors in gage selection, electrical resistance strain gage, potentiometer for strain measurement, strain gage circuit, wheat stone bridge

5. Recording Instrument: galvanometer with oscillograph, transient response galvanometer, frequency response of the wheatstone bridge and galvanometer, cathode ray oscilloscope and potentiometer recorder.

Books Suggested:

1.Mechanical engineering design (In SI Units)', Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2.Design Of Machine Elements Edition 7, Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3.Machine Elements In Mechanical Design, Mott (R L), Columbus, Charles E Merril, 1985.
4.Experimental methods for engineers- J.P.Holman, McGraw Hill.
5.Theories of engineering experimentation-Hilbert Schenck, McGraw Hill.

7. Process Control & Instrumentation (Co-ordinator: A. Venkatesan) (20 hours)

S.No.	Course content
1.	Basic Concepts
2.	Units of measurements, Definitions (accuracy, precision, repeatability, span, range, hysterisis, drift, sensitivity, resolution, lag etc.) -- Sensors, transducers, Transmitters, PI diagrams, Symbols., Digital and analog devices.
3.	Sensing, Transmission, Receiving of the following Process Variables
4.	Temperature: classification, thermocouples, RTD, Thermistors, Pyrometers.
5.	Flow: Direct type, inferential type, constant area sensors, differential pressure meters, variable area meters, magnetic, ultrasonic, vortex type flow meters, and mass flow meters.
6.	Level: Direct type (Float, gauge glass, torque tube, piston tube, reflex etc) indirect type (Pressure gauge, purge, d/p with open/closed tanks, Ultrasonic, nucleonic, capacitance & conductivity).
7.	Pressure: Manometers, Bourdon, bellows, diaphragms, D/P Tx, (electronic & pneumatic), strain gauges, load cells.
8.	Analytical: pH, viscosity, conductivity, humidity, isotopic purity, and turbidity.
9.	Control System: Feedback Control theory, Modes of control, generation of control modes, Controllers, feedback & feed forward control, final control elements and valve positioners.
10.	Safety principles: Trip logic, annunciators, simple logic circuits, and smoke/fire detectors.
11.	Current Trends In Instrumentation: Smart transmitters, Instrumentation for a process loop, Paperless recorders, DAS, PLC, DRS, etc.

Books Suggested:

1. Instrument Technology Vol. I to V E.B. Jones.
2. Mechanical & Industrial Measurements, R.K. Jain
3. Automotive Process Control, Donald P. Eckman
4. Measurement Systems Application & Design, Ernest Doebelin.
5. Process Instrument & Control Handbook, Douglas Considine.
6. Instrument Engineers Handbook, Vol. I&II, Dela G. Liptak
7. Instrumentation for Process Measurement & Control, N.A. Anderson

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
ELECTRONICS AND INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
EL2	Reactor Control Engineering	20	2
EL3	Nuclear Instrumentation	20	2
EL4	Reliability Engineering	20	2
EL5	Software Engineering	20	2
EL8	Human Machine Interface for Reactor Control Instrumentation	45	6
EL10	Modern Control of Dynamic Systems	30	4
Total		**155**	**18**

SPECIALISED COURSES

Course Code	Course Name	Hours	Credits
EL6	Artificial Intelligence and Digital Signal Processing	40	4
EL7	Process Instrumentation	35	4
EL9	Embedded and Computer based systems Design	45	6
EL11	Analytical Instrumentation	25	2
Total		**145**	**16**

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-002-P	Project	Duration : 9 Weeks	
2.	02ENGG04-002-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. **Engineering Mathematics (EM) (35 hours)**

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

8. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
9. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
10. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
11. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
12. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).

13. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
14. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

Sl.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

13. Introduction to Materials Science for Engineers - James Shackelford
14. Physical Metallurgy Principles & Practice - V.Raghavan
15. Introduction to Solids - L.V.Azaroff
16. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
17. Materials in Nuclear Application - C.K.Gupta
18. Nuclear Chemical Engineering - Benedict and Pigford
19. Physical Metallurgy, Reed - Hill
20. Heat treatment of steel - Avener
21. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
22. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
23. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
24. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Fast Reactor Physics and Shielding (RP) (35 hours)

S.No.	Course content
A	NUCLEAR THEORY BASICS :
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units
2	**Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

8. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
9. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
10. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
11. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
12. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
13. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
14. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics and Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

13. Introduction to Health Physics – Herman Cember
14. Introduction to Radiation Protection – Alan Martin
15. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
16. Nuclear Radiation Detection - W.J. Price
17. Radiation Detection and Measurement - G.F. Knoll
18. Biological Effects of Radiation – J.E. Coggle
19. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
20. Atoms, Radiation and Radiation Protection by James E. Turner 1986
21. Problems and solutions in Radiation Protection by James E. Turner, 1988
22. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
23. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
24. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) – (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :**
	Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR’s, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology (NRST)**

1 **Properties of Sodium:** Physical and chemical properties, (hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

11. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
12. Steam Power Station, G.A. Gassort.
13. Power Plant Engineering & Economics, Strosal & Vapet.
14. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
15. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
16. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
17. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
18. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
19. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
20. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Reactor Control Engineering (EL2) (20 hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (EL3) (20 hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (EL4) (20 hours)

S.No. **Course content**

12. **Introduction: Reliability Engg. Applied to C&I Systems**
Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

13. **Reliability Maths/Statistics:**
    - Mathematical and statistical expressions required for reliability study.
    - Types of failures in electrical, electronic and computer components
    - Failure probability concept, statistical distribution models_
    - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
    - Chi-square distribution and its use in confidence and risk factors
    - Baye’s theorem
    - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
    - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
    - Derivation of exponential reliability expression_
    - R(t)=[exp-(lt)] for electronic components and systems.
    - Examples to solve

14. **Fault Tolerance and Systems Reliability:**
- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model

Example from C&I system in the NPPs

15. **QA/QC Concepts in Brief:**
- QA/QC Concepts in the components, systems procurement, manufacture and
- Site installation for C&I systems in the NPPs.

16. **Environmental Qualification and Reliability Testing:**
- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

17. **PSA/PRA Concepts in NPPs:**
- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

18. **Additional safety concepts:**
- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), ('Formal Methods' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Software Engineering (EL5) (20 hours)

S.No.	Course content
1.	Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work- products of different phases
2.	Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics, CASE tools.
3.	Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalization, composition, polymorphism. Modeling structure and behavior, Use case diagrams, class diagrams, state diagrams, sequence diagrams, architectural and detailed design., Modeling real-time software. Introduction to Object Oriented Languages. CASE tools.
4.	Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities.
5.	Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods. Testing principles, unit testing, Integration testing, acceptance testing., Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing.
6.	Software Configuration Management: Configuration items (with examples), baselines, libraries, version control
7.	Software Engineering Standards

Books suggested:

1. Software Engineering by Roger S. Pressman, McGraw Hill International Students Edition
2. Software Engineering by Ian Sommerville, 5th Edition, Addison Wesley
3. An Integrated Approach to Software Engg. by P. Jalote, Springer/Narosa Publishers
4. Unified Modeling Language User Guide by G. Booch, J. Rumbaugh, I. Jacobson, Addison Wesley
5. Real-time UML, second edition, Bruce P. Douglass, Addison Wesley

5. Human Machine Interface for Reactor Control Instrumentation (EL8) (45hours)

S.No.	Course content
A .	**Reactor Instrumentation:**
1.	Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification
2.	RPS & RRS for FBRs : Core Temperature Monitoring System, Diversified Safety Logics, Control Logics for CSRDM & DSRDM
3.	Supervision Systems : Startup systems, Discordance supervision systems for SCRAM signals & CSRs, Alarm Generation system, ESR & PDA
4.	Component Handling Systems: I & C for Rotatable plugs, Transfer Arm, IFTM, CTM, Under Water Trolley and Storage Bays, HMI in HCR for Component handling and fuel movement monitoring.
5.	Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, low selector, high selector, median selector, voting logics, Interfaces with electrical Control gear.
6.	C & I Cables : Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
7.	Incident monitoring & mitigation systems : RCB Isolation, I&C for SGDHR, Seismic Instrumentation, Post Accident monitoring system, Video monitoring system
8.	Special systems: Fire Alarm System, Physical protection systems, Biometric Sensors, etc.
9.	Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station, DDCS for PFBR. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards, PLCs for package systems.
10.	PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

11. Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

B. Human Machine Interface (HMI)

1. Overview of plant automation.
2. Design of HMI, Soft Console versus Conventional control panels.
3. Guidelines for design of HMI displays.
4. Case study of a commercially available Professional HMI package.
5. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package
6. Practical.

Books suggested:

1. Intellution Ifix documentation
2. NPC Guidelines for development of soft consoles.

6. Modern Control of Dynamic Systems (EL10) (30 hours)

S.No.	Course content
1.	**1.** State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	**.** Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	**.** Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

SPECIALISED COURSES

1. Artificial Intelligence & DSP (EL6) (40 hours)

S.No.	Course content
	A. Introduction to Artificial Intelligence
1.	Introduction – Nature of AI problems
2.	Search – State space search
3.	Robotics – Kinematics and dynamics
4.	Knowledge Representation – Predicate logic
5.	Neural Networks – Feed forward vs Feedback
6.	Fuzzy Logic – membership functions
7.	Reinforcement Learning – Intelligent agents
8.	Genetic Algorithm – Solution representation
9.	Engineering applications including in Robotics
	B. Digital Signal Processing
1.	Introduction: Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, convolution, correlation, sampling theory, aliasing, anti-aliasing filter, quantization noise, signal reconstruction.
2.	Discrete Fourier Transform: Interpretation of DFT, properties of DFT, DFT of real signals, periodic & linear convolution and correlation using DFT.
3.	Fast Fourier Transform: Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, computation of Inverse DFT using FFT algorithm, efficient computation of the DFT of two real sequences and a 2N-point real sequence,

spectrum analysis using the FFT, windows in spectrum analysis, use of FFT algorithm in linear filtering and correlation.

4. Digital filters: FIR and IIR filters, design techniques for FIR and IIR filters, realization of FIR and IIR systems, overview of DSP processors.

5. DSP Applications: Applications of digital signal processing in nuclear and other fields.

Books suggested:

1.Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
2.John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice- Hall of India,1995.
3.Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.

2. Embedded & Computer based systems Design (EL9) (45 hours)

S.No.	Course content
A.	**Microprocessor Based Hardware Design:**
1.	Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Micro-controllers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
2.	Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3.	Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
4.	Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
5.	IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, testability.
6.	Embedded computer system design example.
B.	**Computer Communication and Networks**
	Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.)

C. **Fault Tolerant and Distributed Architectures**

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.

2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. **Real-Time System Design**

1. Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.

2. Overview of LINUX and Embedded NT.

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.

3. Process Instrumentation (EL7) (35 hours)

S.No.	Course content
7.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors,

flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.

8. Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
   Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

9. Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

10. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

11. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

12. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems- Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system- Gammatography etc.,
    Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

13. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
    Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
14. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.
    Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
15. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrment Engineer’s Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Fieldbus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

4. Analytical Instrumentation (EL11) (25 hours)

S.No.	Course content
	Measurement related issues
1.	Sensitivity, detection limit, signal-to-noise ratio enhancement
2.	Absorption and Emission Spectroscopy
3.	UV-VIS-IR Spectrophotometry
4.	Atomic Absorption Spectrophotometry
	IR absorption methods for detection of Carbon, Sulphur, Oxygen, Nitrogen
5.	**Fluorescence Spectrometry**
6.	Generation of X-Rays
7.	X-Ray Fluorescence Spectrometry
8.	X-Ray Diffraction Spectrometry
9.	Laser florescence
10.	**Mass Spectrometry**
	Applications and importance of mass spectrometry
	Various types of ion sources
	Various types of mass analysers
	Various methods of detection
	Computer based automation and measurements
11.	**Thermo analytical methods**
	Thermal analysers-DTA and TG
	Differential Scanning Calorimeters
12.	**Electro analytical instruments**
	Voltametry, amperometry and Coulometry
	Conductivity and pH

Books Suggested:

1. Instrumental methods of analysis, - Willard & Others, Pub: CBS, New Delhi, 7th Ed.
2. Principles of instrumental analysis, - Douglas A.Skoog and James J. Leary, Saunders College Publishing, Harcourt Brace College Publishers. (IGCAR Acc. No. 063944)

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
CHEMICAL ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING (CHEMICAL)
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE1	Nuclear Chemical Engineering	35	4
CE2	Chemical Engineering Thermodynamics	40	4
CE3	Transport Phenomena	40	4
CE4	Multi Phase Flow Systems	40	4
CE5	Code Design for Pressure Vessels and Piping	25	2
CE6	Computational Fluid Dynamics and Heat Transfer	40	4
CE7	Advanced Chemical Reaction Engineering	25	2
Total		**245**	**24**

SPECIALISED COURSE
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE8	Process Analysis and Control	25	2
CE9	Advanced Mass Transfer	25	2
Total		**50**	**4**

ELECTIVE COURSES
(One course amongst the three to be chosen)

Course Code	Course Name	Hours	credits
CEEL	Preparedness &Response to Nuclear Emergencies	30	4
	Artificial Intelligence Methods &Applications	30	4
	Membrane/ Separation Process and Technology	30	4

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-003-P	Project	Duration : 9 Weeks	
2.	02ENGG04-003-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers. B-splines,Bezier curves, Response surface method, different levels of factorial design.

Book suggested

15. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
16. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
17. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
18. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
19. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
20. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
21. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
9.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
10.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
11.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
12.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
13.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
14.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
15.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
16.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

25. Introduction to Materials Science for Engineers - James Shackelford
26. Physical Metallurgy Principles & Practice - V.Raghavan
27. Introduction to Solids - L.V.Azaroff
28. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
29. Materials in Nuclear Application - C.K.Gupta
30. Nuclear Chemical Engineering - Benedict and Pigford
31. Physical Metallurgy, Reed - Hill
32. Heat treatment of steel - Avener
33. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
34. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
35. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
36. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick’s law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

15. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
16. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
17. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
18. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
19. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
20. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
21. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

   Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

   Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

25. Introduction to Health Physics – Herman Cember
26. Introduction to Radiation Protection – Alan Martin
27. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
28. Nuclear Radiation Detection - W.J. Price
29. Radiation Detection and Measurement - G.F. Knoll
30. Biological Effects of Radiation – J.E. Coggle
31. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
32. Atoms, Radiation and Radiation Protection by James E. Turner 1986
33. Problems and solutions in Radiation Protection by James E. Turner, 1988
34. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
35. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
36. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR’s, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

21. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
22. Steam Power Station, G.A. Gassort.
23. Power Plant Engineering & Economics, Strosal & Vapet.
24. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
25. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
26. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
27. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
28. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
29. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
30. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.

9. Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.

10. Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.

11. Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.

12. Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements

2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.

3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types

4. Design criteria, Loadings to be considered, Analysis method and validation methodology

5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features

7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Nuclear Chemical Engineering (CE1) (30 Hours)

S.No.	Course content
1.	**An Introduction to Nuclear Chemical Engineering** General Introduction and course schematics
2.	**Production of Nuclear Materials** Production of nuclear fuels (i.e.)uranium, thorium and zirconium form ores. Alternate sources for uranium Isotope separation technologies for uranium and water Fuel fabrication technologies for various types of reactors Less common nuclear materials like Zr, Hf, Th, Be,V, Nb and Ta
3.	**Solvent Extraction of Nuclear Materials** Introduction to archival extractants and flowsheets Science and technology of primary extractant (TBP) Alternate extractants for fuel reprocessing applications Extractants for nuclear waste management applications Classical and novel nuclear solvent extraction equipment Criticality and its prevention. Other safety aspects
4.	**Nuclear Fuel Reprocessing** PUREX, Advanced PUREX, SuperPUREX processes Reprocessing of thermal reactor (PHWR and AHWR) Fuels Reprocessing of fast reactor (FBTR & PFBR) Fuels UREX process and its variants Supercritical Fluid Extraction based Superdirex Process Pyrochemical and other non-aqueous processes for reprocessing
5.	**Nuclear Waste Management** Characterization of nuclear wastes Conditioning and remediation. Post-PUREX and Post-UREX processes for isolation of important radionuclides (TRUEX, UNEX, ARTIST, SETFICS, SESAME etc.) Decontamination and decommissioning
6.	**Modeling and Simulation in Nuclear Chemical Engineering** Generation of SX data by conventional & **AKUFVE** techniques Modeling of solvent extraction data Computer codes for simulation of nuclear SX Simulation of solvent extraction process flowsheets Experimental design based variation analysis of flowsheets

Books Suggested:

1. Benedict M., Pigford T.H. and Lewi H. Nuclear Chemical Engineering, McGraw Hill. 2nd ed. (1981)
2. Long, J.T. , Engineering for Nuclear Fuel Reprocessing, American Nuclear Society, IL (1978)

3. Schulz. W.W, Navratil, J.D. and Talbot A.E., Science and Technology of Tributyl Phosphate, Vol.1, CRC Press Inc., Boca Raton, FL (1984)
4. Schulz. W.W, Burger, L.L.,Navratil, J.D. and Bender K.P., Science and Technology of Tributyl Phosphate, Vol.3, CRC Press Inc., Boca Raton, FL (1984)
5. Knief, R.A. Nuclear Energy Technology, Hemisphere Publishing corporation, NY, (1981)
6. Vilani, J., Isotope Separation, (IGCAR library)
7. Selected IGCAR Reports Concurrent literature on AFCI, UREX and allied processes

2. Chemical Engineering Thermodynamics (CE2) (30 Hours)

S.No.	Course content
1.	Classical thermodynamics - the scope of classical thermodynamics, basic concepts and definitions. Laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures.
3.	Multicomponent systems: the chemical potential, fugacity, activities, and activity coefficients.
4.	Solubilities of gases in liquids, solids in gases and in liquids.
5.	Vapour liquid equilibria at low and high pressure. (Van Laar, Peng-Robinson equations). Thermodynamics of super critical fluid
6.	Liquid-Liquid equilibria.
7.	Models for Non ideal, Non-electrolyte solutions and ionic liquids.
8.	Solution thermodynamics
9.	Phase Equilibrium: Phase rule, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations, Equilibrium in systems with supercritical components, phase stability applications.
10.	Chemical Reaction Equilibria: Equilibrium constants for Homogeneous and heterogeneous reactions.
11.	Statistical Thermodynamics

Books Suggested:

1.Denbigh, K. G., The Principles of Chemical Equilibrium, Cambridge, 1971.

2.Tester, J. W. and Modell, M., Thermodynamics and its Applications, 3rd ed., Prentice-Hall, 1997.

3.Bejan, A., Advanced Engineering Thermodynamics, Wiley, 1988.

3. Transport Phenomena (CE3) (40 Hours)

S.No.	Course content
1.	Phenomenological description of continuum approach. Reynolds transport theorem. Basic laws of conservation of mass, momentum and Energy and Multicomponent systems.

2. Transport properties. Modeling of Engg systems and the specification of boundary conditions. Shell balances, Navier-Stokes equations; Momentum, Heat and Mass transfer in steady and unsteady viscous flows; turbulent flows; shell and differential thermal energy balances; steady and unsteady conduction; laminar, forced and natural convection; shell and energy balances of mass of species; diffusion under various driving forces, diffusion with chemical reaction; convective diffusion in dilute solutions; integral balances. Transport coefficient and the macroscopic treatment of momentum, Energy and mass transport in complex system.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Multi-phase flow systems (CE4) (30 Hours)

S.No.	Course content
1.	Multiphase flows and Classification of Multiphase, Flow Patterns (gas-liquid, liquid-liquid and gas-solid and gas-liquid-solid) - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum and energy transfer for different models: Multi-dimensional and flow regime specific models.
2.	Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. (Gas-liquid mixture transport in horizontal and vertical pipe.), vapour-liquid flow, flow boiling, sub-cooled boiling, critical heat flux.
3.	Applications of two-phase flow in the design of steam generators, thermo-syphon evaporators, condensers with non condensibles and air lift pumps. Hydrodynamic of liquid-liquid flow design variables such as holdup, characteristic velocity and pressure drop.
4.	Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. (Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile and pressure drop for turbulent slurry flow.)
5.	The phenomena of fluidization and its industrial application. Characteristics of particles. Principle of fluidization and mapping of various regimes. Two phase theory of fluidization. Bubbles in fluidized bed. Entrainment and Elutriation. Fast fluidized bed. Mixing, segregation and gas dispersion. Heat and mass transfer in fluidized bed. Solid-liquid fluidized bed and three phase fluidized bed. Design of fluidized bed reactors

Books suggested:

1. Wallis, G.B. - " One Dimensional Two phase flow", McGraw Hill Book Co., New York, 1969.
2. Govier, G.W. and K.Aziz., - " The flow of Complex Mixtures in Pipes ", Van Nostrand Reinhold Co., New York, 1972.
3. Brodkey, R.S. - " The Phenomena of Fluid Motions ", Addison - Wesley Publishing Co., New York, 1967.
4. Gad Hestsroni, (Ed.in Chief) - " Handbook of Multi Phase Systems ", Hemisphere Publishing Corporation, Washington and McGraw-Hill Book Company London, 1982.
5. Two-phase flow in pipe lines and heat exchangers – D.Chisholm, Longman Inc, NewYork.
6. Fluidization Engineering- Author: Daizo Kunni and Octave Levenspiel, Butterworth-Heinemann
7. Fluidized bed technology in Materials Processing**, -**Author: C. K. Gupta and D. Sathiyamoorthy, CRC Press.
8. Chemical Reaction Engineering, - Octave Levenspiel,Wiley Eastern Limited.
9. Handbook of separation techniques for Chemical Engineers, - Philip A. Schweitzer,: McGraw- Hill

5. Code Design for Pressure Vessels & Piping (CE5) (25 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.

6. Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.

7. Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.

8. Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.

9. Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.

10. Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

6. Computational Fluid Dynamics & Heat Transfer (CE6 & CE610) (40 Hours)

<u>Syllabus for CE6 : Computational Fluid Dynamics (30 hrs.)</u>

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme

B. Numerical Solution of Complete Fluid Flow and Energy Equation:

1. Formulations of governing equations used in numerical simulation:
2. Streamfunction-temperature formulation
3. Stream function-vorticity-temperature formulation
4. Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5. Primitive-Variable (P-V-T) formulation
6. Pressure velocity coupling for incompressible flow.
7. Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8. Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9. Simple grid generation techniques for structured grid:
10. Elliptic. parabolic and hyperbolic equation method
11. Grid adaptation
12. Domain decompositions in CFD and heat transfer
13. SIP and preconditioned conjugate gradient methods for solution
14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Syllabus for CE610 : Heat Transfer (10 hrs.)

C. Laminar Boundary Layer and Forced Convective Heat:

1. Formulation of differential equation for hydrodynamic and thermal boundary layer
2. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
3. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
4. Convective heat transfer for internal and external flows
5. Low and high Prandtl number limits and different thermal boundary conditions
Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

D. Turbulent Flow and Heat Transfer:

Reynolds decomposition for turbulence
Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder
Calculation of friction factor and drag coefficient
Analytical and semi-analytical correlations for calculating heat transfer coefficients
Analogy between heat and momentum transfer
Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models
Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

E. Natural Convection:

Basic Equations of natural convection
Boussinesq approximation
Derivation of Dimensionless groups from basic equations
Analytical approximations
Numerical solution of approximate equations

F. Reactor Heat Transfer:

Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.

Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.

Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.

low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.

Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.

Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff’s law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies

G. Heat Transfer With Phase Change :

Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.

Basic equations of two phase flow; Homogenous & separated flow models for two hase flow; void fraction & phase velocity ratio (Zivi’s model)

Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow’s correlation) and flow boiling (Chen’s correlation)

Condensation heat transfer: Nusselt’s theory and its limitations: Jet condensation fundamentals and its application in containment cooling.

Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept.

Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.

Critical Flow: Models for single – phase and two-phase critical flow.

Books suggested:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.

4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

7. Advanced Chemical Reaction Engineering (CE7) (30 Hours)

S.No.	Course content
1.	Stoichiometry rates and thermodynamics of chemical reactions. Influence of concentration and temperature. Reaction mechanism. Generalized balance equation for reactive systems.

2. Collection and analysis of rate data: differential method, Integral method, Graphical method, polynomial fit method, Methods of initial rates, Methods of excess, Methods of half life. Kinetics of homogeneous and heterogeneous reactions.

3. Conservation equations for chemically reacting mixtures; heterogeneous catalytic reactions.

4. Chemical reactions and processes of transport: external diffusion effects on heterogeneous reactions, diffusion and reaction in porous catalysts.

5. Design and analysis of chemical reactors: Isothermal and non-isothermal reacting systems, catalytic and non-catalytic reactions systems.

6. Uniqueness and multiplicity of steady states, stability analysis.
   Non-ideal reactors: distributions of residence time for chemical reactors, models for non-ideal reactors.

7. Modeling of multiphase reactors: fixed, fluidized, trickle bed, slurry etc.

Books Suggested:

1. Aris R., Elementary Chemical Reactor Analysis, Prentice-Hall 1969.
2. Foggler, H. S., Elements of Chemical Reaction Engineering, Prentice Hall of India, 1994.
3. Froment G.F. and Bischoff K.B., Chemical Reactor Analysis and Design, John Wiley, 1994.
4. Smith J.M. - " Chemical Engineering Kinetics ", McGraw-Hill, 1981.

SPECIALISED COURSES

1. Process Analysis and Control (CE8) (25 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.
2.	Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3.	Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.

4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

2. Advanced Mass Transfer (CE9) (25 Hours)

S.No.	Course content
1.	Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Film, Penetration & Surface Renewal models, Solvent extraction theory
2.	Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors. Adsorption and ion exchange equipment.
3.	Membrane separation and other advanced mass transfer processes. Process intensification approaches. (few hours for seminar by TSO's).

Books suggested:

1. Transport phenomena in liquid extraction – G.S. Laddha and T.E. Degaleesan. McGraw Hill, 1978.
2. Separation process principles – J.d. Seader, Ernest J.Henley. John Wiley & Sons. 2nd Ed. 2005.
3. Mass transfer – Thomas K.Sher wood, Robert L.Pigford, Charles R. Wilkey. McGraw hill.
4. Mass transfer operations - Robert E. Treybal. Mcgraw-hill (1980)
5. Handbook of solvent extraction – The. C. Lo. Malcolm, H.I. Baird, Carl Hanson (editor), Krieger Pub. Co. Reprint edition (Feb 1991).

ELECTIVE COURSES

1. Preparedness & Response to Nuclear Emergencies (CE-EL) (30 Hours)

S.No.	Course content
1.	Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
2.	Radiation Shielding & Study of Criticality parameters and control
3.	Nuclear Waste Management
4.	Nuclear Accidents/emergencies
5.	Transport of Radioactive material
6.	Radiological accidents/emergencies
7.	Effects of Hiroshima & Nagasaki bombing
8.	Detection of Nuclear detonation

9. Nuclear weapons: effect (Blast, heat, Radiation and EMP)

10. Medical decontamination with demonstration

11. Nuclear weapon tests (atmospheric)

12. Nuclear & Radiological terrorism (Method to contain and control)

13. Chemical warfare & Biological warfare (Method to contain and control it)

14. Emergency Response methodology/ Philosophy

15. Systems and methodology for Radiological impact assessment

16. Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities

17. Emergency Monitoring & Shelters

18. Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment

19. Civil defence WEB plan for Nuclear attack on major cities

20. Monitoring of High radiation field area

21. Lab Visits

Books suggested:

Material will be provided during the course.

2. Artificial Intelligence Methods & Applications (30 hours)

S.No.	Course content
1.	**Robotics** Forward and Inverse kinematics, Jacobians, Manipulator Dynamics, Trajectory generation, Sensors, Manipulator Control, Force control, Path planning, Mapping & Localisation of Mobile robots, Behavior based control, Robot learning.
2.	**Genetic Algorithm** Introduction to GA and its terminology, GA operators and working principle of GAs. Different selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling and elitism. Constraint handling. Multimodal function optimization. Application of GAs, real-coded GAs. Multiobjective optimization, difference with single objective optimization, concept of Dominance and Pareto-optimality. Multiobjective GAs.
3.	**Fuzzy Logic** Introduction;Need, Historical Development and Perspective of applications. Crisp and Fuzzy Sets, Operations on fuzzy Sets. Fuzzy Arithmetic, Fuzzy relations, Fuzzy logic. Possibility Theory and Uncertainty Based information. Construction of Fuzzy Sets (with examples), Approximate Reasoning.

Applications; Pattern Recognition and Process Control (with examples).

Books Suggested:
Material will be provided during the course.

3. Membrane/Separation Processes and Technology (30 hours)

S.No.	Course content
1.	Type of membranes and membrane processes
2.	Membrane transport theory – solution, diffusion model
3.	Membrane and modules
4.	Concentration polarization – boundary layer film model – concentration polarization in liquid separation processes
5.	Reverse osmosis – membranes and materials, RO membrane categories, membrane modules, fouling control and cleaning
6.	Ultra-filtration – characterization of UF, membrane fouling and cleaning – modules and system design
7.	Other membrane processes – microfiltration, nanofiltration, pervaporation and electrodialysis
8.	Application of membranes in water and wastewater treatment
9.	Application of membranes in radioactive waste management

Book suggested:

1. Membrane Technology and Applications (2nd edition) by Richards W. Baker
2. Membrane Filtration Handbook – Practical Tips and Hints (2nd edition) by Jorgen Wagner
3. Application of Membrane Technologies for Liquid Radioactive Waste Processing – IAEA Technical Report Series No. 431.

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
Materials Science

Course Code	Course Name	Hours	Credits
MS1	Engineering Mathematics	35	4
MS2	Computational Methods	30	4
MS3	Materials and Metallurgy	25	3
MS4	Reactor Physics and Fuel Design	30	4
MS5	Health Physics	25	2
MS6	Metallurgical Thermodynamics	30	4
MS7	Experimental Methods for Materials Research	45	6
MS8	Structural Materials for Nuclear Reactors	45	6
MS9	NDE Science and Technology	30	4
MS10	Physical Metallurgy	45	6
MS11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
MS12	Introduction to Materials Science and Engineering	45	6
MS13	Corrosion Science and Engineering	30	4
MS14	Mechanical Behavior of Engineering Materials	30	4
MS15	Manufacturing Technology	30	4
Total		**505**	**65**

1. Computational Methods (MS2 -45 hours)

S.No	Course content
1.	**Programming:** Introduction to programming with C# as the reference language (C# software will be provided for practice), Getting familiarized with Matlab
2.	**Numerical Techniques:** Overview of standard numerical techniques with wpecial emphasis on statistics and solving ordinary and partial differential equations
3.	**Optimization:** Overview of techniques with special emphasis on non-linear optimi9zation using gradient descent, conjugate gradient and genetic algorithm
4.	**Neural network for predictive applications:** Overview of various neural network architectures, Multilayer perceptron model for prediction, need for neuro-fuzzy models
5.	**Atomistic modeling:** Introduction to Monte-Carlo Simulation, Basics of molecular dynamics, prediction of thermo-physical properties by molecular dynamics, computational challenges
6.	**Introduction to application of FEM:**Introduction to FEM and its application, demonstration of few simple application using Abaqus (FEM software)
7.	**Current status in modeling and simulation:** With respect to mechanical metallurgy

Books Suggested:

1. Sams Teach Yourself C# in 21 Days, B.L. Jones, SAMS publications
2. Numarical Recipes in C++: The art of scientific computing, *W.H. Press et al*, Cambridge University Press
3. Numerical Mathematical Analysis *J.B. Scarborough, MacMillan Publishers*
4. Genetic algorithms in search, optimization and machine learning, *D.E. Goldberg, Addison Wesley*
5. Guide to neural computing applications, *L. Tarassenko, Arnold publishers*
6. Monte Carlo Basics, *K.P.N. Murthy, ISRP publishers*
7. Molecular Dynamics Simulation by *J.M. Haile, John Wiley and sons*

2. Fast Reactor Physics and Fuel Design (MS4/CH8- 30 hours)

S.No.	Course content
1.	**Basic Nuclear Physics Concepts:** Properties of nuclei. Nuclear forces, Nuclear models. Nuclear decay, Liquid drop model and nuclear stability, Nuclear reactions including fission, Compound nucleus formation, Microscopic cross-section, Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	**Chain Reaction:** four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.

5. **Reactor Kinetics:**Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.

Books Suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C. Edlund. Van Nostrand, 1952.
2. Introducation to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Physics of Nuclear Reactors, Jakeman D., English Universities Press, 1966.
4. A.E. Walter and A.B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981.

3. Metallurgical Thermodynamics(MS6- 30 hours)

S.No.	Course Content
1.	**Classical thermodynamics -** the scope of classical thermodynamics, basic concepts and definitions. First and second laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures. The chemical potential, fugacity, activities, and activity coefficients, Phase rule
3.	Solubilities of gases in liquids, and solids
4.	**Solution thermodynamics**: Integral and Partial Molar Thermodynamic Properties, Solution Models, Ideal Solution, Regular Solution, Real Solutions
5.	**Phase Equilibrium and Stability**: Phase equilibria in multicomponent systems, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations,
6.	**Chemical Reaction Equilibria**: Equilibrium constants for Homogeneous and heterogeneous reactions.
7.	Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Pourbaix Ellingham Diagrams, Phase Diagrams,
8.	**Experimental Methods**: Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.

Books Suggested:

1.D. Gaskell, Materials Thermodynamics, Talyor and Reid, 1981.
2. O. Kubaschewski, C.B. Alcock and P.J. Spencer, Materials Thermochemistry, Pergamon, 1985

4. Experimental Methods for Materials Research (MS7-45 hours)

S.No	Course Content
1	Vacuum Techniques (3): Fundamentals, Creation & Pressure Measurements, units, Pumps – fore Vacuum, high Vacuum and UHV
2	Thin Film synthesis methods- Physical, Chemical and MBE

3. X-RAY TECHNIQUES - techniques based on measuring the energy or angular distribution of scattered x-rays,

1.1 Wide angle elastic scattering (XRD): Atomistic – form factors; unit cell structure factors, Bragg equation, reciprocal lattice, Laue equations; Expwrimental methods- transmission, reflection, thin film, in-situ; Otjer information-particle size distributions.

1.2 Inelastic scattering- x-ray absorption spectroscopy: Basics- edges and extended fine structure; XANES and EXAFS quantitation; Surface sensitivity; Experimental methods

1.3 Small angle scattering-SAXS: Basics- what SAXS sees; Mathematical modeling;

1.4 X-ray fluorescence spectroscopy: Basics- core hole formation, fluorescence yield, transport ("ZAF"); Experimental realization – Bulk analysis; lab and synchrotron x-ray sources; Surface analysis – TXRF; Microscopy – x-ray beam manipulation.

4. **ELECTRON MICROSCOPIES:**

2.1 Transmission electron microscopy (TEM/STEM):

Electron interactions in solids-elastic and inelastic scatterin, phase change; Contrast generation-bright field, dark field, "high-resolution"; Images-information and resolution; Diffraction; Beam damage; Experimental methods hardware, specimen preparation; Inelastic scattering- electron energy loss; Emitted x-rays – elemental analysis, sensitivity, spatial resolution; STEM

2.2. Scanning electron microscopy:

Beam transport in bulk solids; Signals and images- backscattered and secondary electrons; Diffraction- channeling patterns – EBSD; X-ray generation and transport, detection and analysis; Other useful signals; Experimental methods;

EPMA Electron probe micro-analyzer

2.3. LEELS

5. ION BEAM TECHNIQUES

techniques using ions or neutrals made from them as the bombarding species

3.1. Ion beams – production-ion guns; manipulation- ion, filters

3.2. Rutherford (Nuclear) Backscattering Spectroscopy- (RBS):

High energy ions in solids- electronic and nuclear (Rutherford) stopping; Quantitative description; Experimental methods – energy spectroscopy

3.3. Nuclear reaction analysis – elemental specificity – depth profiling

3.4. PIXE (Proton Induced X-ray Emission) Signal to noise ratio – trace element analysis

3.5. Surface Mass Spectriscopy-SIMS:

Ejection of matter by bombardment: sputterin; Fate of ejected materials subsequent reaction, charge state; Mass dedtection – quad, magnetic sector, ToF; experimental issues

6. ELECTRON SPECTROSCOPIES -

techniques based on measuring the energy distribution of emitted electrons

4.1 Photoelectron spectroscopy:

Basics- energy balance, element identification; Not-so Basics- relaxation, chemical states, satellites; Surface sensitivity; Quantitation; UPS- the unfamiliar cousin

4.2 Auger Electron Sepctroscopy:

Electron excitation- why bother ? The Auger spectrum- energy balance; Chemical effects; Quantitation; Imaging- meaning of maps.

4.3 Experimental methods;

Surface of real-world things; Below the surface- profiling, variable energy; Hardware and software; samples and handling.

7. PROXIMAL PROBE MICROSCOPIES

Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM): Basics; Experimental methods; Spectroscopy in Scanning Probe Microscopy

8. NUCLEAR SPECTROSCOPY

Positron annihilation, Mossbauer – Application to defects, radiation damage defects in metals and alloys

9. **VIBRATIONAL SPECTROSCOPIES**

7.1 Vibrations in molecules and solids – normal coordinates, group frequencies

7.2 Infrared spectroscopy;

IR absorption – dipole scattering, selection rules; Optical arrangements-transmission, specular reflectance, diffuse reflectance, attenuated total reflectance, microscopy, in-situ; Signal collection and Fourier transform processing, data analysis

7.3 Raman: Energy transfer, selection rules; Normal, resonance, surface-enhances, Fourier transform, UV

10. **8.RESONANCE ABSORPTION SPECTROSCOPIES**

8.1 Nuclear Magnetic Resonance (NMR):

Fundamentals; Experimental Techniques; Magnetic Resonance Imaging

8.2 Electron Paramagnetic Resonance (EPR): Fundamentals; Experimental Techniques

BOOKS FOR STUDY AND REFERENCE:

1. Cullity Addision, B.D., "Elements of X-ray Diffraction", Wesley Publishing Co., 1967.
2. Williams (D B), Carter (C B), Transmission Electron Microscopy: A Textbook For Materials Science, New York, Plenum, 1996
3. J.R. Tesmer et al 'Handbook of modern ion beam materials analysis' (MRS, Pittsburgh,1995)
4. L.C. Feldman, J.W. Mayer 'Fundamentals of surface and thin film analysis' (North-Holland, N.Y, 1986)
5. Prutton, M., "Surface Science and Technology, Volume27, "Analytical techniques for thin films", Academic Press, Inc.Newyork, 1991.
6. Bacon, G.E., "X-ray and Neutron Diffraction", Pergamon Press, 1966.
7. Concise Encyclopedia Of Materials Characterization Ed. Cahn (R W) and lifshin (E) Ed Oxfod, Pergamon, 1993
8. Advances in Materials Characterization Ed. G. Amarendra, Baldev Raj, M.H. Manghnani, University Press (India), 2007

8. Structural Materials for Nuclear Reactors (MS8)(Coordinator: –45hrs)

S.No.	Course Content
1.	Three stage Nuclear Power Program (Importance of Material Selection)
2.	**Thermal Reactors:** Concept, Selection of Materials – Core and out of core, Processing of Materials, Properties/Performance of Materials
3.	**Fast Breeder Reactors:** Concept, Selection of Materials for different systems, Brief description of different systems, Core materials, Design criteria for clad and wrapper, Radiation damage, Evolution of materials for clad and wrapper, Material performance, Material processing and fabrication, Structural materials, Design criteria, Materials processing and fabrication, Steam generator materials, Design criteria, Selection of materials, Materials processing and fabrication, Properties of materials and performance
4.	**Materials in Reprocessing Applications,** Closing of nuclear fuel cycle, Design concept of reprocessing plant component, Selection of materials, Processing and fabrication, Evaluation of properties and performance
5.	**Materials in Waste Storage Applications**

Books Suggested:

1. Materials research: Current scenario and future projections, Chidambaram R, Banerjee S Ed, Allied Publishers, New Delhi, 2003
2. High temperature reactor materials (workshop La Jolla,CA March18-21,2002), Allen T, Oak Ridge, U.S.Department of Energy, 2002.
3. Nuclear materials: Issues and concerns Vol 2., Bhaskara Rao D Discovery Publishing House, New Delhi, 2001.
4. Materials R & D for PFBR: Compilation of articles: (Eds) S.L. Mannan and M.D. Mathew, IGCAR, Kalpakkam, 2003.
5. An overview of R&D on fast reactor fuel cycle, Baldev Raj, Int. J. Nuclear Energy Science and Technology, Col.1, Nos.2/3, 2005, pp.164-177.
6. Selection of materials for PFBR, S.L. Mannan, S.C. Chetal, Baldev Raj, S.B. Bhoje, Trans IIM, Vol..56, No.2, April 2003, pp.155-178.
7. Development of fuels and structural materials for fast breeder reactors, Baldev Raj, S.L. Mannan, P.R. Vasudeva Rao and M.D. Mathew, Sadhana, Vol.27, Part 5, October 2002, pp. 527-558
8. Input of the atomic energy programme on special materials development in India, C. V. Sundaram, Trans IIM, vol. 41, No.5, Oct 1988, p.407.
9. Recent trends in fast breeder reactor materials, C.V. Sundaram, P. Rodriguez and S. L. Mannan, IE (I) Journal –MM, Vol.67, Sept. 1986, pp.1-11.
10. Radiation effects in nuclear reactor materials – correlation with structure, P. Rodriguez, R. Krishnan and C.V. Sundaram Bull. Mater. Sci. Vol. 6, No.5, May 1984, PP.339-367.

Nuclear Reactor Materials, C.O.Smith, Addison Wesley, 1967

9. NDE Science and Technology (MS9 - 30 hours)

S.No.	Course Content
1.	**Introduction to NDE:**Importance and need for NDE, classification of techniques, origin of defects; material processing related-casting, forging, rolling, welding etc., and service related-fatigue, creep, corrosion, irradiation etc. Detection, characterisation, sensitivity, reliability, accuracy,
2.	**Surface NDE:**Principle, instruments & sensors, capabilities, applications and limitations of visual, liquid penetrant, magnetic particle, eddy current and flux leakage techniques
3.	**Volumetric NDE:**Principle, instruments & sensors, capabilities, applications and limitations of radiography and ultrasonic techniques. Gamma, Micro-focal, LINAC and real-time radiography and tomography. IRIS, TOFD, SAFT, MEMS, Non-linear ultrasonics related to ultrasonics.
4.	**Dynamic NDE:**Acoustic emission, infrared radiography, intelligent processing of materials and continuous monitoring.
5.	**Digital NDE:**Forward and inverse problems, signal processing, numerical modeling, imaging, automation, probability of detection (POD), multiple NDE, data fusion and robotics.
6.	**Industrial NDE:**NDE for quality assurance, structural integrity, material characterization, condition monitoring and in-service inspection, reference standards for calibration, codes & standards, selection of NDE techniques
7.	**Practicals:** 1. Ultrasonic testing – detection of defects in weld/HAZ and measurement of thickness

2. X-radiography of welds and interpretation of radiographs
3. Eddy current testing of plates and heat exchanger tubes for defects
4. ***Seminar***: Preparation and submission of report on a topic in advanced NDE. Presentation and viva-voce

Books Suggested:

1. A practical NDT – Baldev Raj, T. Jayakumar and M. Thavasimuthu, Narosa, New Delhi, 1996.

2. ASNT Volumes on Visual, penetrant, magnetic particle, eddy current, ultrasonic, radiography, acoustic emission, thermography and other techniques, ANST, Ohio, Coloumbus.

3. Grandt, A. F. Jr., Fundamentals of Structural Integrity: Damage Tolerant Design and Non-destructive Evaluation, John Wiley & Sons, Inc. Hoboken, NJ, 2004.

4. Bray, D.E. and R.K. Stanley, 1997, Nondestructive Evaluation: A Tool for Design, Manufacturing and Service; CRC Press, 1996.

5. Peter J. Shull, Nondestructive Evaluation: Theory, Techniques, and Applications, Marcel Dekker Inc., 2002.

10. Physical Metallurgy (MS10- 45 Hrs)

S.No.	Course Content
1.	Structure and Properties of Materials
2.	**Crystalline solids:** Introduction: Engineering materials, materials cycle, application and selection criteria of materials. Significance of microstructure; crystalline defects:- dimensions, origin and their effect on properties; amorphous structure.
3.	**Phase diagrams**: Origin, construction, interpretation and application of binary phase diagrams with reference to a few important metallic and ceramic systems. introduction and classification of phase transformations, calculation of phase equilibria based on thermodynamic principles
4.	Correlation between Free energy, selection of a Phase and order parameter, different thermodynamic classification of phase transformations, order of a transformation
5.	**Diffusional transformations:** Diffusion in solids: phenomenological approach and atomistic approach. Nucleation and growth theories of vapour to liquid, liquid to solid, and solid to solid transformations; homogeneous and heterogeneous strain energy effect during nucleation; interface-controlled growth and diffusion controlled growth; overall transformation kinetics. Principles of solidification, evolution of microstructures in pure metals and alloys. Precipitation from solid solution: types of precipitation reactions, crystallographic description of precipitates, precipitation sequence and age hardening, spinoidal decomposition.
6.	**Iron-carbon alloy system:** iron-carbon diagram, nucleation and growth of pearlite, cooling of hypo-eutectoid, eutectoid, and hyper-eutectoid steels, development of microstructures in cast irons. Heat treatment of steels: TTT and CCT diagrams
7.	**Diffusionless transformations:** martensitic transformation, hardenability, role of alloying elements in steels. Bainitic transformation, Widmanstatten transformation, Massive transformation. Order-disorder transformation.

8. Diffusion, rate theory, mechanisms of, measurement techniques
9. Phase transformations in some nuclear non-ferrous metals and alloys
10. Characterization of microstructure – microscopy techniques, X-ray spectroscopy and diffraction.
11. **Metallographic techniques**: Optical metallography, image analysis, quantitative phase estimation.
12. Properties of X-rays: continuous and characteristics x-rays, absorption, filter, production and detection of X-ray Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.
13. **Electron optical methods**: (a) Scanning electron microscopy and X-ray microanalysis including electron probe microanalysis, electron optics, electron beam specimen interaction, image formation in the SEM; (b) Transmission electron microscopy and analytical transmission electron microscopy: Electron diffraction, reciprocal lattice, analysis of SAD patterns; different electron diffraction techniques, atomic resolution microscopy, analytical devices with TEM, field ion microscopy, scanning tunneling microscopy, advanced techniques.
14. **Introduction to novel materials and processes**: composites, intermetallics, cermets, metallic foams, intelligent materials, Dependence of their properties on structure, Nanocrystalline Materials: Synthesis, Structure and Properties.: Amorphous Materials; Metallic glasses, Glass forming ability, Bulk Metallic Glasses, Properties; Quasi crystalline Materials; Structure, Synthesis, Properties;
15. **Advanced Processes**: Rapid solidification processing, Laser surface Modification, Mechanical Alloying, Rapid prototyping, Self propagating High temperature synthesis, inert gas condensation etc.
16. **LABORATORY** Microstructures of alloys of Fe, Al, Cu and Ti for each type of transformation at different levels of resolution; Crystal structure by diffraction techniques; Defects of different dimensions; Advanced processes – Laser Ablation, Magnetron Sputtering and Plasma and Chemical deposition methods.

11. Fuel Cycle Physics& Introduction to Fuel Cycle (MS11/PY11 - 30 Hrs)

S.No	**Course content**
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.

8. Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9. U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10. Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11. Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12. Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13. Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14. Isotopic separation operation of bred uranium in thorium cycles to remove U-232.
MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. **Introduction to Materials Science & Engineering (MS12/CH4-40 hours)**

S.No.	Course content
1.	**Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.
2.	**Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.
3.	**Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.
5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.
6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.
7. **Phase Diagrams &Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley &Sons, N.Y., 2003.
7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

13. Corrosion Science and Engineering (MS13/CH13 - 30 hours)

S.No.	Course content
1.	Thermodynamics of Aqueous Corrosion: Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.
2.	Kinetics of Aqueous Corrosion: Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.
3.	Forms of Corrosion: General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion. Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.
4.	Corrosion in Reactor and Reprocessing Plants: Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.
5.	Prevention and Control of Corrosion: Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.
6.	**Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.
7.	**Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, “Corrosion and corrosion control – An introduction to corrosion science and engineering”, Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, “Corrosion Engineering”, Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.

4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

14. Mechanical Behaviour of Engineering Materials (MS14- 30 hours)

S.No.	Course Content
1.	**Engineering Materials:** Alloys, intermetallics, ceramics, composites, polymers.
2.	**Basic Crystal Structure of Materials**: Unit cell, packing fractions, planes and directions, slip systems
3.	**Defects in Materials:** Point defect, line defect (dislocation), surface defects (grain boundary, twins, stacking faults), volume defects
4.	**Dislocation:** Types, Burger's vector, stress field and energy, stacking faults, dislocation glide and slip systems in crystal, interaction between dislocations, interaction between dislocations and point defects, dislocation pile up, dislocation climb, dislocation sources, multiplication of dislocations.
5.	**Elastic Behaviour of Materials:** Stress and strain at a point and their relationship
6.	**Plastic Behaviour of Materials:**
7.	**Tensile Deformation:** single crystal, yield point, CRSS, polycrystalline materials (Schmidt's factor), grain size effect-Hall-Petch relation, thermally activated deformation, constitutive equation for plastic deformation, strain hardening and dynamic strain ageing (DSA).
8.	**Strengthening Mechanism:**Strain hardening, strengthening from grain boundary, solid-solution strengthening, order-disorder strengthening, precipitation strengthening, dispersion strengthening, strengthening by point defects, martenisitic strengthening, and composite materials.
9.	**Creep:** Creep curve, mechanisms of creep deformation, activation energy for creep deformation, structural changes during creep, deformation mechanism map, super plasticity, presentation of creep data, prediction of long-term creep properties, irradiation creep, grain boundary sliding, nucleation, growth and coalescence on inter granular cavities, effect of impurity segregation on cavitation, creep fracture of weld joint, design of creep deformation and fracture resistance materials.
10.	**Fatigue:** Types of loading, high cycle fatigue, low cycle fatigue, thermo-mechanical fatigue, creep-fatigue interaction, fretting fatigue and corrosion-fatigue of various engineering materials, effect of surface treatment and coating, fatigue behaviour of welds, characterization of fatigue deformation and damage, fatigue under combined stresses, notch sensitivity, design criterion, life prediction techniques, alloy design against fatigue.
11.	**Fracture Mechanics:** Ductile to brittle transition, Griffith's law, strain energy release rate, introduction to linear and non-linear fracture mechanics, fracture toughness, fatigue and creep crack growth, material design against fracture.

Books Suggested

1. Physical Metallurgy Principle – R. E. Reed-Hill
2. Modern Physical Metallurgy – R. E. Smallman
3. Mechanical Metallurgy – G. E. Dieter
4. Plastic Deformation of Metals – R. K. W. Honeycomb
5. Introduction to Creep – W. W. Evans
6. Fatigue of Materials - S. Suresh, CambridgeUniversity Press.
7. Deformation and Fracture Mechanics of Engineering Materials – R. W. Hertzberg

15. Manufacturing Technology (MS15 - 30 hours)

S.No.	Course content
1.	**Nuclear materials and their melting practices**: Selection criteria for in-core, structural and steam generator materials, Radiation damage, Properties of nuclear materials. Principles of Vacuum melting & casting processes, including general descriptions of vacuum induction melting, vacuum arc re-melting and electro-slag refining.
2.	**Hot and cold working processes and tube making processes**: Fundamentals of mechanical processing, defects during manufacturing, Various techniques for producing seamless pipes, design of tooling for hot extrusion and principles of pilgering and Various presses and their characteristics.
3.	**Special metal forming processes**: High velocity forming processes like explosive forming, pertroforge forming, electro magnetic and hydraulic forming, comparison of HVF methods, Super-plastic forming.
4.	**Powder metallurgy** : Introduction, characterization of metal powders. Manufacturing of metal and composite powders. Compaction and sintering of metal powders. Secondary operations. Applications of typical P/M components.
5.	**Computer aided design:** Role of computers in design and manufacture, Solid modeling – techniques and algorithms for modelling – data structures for solid models; Surface modeling – curves and surface representation – composite surfaces – application to computer aided manufacture; Current developments in CAD – feature based modeling – Design by feature – function, feature linkages – Application of feature based models. Parametric modeling.
6.	**Metal joining principles and processes**: Fusion and non- fusion welding processes, modern welding processes, design of welded joints, Introduction to residual stresses and distortion in welds.
7.	**Weldability of materials**: Welding of austenitic stainless steels, ferritic steels, weldability tests, dissimilar welding and selection of weld consumables and welding defects, principles of post weld heat treatment and stress relieving.
8.	**Welded Fabrication**: Codes and Standards, Procedure and performance Qualification, Evaluation of the welded joints, NDT of welds.
9.	**Hard facing Technology**: Introduction, Need for hard facing, Hard facing processes, Hard facing in nuclear power plants.
10.	**Heat Treatment**: Annealing, normalizing, quenching and tempering, Precipitation hardening, Recrystallisation annealing, Importance of heating and cooling rate and hold time in heat treatment, Heat Treatment furnaces.

Books Suggested:

1.Metal Forming Handbook, Schuler, Springer Verlag, Berlin, 1998.
2.Welding Technology for Engineers, Baldev Raj, Shankar (V) And Bhaduri (A K), Narosa Publishing House, New Delhi, 2006.
3.Fundamentals of Metal Forming, Wagoner (R H), John Wiley & Sons, New York, 1997.
4.CAD/CAM from Principles To Practice, Chris Mcmahon And Jimmie Browne, Addison – Wesley, 1993.
5.Manufacturing Technology: Foundry, Forming And Welding, Rao (P N), Tata Mcgraw-Hill, New Delhi, 1987

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING I

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (MECHANICAL/CHEMICAL)

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE1	Code Design for pressure vessel and piping	30	4
2.	FRE2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	30	4
3.	FRE3	Transport Phenomena	30	4
4.	FRE4	Reliability Engineering	20	2
5.	FRE5	Process Design and Control	30	4
6.	FRE6	Vibration Engineering and Condition Monitoring	20	2
7.	FRE7	Seismic Design of Nuclear Reactors and Facilities	30	4
8.	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**210**	**26**

MODULE III- OPERATIONS

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE9	Plant Dynamics and Control	25	3
2.	FRE10	Turbine Generator Fundamentals	25	3
3.	FRE11	Mechanical and Electrical Equipments	25	3
4.	FRE12	Maintenance Engineering	25	3
5.	FRE13	Regulatory Framework for NPPs	25	3
6.	FRE14	Practical's	**6 Weeks**	**12**
		Total	**125**	**27**
		Total	**510**	**74**
1.	Viva Voce	**Grand Total**		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

31. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
32. Steam Power Station, G.A. Gassort.
33. Power Plant Engineering & Economics, Strosal & Vapet.
34. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
35. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
36. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
37. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
38. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
39. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
40. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.

2. **Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3. **Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4. **Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5. **Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6. **Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7. **Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8. **Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities
8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II - CORE ENGINEERING (MECHANICAL/CHEMICAL)

1. Code Design for Pressure Vessel and Piping (FRE1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical, spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures. Thermal stresses in plates and shells.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc (WRC-297)
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Design of tube sheets as per TEMA and ASME Sec VIII Div. 1.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Difference between Sec. VIII Div.1 & Sec III-NB.

12. Introduction to design codes (structure of RCC-MRx) both insignificant and significant creep. Service levels and design class. Introduction to shell and piping design. Thin Shell Design Against Buckling as per RCC-MR Appendix A-7, Elastoplastic instability under monotonic loading – linear elastic analysis, Elastoplastic instability under cyclic loading - elastic linear analysis -negligible creep, Elastoplastic instability in significant creep - simplified method.

Books suggested:

11. Harvey J F , 'Pressure vessel design' CBS publication
12. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
13. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
14. American standard code for pressure piping , B 31.1
15. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Heat Transfer and Computational Fluid Dynamics (FRE2) (30 Hours)

S.No **Course content**

1. **Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity, momentum and energy equations) with special reference to Navier-Stokes & Bernoulli equations.
2. **Laminar Boundary Layer and Forced Convection:** Formulation of differential equations for hydrodynamic and thermal boundary layers. Different analytical methods for reduction of boundary layer equations and theoretical formulation for boundary layer thickness. Study of jets and flow separation in the light of Boundary Layer Theory. Convective heat transfer in internal and external flows. Low and high Prandtl number limits and different thermal boundary conditions.
3. **Turbulent Flow and Heat Transfer**: Reynolds decomposition for turbulence. Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical correlations for heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy.
4. **Natural Convection**: Basic Equations of natural convection. Boussinesq approximation. Derivation of dimensionless groups from basic equations. Analytical approximations.
5. **Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Law, porosity & permeability, homogenization method, continuity equation & energy equation.
6. **Heat Transfer with Phase Change**: Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling & (b) flow boiling: Heat transfer correlations for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post-dryout heat transfer. Various

models available for calculation of heat transfer coefficient. Critical Flow. Models for single - phase and two-phase critical flows.

7. **Radiation heat transfer**: Radiation heat transfer. Reflection, absorption, transmission and emission; concept of black and grey bodies; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Shape factor & law of reciprocity; Radiation heat transfer between two grey bodies
8. **Numerical Methods in Heat Transfer**: Discretization of conduction equation with Dirichlet & Neumann boundary conditions; Temporal integration: Explicit & Implicit schemes. Discretization of convection-diffusion equations (Upwind & Exponential schemes). Estimation of flow field: stream function-vorticity formulation and primitive variable formulation. SIMPLE family of algorithms. Turbulence Modeling: Eddy diffusivity models: k-ε and k-ω models. Reynolds stress models: algebraic & differential versions. Large eddy simulation and Director numerical simulation.

Books suggested:

AHMT

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974.
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.
3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

CFD

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

3. Advanced Mass Transfer (FRE3) (30 Hours)

S.No. **Course content**

1. **Momentum Transport:**

   1.1 Viscosity and Mechanisms of Momentum Transport: Generalized Newton's Law of Viscosity, Pressure and Temperature Dependence of Viscosity, Molecular Theory of the Viscosity of Gases and Liquids, Viscosity of Suspensions and Emulsions, Convective Momentum Transport.

1.2 Velocity distributions with two independent variables: Time-Dependent Flow of Newtonian Fluids, Flow near Solid Surfaces by Boundary-Layer Theory.

1.3 Macroscopic Balances for Isothermal Flows: Macroscopic mass, momentum, mechanical energy balances; Estimation of viscous loss, Performance of Liquid-Liquid Ejector, Thrust on pipe bends***.***

2. **Energy Transport:**

Fourier's Law of Heat Conduction; Thermal Conductivity, its measurement & its dependence on temperature / pressure. Theory of thermal conductivity of gases, gas mixtures and liquids, Effective thermal conductivity of composite solids, Convective transport of energy.

3. **Mass Transport:**

3.1 Diffusivity and the Mechanisms of Mass Transport: Fick's Law of Binary Diffusion, Diffusivity, its measurement & its dependence on temperature / pressure, Theory of diffusion in gases, binary liquids, colloids etc. Molar transport by convection.

3.2 Concentration Distributions in Solids and Laminar Flows: Diffusion through Gas Films, homogenous / heterogeneous chemical reactions, Diffusion into a Falling Liquid Films.

3.3 Equations of Change for Multi-component Systems: Equations of Continuity for a Multi-component Mixture, Multi-component Equations of Change, Multi-component Fluxes and their applications.

3.4 Concentration Distributions with More than One Independent Variable: Time-Dependent Diffusion, Steady-State Transport in Binary Boundary Layers, Boundary Layer Mass Transfer with complex interfacial motion. Concentration Distributions in Turbulent Flows.

3.5 Interphase Transport in Nonisothermal Mixtures: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions, Combined Heat and Mass Transfer by Free Convection, Effects of Interfacial Forces on Heat and Mass Transfer, Transfer Coefficients at High Net Mass Transfer Rates.

3.6 Other Mechanisms for Mass Transport: Equation of Change for Entropy, The Flux Expressions for Heat and Mass, Concentration Diffusion and Driving Forces, Applications of the Generalized Maxwell-Stefan Equations, Mass Transport across Selectively Permeable Membranes, Mass Transport in Porous Media.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Reliability Engineering (FRE4) (20 hours)

S.No	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.
3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY

5. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.

2. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.
4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

6. Vibration Engineering and Condition Monitoring (FRE6) (20 Hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; A seismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

7. Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

7. Seismic Design of Nuclear Reactors and Facilities (FRE7) (30 Hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

7. **Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.
15. **High Temperature and Creep Fatigue Interaction:** Damage mechanisms and failure modes, Time-dependent and frequency-dependent damage, Cumulative damage rules, Different approaches for life prediction under creep-fatigue conditions: Frequency-modified approach, strain range partitioning (SRP), Ductility exhaustion method, Creep-fatigue interaction Diagram, Thermomechanical fatigue, Codes and Standards

Books Suggested:

1. Chopra, A.K., "Dynamics of Structures, Theory and applications to Earthquake Engineering", Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures", New York, McGraw-Hill Book Company.
3. Mariopaz, "Structural Dynamic (Theory and Computation)", CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., "Numerical Methods in Finite Element Analysis", Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, "Engineering Seismology", IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, "Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites". AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design", BIS, New Delhi.

8. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.

- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.
- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.
- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings, Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.

- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.
- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evolution of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extension of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Independence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.

- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974

11. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

1. Class room Training

a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

2. Field training

a. Reactor Operation
b. Maintenance Activities
c. Technical Service Activities
d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING II

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (ELECTRICAL/ELECTRONICS)

S. No.	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE15	Reactor Control Engineering	30	4
2	FRE16	Nuclear Instrumentation	25	2
3	FRE4	Reliability Engineering	20	2
4	FRE5	Process Design and Control	30	4
5	FRE17	Embedded System Design & Human Machine Interface	45	6
6	FRE18	Process Instrumentation	45	6
7	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**215**	**26**

MODULE III- OPERATIONS

S. No	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE9	Plant Control	25	3
2	FRE10	Turbine Generator Fundamentals	25	3
3	FRE11	Mechanical and Electrical Equipments	25	3
4	FRE12	Maintenance Engineering	25	3
5	FRE13	Regulatory Framework for NPPs	25	3
6	FRE14	Practical’s	6 Weeks	12
		Total	125	27
		Total	515	74
1	**Viva-Voce**			**2**
		Grand Total		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. El-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP) (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II A- CORE ENGINEERING (ELECTRICAL AND ELECTRONICS)

1. Reactor Control Engineering (FRE15) (30 Hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors- modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (FRE16) (25 Hours)

S.No. **Course content**

1. **1.** Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2. **2.** Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3. **3.** Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4. **4.** Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5. **5.** Introduction to various reactor instrumentation and radiation monitors:
6. **6.** Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (FRE4) (20 Hours)

S.No **Course content**

1. **Introduction: Reliability Engineering Applied to C&I Systems**
Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
2. **Reliability Maths/Statistics:**
   - Mathematical and statistical expressions required for reliability study
   - Types of failures in electrical, electronic and computer components
   - Failure probability concept, statistical distribution models
   - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
   - Chi-square distribution and its use in confidence and risk factors
   - Baye's theorem
   - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
   - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions
   - Derivation of exponential reliability expression

- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

3. **Fault Tolerance and Systems Reliability:**
   - Fault tolerance concept for electronic and Computer based C&I systems.
   - Circuit hardware redundancy concept to enhance system reliability, types of redundancy
   - Series, parallel, active, passive, and voting redundancy
   - Redundancy and other fault tolerance methods for software
   - FMEA, FMECA concepts for C&I and Examples to solve
   - Concepts for the analysis of System Reliability, availability, and maintainability.
   - System reliability and availability analysis methods
   - Boolean logic
   - Digraph, cutest-tie set method
   - Fault tree model, and consideration of CCF, CMF, software errors
   - Markov Model

   Example from C&I system in the NPPs
4. **QA/QC Concepts in Brief:**
   - QA/QC Concepts in the components, systems procurement, manufacture and Site installation for C&I systems in the NPPs.
5. **Environmental Qualification and Reliability Testing:**
   - Environmental qualification, testing of the C&I systems
   - Effects of various environments on the electrical/ electronic components
   - Climatic Qualification tests: Temperature, Humidity
   - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
   - Reliability Testing of the electronic components, equipment and C&I systems
   - Reliability screening tests for electronic components
   - Accelerated environmental tests
   - Failure terminated and time terminated tests
   - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
   - Few examples to solve
6. **PSA/PRA Concepts in NPPs:**
   - Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs
   - Explain Event Tree
   - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency
   - Level-1, Level-2, Level-3 PSA studies (Brief introduction only)

7. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier
Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ.
(1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill
Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants
(2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment
(1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier
Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher
(2001),
('Formal Methods' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

5. Embedded System Design and Human Machine Interface(FRE17) (45 Hours)

S.No. **Course content**

Embedded System Design

A. Microprocessor Based Hardware Design:

1. Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16-bit Micro-controllers (e.g. 80196), Overview of 8-bit Atmel Micro-controller (AT89C51), Real Time Clock, DSPs (e.g. TMS320, SHARC family) and ARM processor.
2. Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3. Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play
4. Design Case Study: Single board computer architectures, Remote Terminal Unit, Circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.

B. Computer Communication and Networks

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.);Concept of Fieldbus, fieldbus standards, Industrial networks and Protocols.

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Programmable Logic Controller Design

Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, Relevant communication protocol and standards, PLCs for package systems.

Human Machine Interface

E. Human Machine Interface (HMI)

1. Overview of plant automation, Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
2. Design of HMI, Soft Console versus Conventional control panels, Virtual Control Panel.
3. PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.
4. Guidelines for design of HMI displays.
5. Case study of a commercially available Professional HMI package.
6. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons

7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek& R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.
17. IntellutionIfix documentation
18. NPC Guidelines for development of soft consoles

6. Process Instrumentation (FRE18) (45 Hours)

S.No.	Course content
1.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.
2.	Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions-grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors - performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques. Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry-Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
3.	Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and

differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

4. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
5. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position
6. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

   Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.
7. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

   Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
8. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

   Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
9. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

   Note:Course Work -35 Hours and Practicals -10 Hours

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication

3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrument Engineer's Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Field bus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

7. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.
- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.

- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal

pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.

- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings,

Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.
- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.

- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evoluation of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extention of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Indepence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.
- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
-

6. Practicals (FRE 14) (6 Weeks)

12. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

3. Class room Training

a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

4. Field training

a. Reactor Operation

b. Maintenance Activities

c. Technical Service Activities

d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

Homi Bhabha National Institute, RRCAT, Indore

Syllabus for
PGD in Engineering Sciences
(PROGRAM CODE: ENGG00)

Raja Ramanna Centre for Advanced Technology, Indore

Courses offered at HBNI, RRCAT for PGD in ENGINEERING SCIENCES

(Specialization in Accelerators and Lasers)

- Total credit requirement for Ph. D. (Physics) : 60

Core courses	28 credits
Elective courses	20 credits
Laboratory experiments	04 credits
Two reading courses	08 credits

- Total credit requirement for M.Tech. (Engineering Physics) : 60*

Core courses	38 credits
Elective courses	12 credits
Laboratory experiments	04 credits
Short term project	06 credits

* An additional course (Foundation course) of 5 credits is offered to M.Tech. students as a bridge course.

Contents

Syllabus for PGD (Engineering Physics) courses

A : Core Courses

03ENGG00-001-C Engineering Mathematics Credit (3)

Complex Analysis: Analytic functions, Cauchy-Reimann conditions, Cauchy integral theorem, Laurent expansion, conformal mapping, singularities, calculus of residues, evaluation of definite integrals.

Vector Calculus: Gradient, divergence and curl operations and their physical interpretations, vector integrations, Gauss theorem, Stokes theorem.

Matrix: Basic concept of matrix algebra, symmetric, skew-symmetric and orthogonal matrices, eigenvalues and eigenvectors of a matrix, hermitian, skew-hermitian and unitary matrices, illustration of symplectic matrices in particle transporting accelerator.

Integral Transform: Fourier integral, Fourier transform and inversion theorem, Fourier transform of derivative, convolution theorem, transfer function, Laplace transform, Laplace transform of derivatives, convolution theorem, inverse Laplace theorem.

Ordinary and Partial Differential Equations: Review of ordinary differential equations, introductions to partial differential equations, classification of partial differential equations, boundary and types of partial differential equations, solutions of one dimensional diffusion equation, two-dimensional Laplace equation, use of integral transform in solving partial differential equations. Introduction to difference equations.

Probability and Statistics: Bayes' formula, random variables, expected value and variance, discrete and continuous distributions, location parameters, joint distributions, conditional distributions and independence, covariance and correlation, bivariate normal distribution, Poisson process, the central limit theorem, statistical inference (with an aim to better understand and analyze experimental data), point estimators, estimating variance, confidence intervals, comparing two samples, estimation methods, hypothesis testing, goodness of a fit.

References:

1. "Mathematical Methods for Physicist", G. Arfken
2. "Mathematical Methods for Scientists and Engineers", Donald A. McQuarrie
3. "An Introduction to Probability: Theory and its Applications- Vol.1 and Vol 2", William Feller
4. "Ordinary Differential Equations" V.I. Arnold
5. "Advance Engineering Mathematics", Erwin Kreyszig

03ENGG00-002-C Magnet Physics and Technology: Credit (4)

Origin of Magnetism: Classical and quantum concepts, magnetic moments, angular momentum and quantization of angular momentum.

Classification of Magnetism: Diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetism.

Role of Magnets in Accelerators: Dipole, quadrupole, sextupole, and combined function magnets, DC and fast cyclic magnets, septum magnets, and kicker magnets.

Fundamentals of Magnet Design: Magnetic circuit, dipole, quadrupole, sextupole and higher order multipole magnets and coil design, B-H curve.

Application of Magnetic Materials in Accelerators: Materials for DC magnets: low field magnets, high field magnets, permanent magnets, and shielding.

Materials for AC Magnets: Silicon steels, laminated Ni-Fe alloys, and Ferrites. Numerical methods for magnet simulation: computer code and related mathematical formalism, methods of optimization, multipole expansion, Fourier representation of magnetic field.

Magnet Technology: Fabrication procedures, tolerances, and economic issues.
Methods of magnetic field measurements: magnetic induction, search Coil, Hall probe, and nuclear magnetic resonance.

Superconducting Magnets: Basic concept of superconducting magnets, magnet geometries for dipole magnets, superconducting materials, need for twisted composite conductors, hot spot temperature, current densities, quench, training of magnets and persistent switch.

Geodesy and Alignment of Accelerators: Introduction, survey and alignment as applicable to accelerators and its requirement. Position sensitive elements and their typical tolerances for alignment, fiducial references and adjustment system, fiducial posts and targets, and techniques of fiducialsation. Features of support elements and their adjustments during alignment.

Network and Alignment Procedure: Defining coordinate systems, control networks-types, survey procedure, data adjustment and error analysis.

Survey and Alignment Instruments and Toolings: Electronic theodolite, optical level, laser Interferometer, distinvar, inclinometer, offsetmeter etc. Different types of targets and sensors.

References:

1. "Iron Dominated Magnets", Jack T. Tanabe
2. "Synchrotron Radiation Sources - A Primer," Herman Winick
3. "Iron Dominated Electromagnets, Design, Fabrication, Assembly Measurements", Jack T. Tanabe
4. "Conventional Magnets,Proceedings of CAT- CERN Accelerator School, Nov. 1993, Page 23," Neil Marks
5. "Classical Electrodynamics," J. D. Jackson
6. "Superconducting Magnet Systems," H. Brechna
7. "Physics of Magnetism," S. Chikazumi
8. "Soft Ferrite its Applications", E.C Snelling
9. "Permanent Magnet Materials Their Applications," Peter
10. "Modern Ferrite Technology", Alex Goldman

03ENGG00-003-C Laser Physics and Technology: Credit (4)

Basic Formalism: Spontaneous and induced transitions, Einstein's approach, A and B coefficients, conditions for light amplification and oscillations, and characteristics of laser light. Homogeneous and inhomogeneous broadening of the transitions, spectral narrowing in a laser, gain saturation, spatial and spectral hole burning and their consequences, Lamb dip spectroscopy and its applications.

Propagation of optical beams in free space and in dielectric slab waveguides, Hermite-Gaussian beam modes, and ABCD law for Gaussian beam propagation.

Optical resonators, concept of cavity modes, resonators with spherical mirrors, resonance frequencies of optical resonators, losses in optical resonators, stable/ unstable resonators, Kirchoff's diffraction treatment for transverse modes.

Methods For Obtaining Population Inversion: Optical pumping, coherent and incoherent pumping, one- and two-photon processes, pumping geometries, pump sources, electrical pumping by discharge in gases, excitation mechanisms, self sustained and e-beam sustained operation, chemical pumping, and gas dynamic pumping.

Laser Dynamics: Laser oscillation, three and four level lasers, rate equation modeling, power in laser oscillators, optimum output coupling low- and high-loss regimes, multimode laser oscillation and mode locking. Different techniques of mode locking. Relaxation oscillations, cavity dumping and Q-switching. Techniques of Q-switching. Pulse compression techniques for ultrashort pulse generation. Spectral control of laser output, tunability of output frequency, single frequency operation, and frequency stabilization.

Physics and Technology of Specific Laser Systems: Solid state lasers, vibronic lasers, semiconductor diode lasers, diode pumped solid state lasers, fiber lasers, dye lasers, atomic and molecular gas lasers, chemical lasers, excimer lasers, free electron lasers. Measurement of parameters of a laser system.

Nonlinear Optics: Crystal optics, electro-optic effect, wave propagation in nonlinear media, phase matched second harmonic generation, optical parametric oscillator, two-photon absorption, stimulated Raman scattering, frequency mixing in gases and vapours, self-focusing, optical bistability and optical phase conjugation. Quantum optics: second quantization, non-classical effects.

References:

1. "Laser Fundamentals", W. T. Silfvast
2. "Laser Electronics", J. T. Verdeyen
3. "Lasers", A. E. Siegman
4. "Quantum Electronics", A. Yariv
5. "Laser Physics and Technology, Proc. of the school on Laser Physics and Tech." Eds. P. K Gupta, R. Khare
6. "Nonlinear Optics", R. W. Boyd
7. "Elements of Nonlinear optics", P. N Butcher and D Cotter

03ENGG00-004-C Electromagnetic Theory: Credit (3)

Electrostatics: Laplace equation and the uniqueness theorems, variational approach to solutions of the Laplace and Poisson equations. Formal solutions of electrostatic boundary value problems with Green function. Method of relaxation for 2D electrostatic problems, method of images, separation of variables and special functions, finite element method, and multipole expansions. Electrostatic field in matter.

Magnetostatics: Maxwell equations of magnetostatic, macroscopic Maxwell equations in magnetic material and boundary conditions on B and H, and solution of boundary value problems in magnetostatics.

Electromagnetic Wave: Wave equation, solutions in free space, plane waves, Gaussian beams, equations in material media, dispersion relations, Fresnel's laws of reflection and refraction, total internal reflection and evanescent waves. Lorentz transformation of electromagnetic fields.

Wave-guides, Resonant Cavities and Optical Fibers: Hollow metallic waveguides, dielectric waveguides, optical fibers, resonant cavities, and elements of microwave transport line.

Radiation by Moving Charges: Lienard-Wiechert potentials and fields, power radiated by an accelerated charge, Larmor's formula, and angular distribution of emitted radiation.

References:

1. "Electromagnetic Theory", D. J. Griffith
2. "Classical Electrodynamics", J. D. Jackson
3. "Electrodynamics: An introduction including quantum effects", H. J. W. Muller-Kirsten
4. "Microwave Devices and Circuits", S. Y. Liao.

03ENGG00-005-C Accelerator Physics and Beam Diagnostics: Credit (4)

Introduction: Motion under electric and magnetic fields. DC and RF acceleration. Relativistic kinematics, Brief history and review of particle accelerators.

Synchrotron/Storage Rings: Accelerator magnets - dipole, quadrupole and sextupole magnets. Multipole expansion method. Equation of motion, betatron oscillations, weak and strong focusing, transfer matrices, beam stability, twiss parameters, motion of particles with momentum deviation, momentum compaction, and chromaticity. Magnetic field errors, closed orbit distortion and its correction, resonances - integer and half integer, beam acceleration, synchrotron oscillations, phase stability, transition energy, beam emittance, Liouville's theorem, single turn injection, H-injection, and fast extraction.

Beam Transfer Lines: FODO cells, quadrupole triplet, phase space matching, emittance dilution.

Synchrotron Radiation Sources: Synchrotron radiation, Radiation damping, quantum excitations, equilibrium beam emittance, and beam lifetime.

Linear Accelerators: DC accelerators, various types of RF accelerators, EM mode in a simple structure, Q-factor, shunt impedance, transit time factor, filling time, energy gain, dispersion curve, TW and SW accelerators, and beam dynamics in LINACS.

Cyclotrons: Basic principle of cyclotron, resonance condition, orbit stability, limitations of classical cyclotrons, AVF cyclotrons, injection, central region, extraction, time structure, energy resolution, and beam emittance.

Microtrons: Classical microtrons, basic equations, and Racetrack microtrons.

Beam Diagnostics: Physical principles, charge collection, secondary emission, Ionization, fluorescence, scintillation, capacitive pick up, magnetic pick up, wall current, synchrotron radiation detection, and optical transition radiation.

Instrumentation: Faraday cup, secondary emission wire monitor, beam loss monitor, beam profile monitor, beam position monitor, DC beam current transformer, fast current transformer, wall current monitor, photomultiplier, photo diode, image dissector, and streak camera.

References:

1. "Particle Accelerator Physics", Helmut Wiedemann, Springer
2. "Introduction to Accelerator Physics", Arvind Jain, Macmillan India
3. "CERN Accelerator School Proceedings, Fifth General Accelerator Physics Course, 1992 (Available online)"
4. "The principles of circular accelerators and storage rings", P. J. Bryant and K. Johnsen, Cambridge University Press
5. "Principles of RF linear accelerators", T. Wangler, John Wiley and Sons
6. "Collective phenomenon in synchrotron radiation sources", S. Khan, springer
7. "Physics of collective beam instabilities in high energy accelerators", A. Chao, John Wiley and Sons

03ENGG00-006-C Reactor Physics, Radiation Physics, and Safety Issues of Accelerators and Lasers: Credit (3)

Health Physics: Radiation sources - radioisotopes, natural and manmade sources, radioactive series, reactors, accelerators, radiation facilities, solid, liquid and gaseous activity. Control measures - time, distance, decay, shielding, administrative control, radioactive discharge, waste disposal, and exposure control.

Interaction of Radiation with Matter: Interaction of light and heavy charged particles, photons, and neutrons. Interaction of high energy charged particles, electromagnetic cascade, and Hardronic cascade.

Radiation Quantities, Units, and Regulatory Recommendations: Dosimetric quantities, exposure, absorbed dose, equivalent and effective dose, committed dose, ALI, DAC, ICRP, AERB, and dose limits.

Biological Effects of Radiation: Somatic and genetic effects, stochastic and deterministic effects, and LD30/50.

Detection of Radiation: Ionisation chamber, proportional counters, GM tubes, scintillation detectors, semiconductor detectors, thermoluminiscent dosimeters, direct reading dosimeters neutron detectors, BF3 and He3 tubes, Rem-meters, CR-39-foils, pulsed radiation detection. Low and high energy radiation detection.

Reactor Physics: Introduction to nuclear energy - fission and fusion, interaction of neutrons with matter; fission process and energy release, fission cross-section, fissile and fertile materials. Chain reaction, neutron cycle and lifetime, criticality and classical four-factor formula. Thermal and fast systems, slowing down of neutrons, conversion and breeding of fissile materials, concept of neutron flux and current, neutron diffusion theory, critical size and mass, reflected systems and reflector saving, heterogeneous systems. Reactor kinetics, reactivity and importance of delayed neutrons, reactivity changes and coefficients, fission product poisoning, control devices, uranium and thorium fuel cycles and enrichment processes.

Accelerator Safety: Types of accelerators, prompt and residual radiation, source terms, radiation hazards, radiation safety systems, shielding, radiation monitoring, non-ionizing radiation safety, RF and MW safety, magnetic field safety; ozone safety, safety at synchrotron radiation beam lines, spallation neutron sources, and accelerator driven sub-critical systems.

References:

1. "Nuclear Reactor Engineering Vol-1", Samuel Glasstone and Sesonske
2. "Health Physics", Herman Cember
3. "Radiation Detection & Measurement", G. F. Knoll
4. "Atoms, Radiation & Radiation Protection", James Turner
5. "Physics for Radiation Protection", James Martin
6. "Radiological Safety Aspects of the Operation of Electron Accelerators, IAEA Technical Report Series. 188", W. P. Swanson
7. "Radiation Protection for Particle Accelerator Facilities NCRP Report No.144"
8. "Radiological Safety Aspects of the Operation of Proton Accelerators. IAEA Technical Report Series. 283", R. H.Thomas.
9. "A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators Nuclear Technology", A. Sullivan

03ENGG00-007-C Numerical and Mathematical Techniques and Scientific Programming and Computing Methodologies:

Credit (5)

Numerical Methods

System of Linear Algebraic Equations: Direct methods - Gauss elimination and Gauss Jordan methods. Iterative methods - Jacobi, Gauss-Seidel and Successive over relaxation (SOR) methods. Eigenvalue problem .

System of Nonlinear Equations: Newton-Raphson and Secant methods. Roots of polynomials, synthetic division of polynomials, and Baristow method.

Interpolation, Extrapolation, Error and Regression Analysis: Types of errors their analysis.

Numerical Integration: Newton-Cotes, Gauss quadratures, trapezoidal, Simpson's 1/3 and 3/8 rule. Numerical differentiation - forward, backward and central difference quotient.

Differential Equation: Solution of ordinary differential equations. Solution of partial differential equations. Fast Fourier transformation.

Statistical Distributions: Poisson and Gaussian distributions. Monte Carlo simulation, pseudo random numbers, and central limit theorem.

Finite Element Method (FEM)

Introduction: Basic concepts of finite element method, application of finite element method, finite element method versus classical methods, finite element method versus finite difference method, and advantage of finite element method.

Integral Formulations for Numerical Solutions: Variational method, collocation method; subdomain method, weighted residual methods, Rayleigh-Ritz method, Galarkin's method, and least square method

Elements, Nodes, and Co-ordinate Systems: Introduction, element shapes, nodes, nodal unknowns, and coordinate systems

Shape Functions: Introduction, polynomial shape functions, convergence requirement of shape function, and derivation of shape functions.

Introduction to Stiffness (Displacement) Method: Definition of the stiffness matrix, derivation of the stiffness, matrix, assembly of the total stiffness matrix, properties of the global stiffness matrix.

Application of Finite Element Method in Heat Transfer Problem: Fundamentals, one dimensional finite element formulation, and problems.

Fundamentals of Computers: Computer architecture, application of computers, input and output devices, latest processors, desktop PC and servers.

Networking Basic: TCP/IP, DNS, Internet, and Intranet.

Operating System Basic: Linux, windows, shell programming, and CLI, vi, multithreading, multiuser, multitasking, hyper threading, file permissions, and ssh.

Fundamentals of programming: Algorithm, flow charts, high-level languages like Fortran and C, and steps for creating a simple program.

Introduction to C Programming Language: Program structure, header files, basic data types, variables, and declarations.

Operators and Declarations in C: Relational, logical, increment, and decrement operators. Expressions and precedence of operators. Input and output operations, control statements, iterative loops, arrays, and pointer;

Overview of Scientific Computing: Languages and compilers and scientific libraries.

Overview of Trends and Techniques: Sequential, parallel computing, cluster and grid computing.

Architecture Taxonomy: Traditional architecture, Flynn's classical taxonomy, SISD, SIMD, MISD, and MIMD Models.

Steps for Creating a Parallel Program: Decomposition of the program, communication, computations, and composing the results. Parallel example-array processing.

References:

1. "Numerical Methods for Engineers with Personal Computer", S.C Chapra and R. P. Canale
2. "Numerical Analysis", R. L. Burden and J. Douglas Faires
3. "An Introduction to Numerical Analysis", K.E. Atkinson
4. "Numerical Method", E. Balagurusamy
5. "Numerical Methods for Engineers", D. V. Griffiths and I. M. Smith
6. "Data Reduction and Error Analysis for the Physical Sciences", P. R. Bevington and D. K. Robinson
7. "Finite Element Analysis", S. Krishnamurthy
8. "Introduction to the Finite Element Method", Desai and Abel
9. "An Introduction to the Finite Element Method", J. N. Reddy
10. "Concepts and Applications of Finite Element Analysis", R. D. Cook
11. "Finite Element Modeling for Stress Analysis", R. D. Cook
12. "Finite Elements and Approximation", O. C. Zienkiewicz and K. Morgan

03ENGG00-008-C Materials Science and Technology- I: Credit (4)

The structure of materials (metals and alloys, ceramics and glasses, polymers, composites, low dimensional materials, smart materials). Defects in materials, transport properties of materials, mechanical and thermal properties of materials, electrical, magnetic, galvanometric properties, superconductivity. Optical, nonlinear properties of optical materials, quantum size effects. Electronic materials (like spintronics, and other functional materials). Introduction to symmetry and ferroelectric materials.

References:

1. "Solid State Physics", N. W. Ashcroft N. D. Mermin

2. "Principles of the Theory of Solids", J. M. Ziman
3. "Introduction to the Physics of Electrons in Solids", B. K. Tanner
4. "Introduction to the Electron Theory of Metals", U. Mizutani
5. "Introduction to Superconductivity", A. C. Rose-innes E. H. Rhoderick
6. "Physics of Superconductors: Introduction to Fundamentals Applications", V. V. Schmidt; edited by P. Mueller A. V. Ustinov
7. "Superconductivity", Charles P. Poole, Horacio A. Farach Richard J. Creswic
8. "Shape Memory Materials", Ed. K. Otsuka C.M. Wayman.
9. "Phase Transformations in Materials", Ed. Gernot Kostorz.
10. "Magnetocaloric Effect its Applications", A. M. Tishin Y. I. Spichkin.
11. "Callister's Materials Science Engineering", R. Balasubramaniam.
12. "Engineering Materials 1: An Introduction to Properties, Applications Design", Michael F. Ashby David R. H. Jones.
13. "The Physics of Solids", R. Turton
14. "Dielectric Phenomena in Solids", Kwan Chi Kao.

03ENGG00-009-C Applications of Lasers in Nuclear Science, Industry, and Medicine: Credit (3)

Laser Applications: High resolution spectroscopy, ultra-fast spectroscopy, laser cooling, laser metrology, holography and its applications in NDT, optical data storage information processing, and optical communication. Laser photochemistry, laser application in biology and medicine

Laser Isotope Separation: Principles of selective photonic action, selective photonic action on atoms or molecules, atomic and molecular schemes for laser isotope separation, lasers for isotope separation, and uranium isotope separation technology employing lasers.

Laser Material Processing: Laser material interaction, Laser cutting, welding, surface hardening, laser surface re-solidification, laser surface alloying, and cladding, laser shock-hardening, laser rapid manufacturing, laser application in decontamination and decommissioning of nuclear installations.

03ENGG00-010-C. Applications of Accelerators in Nuclear Science, Industry, and Medicine: Credit (3)

Synchrotron Radiation and its Applications: Properties of synchrotron radiation, various types of sources like BM, wavelength shifter, wiggler, and undulators. Beamline design and

synchrotron optics. Applications of synchrotron radiation to condense matter physics, surface physics, biology and Industries

Industrial and Medical Applications of Accelerators: Accelerators for industrial and medical applications. Beam characteristics for medical and industrial applications.

Radiation Processing Using Accelerators: Radiation cross-linking, radiation curing, polymerization, de-polymerization, and radiation grafting. Dose distribution in the irradiated products.

Typical applications: Treatment of wire and cables, viscose rayon sheets, rubber products, heat shrinkable tubes, and sheets. Flue-gas treatment, waste water treatment, electron beam applications in food irradiation and sterilization.

Accelerator Based Radiotherapy: Clinical requirements of an accelerator for radiotherapy. Various components of radiotherapy machine. Photon beam therapy and electron beam therapy. Quality assurance in radiotherapy accelerator.

Applications of Accelerators in Nuclear and Particle Physics: Evolution of nuclear physics with energy of the incident beam. Nuclear physics and related phenomena at incident beam energy less than 10 MeV/nucleon, between 10 and 100 MeV/nucleon, and more than 100 MeV/nucleon. Nuclear physics with radioactive ion beams (RIB).

Spallation Source: General introduction, applications to condense matter, and nuclear physics.

03ENGG00-011-C. VacuumPhysicsandTechnology: Credit (2)

Vacuum Theory: Definitions - throughput, conductance, pumping speed etc. Pressure equations, mean free path, monolayer formation time. Units of vacuum, pressure regions in vacuum.

Vacuum Systems and Components: Vacuum pumps - rotary pumps, dry pumps, turbomolecular pump, titanium sublimation pump, non-evaporable getters, and sputter ion pump. Vacuum gauges - capacitance gauge, Pirani, thermocouple gauges, BA gauge, penning gauge, partial pressure gauge. flanges and seals, vacuum valves and leed throughs.

Vacuum System Design and Development: Design considerations, sources of gas load (vaporization, thermal desorption, diffusion, permeation, electron and ion stimulated desorption etc). Materials, fabrication techniques and leak detection. Processing to achieve ultra high vacuum.

References:

1. "Handbook of Vacuum Science and Technology", Ed. Dorothy M. Hoffman, Bawa Singh, John H. Thomas III and John H. Thomas III
2. "Vacuum Technology -3rd edition", A. Roth
3. "A User's Guide to Vacuum Technology - July 4, 2003", John F. O'Hanlon
4. "Vacuum Engineering Calculations, Formulas", Armand Berman
5. "Vacuum Technology-CERN Accelerator School", CERN

03ENGG00-012-C. Quantum Mechanics: Credit (6)

For Ph. D. (Physics) only

Mathematical Background and Postulates: Illustrations and application of postulates by using simple two-level systems and two-slit interference experiment.

Quantum Mechanics of Composite Systems: N-particle system, identical particles, symmetrization and antisymmetrization postulates, concept of density matrix, properties of density matrix, pure and mixed states.

Symmetry: Symmetries in quantum mechanics, space and time translation, time reversal symmetry and parity invariance. Rotational invariance, angular momentum, spin, and addition of angular momenta.

Approximate Methods: Variational methods, Wentzel-Kramers-Brillouin (WKB) method, time-independent perturbation theory, time dependent perturbation theory, adiabatic and sudden approximations, Fermi-Golden rule.

Scattering Theory: Born approximation, partial wave analysis, two particle scattering.

Relativistic Quantum Mechanics: Klein-Gordon equation, Dirac equation, electron spin, and positron.

Advanced Topics: Quantization of electromagnetic field, coherent, and squeezed states, interaction of radiation with matter, spontaneous emission and Lamb shift, entangled state, EPR paradox and Bell's inequality.

References:

1. "Principle of Quantum mechanics", Ramamurthy Shankar
2. "Quantum Mechanics, Vol. I and II", C. Cohen-Tannoudji, B. Liu, F. Laloe
3. "Modern Quantum Mechanics", J. J. Sakurai

03ENGG00-013-C: Research Methodology: Credit (0)

(Lecture: 20, Credit: 0)

Research Methodology: Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

Documentation: Preparing scientific papers/reports, scientific presentations.

Laboratory safety: Safe practices in laboratory.

Research ethics: Ethical conduct in science, ethical issues in scientific publication, awareness of plagiarism and other scientific misconducts.

Probability and Statistics: Bayes formula, random variable, expected value and variance, discrete and continuous distributions, joint distributions, conditional distributions, covariance and correlation, normal distribution, Poisson process, central limit theorem and its applications,
definition of precision, accuracy, systematic and random errors, propagation of errors in experimental data and their estimation, estimation of variance and confidence intervals.

Mathematical modeling: Measurement of functional relationships, order of magnitude analysis, dimensional analysis, goodness of a fit, linear regression and data fitting.

Data Security: Introduction to Data Security, Data security requirements, Different Cyber threats to Data & possible Solutions, Basic concepts of Cryptography & Data encryption algorithms, Research opportunities in Data Security.

Data management: Data planning, handling, modelling, analysis, visualization, Different Data Models, Data Management Software, Data Backup & Storage

References:

1) Research Methods for Science, M. P. Marder (Cambridge University Press
2) The Ethics of Science, An Introduction, David Resnick (Taylor and Francis, 2005)
3) Avoiding plagiarism, self-plagiarism, and other questionable writing practices: A guide to ethical writing, Miguel Roig
4) Advance Engineering Mathematics, E. Kreyzwig (Wiley, 2006)
5) An Introduction to Probability: Theory and Applications Vol. 1 and 2, W. Feller (Wiley)

C : Engineering Based Elective Courses

for M.Tech (Engineering Physics) only

03ENGG00-001-E. Power Supplies: Credit (4)

AC-DC Converters: Single phase and three phase diode and controlled rectifiers, effect of source inductance, ripple and harmonic analysis, 12-pulse rectifier, firing angle control schemes, THD and power factor, filters - passive and active, passive and active damping of filters.

Power factor Correction: Effects and limiting standards for line current harmonics, Passive PFC techniques, Active PFC.

DC-DC Converters: Principle of operation, steady-state analysis of buck, boost, buck-boost converters, Isolated dc-dc converters- forward, flyback and bridge converters, pulse width modulator and control of dc-dc converters.

Principles of Feedback Control System: Negative feedback, Stability criteria- gain and phase margin, steady state errors, transient response, current loop and voltage loop acting together.

Magnet power supplies in Accelerators: Requirements, Load characterisation, DC and ramping type power supplies, Pulsed power supplies.

High current magnet power supplies: Stability requirements, current cycling, Field stabilization.

Power supplies for superconducting magnets : Load requirements, quench detection, protection and training.

Laser and Plasma power supplies: Load characterisation, Gas discharge, Ballast requirements, CW/Pulsed operation, Current stabilisation, Power coupling schemes to gas discharges.

Thermal Management: Heat transfer, Heat sink design, Water- cooled heat sinks.

03ENGG00-002-E. Power Electronics: Credit (4)

Power Semiconductor Devices: Diode, SCR, MOSFET, IGBT, Static and switching characteristics, Safe operating areas, Drive requirements and circuits, Introduction to the properties of emerging materials and devices, High voltage switches, Turn-on and turn-off snubbers.

Modelling and Analysis : Introduction to modelling and analysis techniques for dc-dc converters, Averaged equivalent circuit modelling and analysis, small-signal analysis with an illustrative converter, Feedback control of power converters: Feedback controller design, voltage- mode control and current- mode control.

Soft-switching Converters: Concept of soft-switching, Load resonant converters: concept and

definition, ac analysis of converters and modes of operation, Full bridge zero voltage switching converter: Phase shifted PWM, Operation and analysis of converter in steady state.

High frequency Magnetics: Ferrites- characteristics and types, skin effect, proximity effect, parasitic components- origin, minimisation and characterisation, design of high frequency magnetic components, introduction to planar magnetics.

Electromagnetic Interference: Measurement techniques, LISN, separation of common mode and differential mode noise, limiting standards and mitigation techniques, design of high frequency filters.

03ENGG00-003-E. Advanced Course on RF and Microwaves: Credit (4)

Microwave Networks: S-parameters, Matrix representation of Microwave networks and its properties, cascade networks, periodic network system and application, mixed mode S parameters and their applications.

Generation of RF power for accelerators: Design requirements, RF power amplifiers using tetrode & triodes and solid state devices, klystrons, IOT, Gyrotron, Cooling and protection, Grounding and shielding.

High Power RF transmission: design aspect of high power RF transmission, directional couplers, dividers, combiners, high power waveguide and coaxial transmission lines, circulators, bends, magic-T, microwave windows, dummy loads, RF couplers.

Accelerator cavities: Characterizing RF cavity, determination of important cavity parameters, Fundamentals of beam-cavity interactions. RF power coupling to cavity.

Low level RF components and systems: Planar circuits, microstrips, substrate materials, lumped and distributed circuits, mixer circuits, phase shifters, filters, switches, couplers, dividers/combiners, Low level RF signal processing and RF feedback systems.

RF systems for accelerators: Design and configuration of typical RF system, Safety interlocks and operation of RF system.

RF/Microwave measurements: Specialty of high frequency measurements, Measurement of RF power, impedance, VSWR, frequency and phase. Measuring instruments used in RF/microwaves, passive and active detectors, spectrum analyzer, VNA calibration systems, Vector measurement with VNA, peak and average power meters, impedance analyzer, frequency counter.

03ENGG00-004-E. Advanced Data Acquisition and Control Systems: Credit (4)

Components of data acquisition system and their selection, signal conditioning modules, polling, hand-shaking, interrupt and event driven, DMA, data sampling methods.

Embedded system software concepts and development tools assembly and HLL, assembler,

compilers, linker, librarian, resident monitors, source level debuggers, in-circuit & in application programming (ICP/IAP) and logic analyzer. In circuit emulator (ICE), object code and HEX file formats, FPGA & CPLD architectures, logic cell structures, programmable interconnect and I/O ports, programming technologies and VHDL, implementation of combinational and sequential circuits, timing issues in FPGA synchronous circuits.

Centralized v/s distributed control system, PAC and PLCs, PC software issues and virtual instrumentation, VISA, image acquisition, data logging, online and offline data processing, data presentation and reporting, BUSES for digital data communication.

PC buses: PCI & PCI Express specifications mechanical, electrical functional.

Back plane buses: VME, CPCI, PXI, VXI mechanical electrical functional specification.

Buses for instrument network: Asynchronous & synchronous communication standards, bus, ring, net topologies, RS-232, RS-485, USB, LAN-Hub, GPIB, Ethernet, field bus serial port expansion cards on PCI, Converters: USB-GPIB, USB-Serial.

Real-time system concepts, timeliness vs speed, hard vs soft real time, scheduling method, concurrency, process & thread concepts, inter process communication and synchronization.

Software reliability: Software implemented fault tolerance, reliability and availability, safety issues. Software reliability standards and practice.

Process control elements, Set point, disturbance, servo system, regulatory system, analog vs digital control systems, Z - transform for digital control systems, feedback control system, continuous time domain PID controllers. Feed forward and cascade controls, digital controllers, digital form of PID controller, Z-transform based dead beat and Dahlin's algorithms, programmable logic controllers and applications, compensator design and stability criterion.

References:

1. "Process Control Systems: Application Design and Tuning", F.G. Shinskey.
2. "Modern Control Systems", K. Ogata, Prentice Hall (India)
3. "Chemical Process Control", G. Stephanopoulos.
4. "Digital System Design with VHDL and Synthesis: An Integrated Approach", K C. Chang.
5. "Digital System Design and Prototyping Using Field Programmable Logic and Hardware Description Language", Zoran Salcic.
6. "VHDL Made Easy", David Pallerin.

03ENGG00-005-E. Reliability Engineering: Credit (4)

Basic engineering statistics: Basic probability, random variables, probability density and cumulative distribution functions of engineering importance such as the binomial, poisson, normal, exponential, weibull, etc. Random sampling and sampling statistics and distribution of sampling statistics, such as the Chi-Square and Students test, point and interval parameter estimation, test of hypothesis, examples to solve on continuous and discrete distributions, mathematical equations relating to hazard rate, reliability, cumulative failure probability and

failure probability (density) function, Bath-tub curve - explanation of different parts of the life characteristic curve and corresponding failure distributions.

Quality and reliability, QA/QC concepts - Acceptance sampling plans, quality measurement, quality improvement and control methods with applications in design, development, and manufacturing, modern quality management philosophies, engineering/statistical methods including process control, control charts, process capability studies, loss functions, design of experiments, and total quality management (TQM) topics.

Reliability, availability and maintainability concepts and principles, reliability statistical analysis concept overview and application, accelerated life testing concepts, principles and application, qualitative and quantitative accelerated life testing principles, life-stress relationships and application to electronic components and semiconductor devices, software reliability issues, reliability prediction for electronic systems, system reliability concepts and case studies, role of redundancy in system reliability, design for reliability concepts and case studies, degradation analysis and case studies, reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software, hardware reliability analysis of electronic and computer based C&I systems based on MIL-STD-217, methods of measuring the reliability effectiveness of complex engineering systems, optimization theory, preventive maintenance models, and statistical analysis.

03ENGG00-006-E . Advanced Course in High Voltage Engineering: Credit (4)

High Voltage Technology: Introduction, classification of voltage levels, high voltage in electric supply network, major components of a high voltage network.

Electrostatic Fields and their Control: Electric field intensity, electric strength, classification of electric fields, degree of uniformity of electric fields, control of electric field intensity.

Dielectric Materials and their Behavior in Electric Fields:

a. Insulating Behavior of Air and other Gaseous Dielectrics: Generation of charge carriers: impact ionization, thermal ionization and photo-ionization, Negative ion formation, Breakdown by avalanche discharge (Townsend Mechanism); Breakdown voltage characteristics in uniform fields (Paschen's Law) Practical factors affecting the breakdown voltage: Corona, Fields non-uniform, high pressure and vacuum.
b. Liquid Dielectrics in High Voltage applications: Mineral insulating oils, Dielectric properties of insulating liquids, Dielectric power losses in insulating materials, Breakdown in liquid dielectrics, Aging of mineral insulating oils.
c. Solid Dielectrics and their Behavior in Electric Fields: Classification of solid insulating materials, Breakdown and pre-breakdown phenomena in solid dielectrics, Partial discharge and its effects on dielectrics.

Generation of High Voltages:

a. Alternating voltages: single step-up transformer, Transformers in cascade, Voltage control

of testing transformers, Series resonant circuits.

b. Direct Voltages: Half wave and full wave rectification, Voltage doublers and cascade circuits.

c. Impulse Voltages: Single stage impulse generator, Multistage Marx generator, Practical Impulse Generators.

High Voltage Test & Measurement: Types of tests, Power frequency tests, DC voltage test and Impulse withstand test, Peak voltage measurements by spark gaps, Sphere gaps and uniform field gaps, Voltage measurement using ammeter in series with high impedance, Voltage measurement using potential dividers, Generating voltmeter, Voltage and current transformers.

High Voltage Design and Applications: Design considerations of high voltage bushings, power cables, transformers and switchgears; high voltage applications and electrostatic hazards.

High Voltage Safety and Protection.

References:

1. "High Voltage Engineering", E. Kuffel and W S Zaengl.
2. "High Voltage Measurement, Testing and Design", T J Gallagher and A J Pearmain
3. "High Voltage Insulation Engineering", Prof. Ravindra Arora and Prof. Wolfgang Mosch
4. "High Voltage Technology", L. L. Alston

03ENGG00-007-E.Digital Signal, Image Processing and Applications: Credit (4)

Introduction: Digital image, steps of digital image processing systems, elements of visual perception, connectivity and relations between pixels. Image acquisition: Frame grabber, optics and illumination Simple Operations - Arithmetic, Logical, geometric operations.

Mathematical Preliminaries: 2D LTI systems, 2D convolution, correlation, 2D random sequence, 2D spectrum.

Image Transforms: 2D orthogonal and unitary transforms- properties and examples. 2D DFT, histogram, image smoothening, image filtering, Sharpening, thresholding.

Image Segmentation and Analysis: Edge detection, line detection, curve detection, Edge linking and boundary extraction, boundary representation, region representation and segmentation, morphology-dilation, erosion, opening and closing.

Image understanding and recognition: Matching by templates, classifiers models, statistical, matching shapes by contour and texture.

Review of LTI systems: Fourier transform for discrete-time signals and its properties, comparison with continuous-time Fourier transform. Discrete time signals, sequences, representation of signals on orthogonal basis, sampling and reconstruction of signals.

Signal analysis using the Fourier transform, impulse function and complex exponential signal, modulation and frequency translation, duality, Fourier transform of periodic signals,

correlation, energy and power spectral density, Hilbert transform, Fourier transform of finite-duration discrete - time sequences.

Z-transform, Discrete Fourier Transform (DFT), Fast Fourier Transform algorithm and applications. Design of FIR & IIR digital filters, effect of finite register length in FIR filter design. Overview of DSP processors, FPGAs.

Typical applications in Lasers and Accelerators.

Reference:

1. "Digital Image Processing", Rafel C Gonzalez, and Richard E Woods.
2. "Fundamental of Digital image processing", A K Jain.
3. "Fundamentals of Electronic Image Processing", A R Weeks Jr.
4. "Practical Image Processing in C; Wiley professional Computing", Dr. Craig A Lindsey.
5. "Digital image processing: concepts, algorithms, and scientific applications", Jaehne, Bernd.
6. "Digital Imaging: Theory and applications", Burdick Howard E.
7. "Two dimensional signal and Image processing", Lim Jae S, V Oppenheim Allan.
8. "Discrete-Time Signal Processing", A. Oppenheim, R. Schafer and J. Buck.
9. "Signals and Systems", Oppenheim, Willsky and Nawab.
10. "Discrete Time Signal Processing", A.V. Oppenheim and Schafer.
11. "Digital Signal Processing: Principle, Algorithms and Applications", John G. Proakis and D.G. Manolakis.
12. "Theory and Application of Digital Signal Processing", L.R. Rabiner and B. Gold.
13. "Introduction to Digital Signal Processing", J.R. Johnson.
14. "Digital Signal Processing", D. J. DeFatta, J. G. Lucas and W. S. Hodgkiss.

D : Laboratory Experiments (Credit :4)

Experiments relating to lasers, accelerators and general electronics techniques will be offered. A student needs to carry out twelve experiments (4 each from laser, accelerator and electronics related areas) in two phases with a total working time of 72 hours which will carry 4 credits.

03ENGG00-001-L: Lasers and Applications

1. Measurement of spectrum and spectral width of diode laser and their dependence on current.
2. Study of characteristics of a Q- switched Nd:YAG laser.
3. Second harmonic generation: phase matching and maker fringes.
4. Saturated absorption in atomic vapour: Doppler broadening, natural line width, power broadening.

5. Study of light propagation through fiber: coupling efficiency, bending losses, splicing and connecting fiber.
6. Studies on Nitrogen laser pumped dye laser.
7. Parametric study of a XeCl Excimer laser.
8. Output power characteristics of a diffusion-cooled CO2 laser.
9. Determination of severance energy for cutting mild steel with CO2 laser.
10. Determination of laser power coupling efficiency in Nd-YAG/CO2 laser welding of stainless steel.

03ENGG00-002-L: Accelerators Related Areas

1. Electrical resistivity measurement on metallic samples at low temperature.
2. Parametric studies of magnetic materials and operating point of magnets.
3. Outgassing of materials, discharge cleaning and ESD studies.
4. Estimation of radioactivity and shielding attenuation coefficient measurements.
5. Determination of cooling power of a cryocooler.
6. Electron gun: Operation and experimental studies.
7. Proton ion source: Operation and experimental studies.
8. X-ray fluorescence studies using radioactive source.
9. Calibration of cryogenic sensors.

03ENGG00-003-L: Electronics

1. Study of stepper motor, dc motor drive and position feed-back.
2. Study of different transducers and their interfacing.
3. Communication buses and protocols, buses for distributed embedded processing.
4. G.U.I. software familiarization and applications.
5. Digital image processing and their applications.
6. Current and voltage regulated power supplies and change from one another.
7. Study of flash lamp and measurement of flash lamp current and K0 factor.
8. Characterization of RF components.
9. Fast current transformers: Study and measurement of response.

E : Reading Courses (Credit : 8)

Ph. D. scholars will work on two reading courses each of four credit worth. For each reading course, a Ph. D. scholar is expected to do self reading (under the guidance of his/her Ph. D. supervisor) of a review paper or book(s)/monograph(s) of specialized subjects related to the

area of his/her proposed area of research. Alternatively he/she may also work out and comprehend a research paper or a part of research paper relevant to his/her Ph. D. work. The topic and the structure/contents of the two reading courses should be decided by the guide in consultation with the respective doctoral committee and the Ph. D. scholar. The two reading courses should be approved by the respective doctoral committee.

The two reading courses will be evaluated on the basis of the detailed reports that will be prepared by the scholar and presentations, which will be held at the end of first year (in the month of August). The total marks for each reading course is 150 with 100 and 50 for report and presentation respectively.

F : Foundation Courses

for M.Tech (Engineering Physics) only

03ENGG00-001-F. Physics Courses for Engineering Graduates Credit (5)

Quantum Physics: Wave-particle dualism. Wave function, operators, expectation values, Schrodinger equation, Some applications: particle in a box, harmonic oscillator and hydrogen atom.

Atomic and Molecular Physics: Hydrogen spectrum, selection rules. Fine and hyperfine structure. Many electron atoms, energy levels structure, angular momentum coupling like LS & JJ; molecular structure, chemical bonding; electronic, vibration and rotational levels of molecules, Frank-Condon principle, radiative and non-radiative processes in atoms and molecules e.g. fluorescence, phosphorescence, energy transfer, and Raman effect.

Special Theory of Relativity: Galilean transformation, Lorentz transformation, relativistic dynamics - length contraction and time dilation, mass-energy relation.

Solid-state physics: Bonding in solids. Bloch theorem, band structure in periodic systems. Fermi levels, semiconductors, metals and insulators. Normal modes of vibrations and phonons. Specific heat of solids.

Nuclear Physics: Binding energy, nuclear structure and models. Alpha, beta and gamma decay. Fission and fusion processes

Optics: Concepts of wave front amplitude, phase and coherence, Basic ideas of interference, diffraction and polarization. Michelson interferometer.

03ENGG00-002-F. Engineering courses for Physics Post-graduates Credit (5)

Engineering Drawing: Basics, dimensional management and tolerance analysis. Surface texture; standard machine elements, their specifications and usage.

Evolution of product, process of design, parameter determination based on numerical calculations; Material properties and selection; Introduction to material joining & machining processes.

Semiconductor and magnetic devices: Rectifier diode, Zener diode ,Bipolar junction transistor, MOSFET, IGBT, SCR, Triac & GTO: Principle of operation, characteristics, Specifications, Ratings, Protections, Series/Parallel operation, Thermal considerations.
Transformers, Inductors, Saturable reactors: Principle of operation, Parameters, Different types, Specifications, Ratings.

Circuit theory and applications and High voltage Switches: Thyratron, Spark gap: Principle of operation, Characteristics, Specifications, Ratings, Protections
Switching circuit analysis: R-L, R-C, R-L-C circuits.

Power amplifiers: Types, Biasing, Load line, Circuit configuration, preliminary design aspects. Basics of operational amplifiers, linear and nonlinear circuits based on opamps; Principles and types of ADC and DAC, specifications; Digital circuits- combinational and sequential; Logic families; Introduction to microprocessors and PCs, interfacing with PC with serial and parallel modes; Transducers: Temperature, pressure etc;

Electronic instruments: Oscilloscope, logic analyzer, multimeter etc.

RF and Microwave systems: Basic concepts: frequency band designations, units of RF power measurements

Transmission lines: EM waves, transmission modes TEM, TE, TM, co-axial lines, microstriplines, waveguides, VSWR, insertion loss, reflection coefficients

RF cavities: Physics of RF cavities, shunt impedance, quality factor, coupling: modes, HOs, multipactoring, transit time factor; superconducting cavities

Passive devices: Microwave diodes, isolators, circulators, directional couplers, power dividers/combiners, RF Load.

Active devices: RF transistors, FETS, klystrons, magnetrons, tetrodes, triodes, solid- state amplifier.

Measurements: Fundamentals of RF and microwave measurements, S-parameters, measuring RF instruments, VNA, spectrum Analyzers, RF power meter.

Typical RF & Microwave systems for accelerators: Pulsed microwave systems, CW RF systems for SRS and proton accelerators.

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BACK TO MAIN

PGD in LIFE SCIENCES
(PROGRAM CODE: LIFE00)
At BARC

1 PHYSICAL SCIENCES

Code:BS502: PHYSICS, MATHEMATICS and STATISTICS

PHYSICS

Mechanics
Various forms of work, energy and power, linear and circular motion, centrifugation

Atomic Structure and Electromagnetic Radiation
Principles of quantization, production and properties of EM radiation, wave/ particle duality

Optics
Interference, diffraction and polarization; CD and ORD spectra, Beer Lambert's law (spectrophotometer), fluorescence and phosphorescence

Radioactivity and interaction of Radiation with Matter
Types of radiation-ionizing and non-ionizing, laws of radioactive decay, binding energy, nuclear reactions, interaction of radiation with matter (scintillation counting / autoradiography)

Principles of Electricity and applications
Concept of voltage, current, power and electric field (electrophoresis)

Transducers
Devices to convert sound, light, heat, mechanical pressur and other energies to electrical signals.

MATHEMATICS

Logarithms
Definition, laws of logarithms, rule for change of base, common and natural logarithms, characteristic and mantissa, positive and negative bases. Accuracy and precision, number of significant digits

Linear and Polynomial Equations
Linear and quadratic equations and identities, slope, roots, relation between roots and coefficients (will be covered in practicals in the context of IRMA assays where polynomials are relevant)

Permutations and Combinations
Permutation and combination, ${}^{n}C_{r}$ and ${}^{n}P_{r}$ notations, factorials

Calculus and Trigonometry
Definition of derivative, physical significance -differentiation of simple functions, maxima and minima, integration and summation, definition of trigonometric functions, identities

STATISTICS

Basic Concepts:
Probability, a priori and posteriori probabilities. Statistical significance of probabilities, sample and population, variables, classification of variables, nominal, ordinal, interval and ratio, fixed and random

Population Distributions
Binomial distributions and Poisson distributions – their properties, parameters and applications.
Normal and 't' distributions – population and sample parameters measures of central tendency, measures of dispersion, variance, degrees of freedom, confidence limits and intervals; Probability of occurrence – use of Z and t tables

Sampling, Estimates and Hypothesis testing
Sampling methods, random sampling and estimates of population parameters from samples, sample statistics, hypothesis testing, drawing inferences and confidence limits, P values, Students t test for comparing means, general and paired t tests, special cases where variances are unequal, central limit theorem

Analysis of Variance:
F-Distribution - test for homogeneity of variance one way ANOVA, comparison of means of multiple groups by partitioning of the total sum of squares as within and between sum of squares, assumptions in ANOVA, missing values, Two way ANOVA design of experiments

Correlation and Regression:
Pearsons' product moment correlation coefficient, comparison of correlation coefficients, partial and multiple correlation, linear regression analysis; Interpretation of regression coefficients, application of correlation and regression in method comparison and evaluation

Nonparametric Statistics:
Spearman's coefficient of rank correlation, Chi square test, nonparametric methods for hypothesis testing based on ranks, Mann Whitney U test, Wilcoxon signed rank T test

Tutorials in Biostatics:

Code: BS501: CHEMISTRY and RADIOCHEMISTRY

Free Radical Chemistry
Water radiolysis, free radical generation by radiation and chemical methods. Mechanism of reaction, stability and detection and ESR spectroscopy

Structural Chemistry
Nature of chemical bond, weak interactions and their Implications in biology.

Mechanisms and Synthesis
Types of organic reactions, disconnection approach, secondary metabolites, isolation, characterization and biosynthesis, role of secondary metabolites.

Bio-Organic Chemistry
Pheromones, phytoalexins and allelomones bioinorganic chemistry

Radioisotopes
Concept of tracers, general principles of radionuclide production, nuclear reactions, production of radioisotopes, Szillard-Chalmer reaction, separation techniques and radiochemical purity, examples of production of biologically and medically useful radioisotopes (reactor produced cyclotron produced generator produced applying transient and secular radioactive equilibria)

Radiopharmaceuticals chemistry
Radiolabelling techniques, therapeutic radiopharmaceuticals, clinical translation of *in vitro* to *in vivo* application

2 BIOLOGICAL SCIENCES

Code: BS601: BIOCHEMISTRY

Intermediary Metabolism:
Overview of different metabolic pathways and their interaction: carbohydrate, fatty acid and nitrogen metabolism

Proteins and Post Translational Modification
Protein structure: Concept of domains, cytoskeletal, transmembrane, secretory and cytosolic proteins.
Types of post-translational modification: Role of leader and signal peptides, organelle targeting. Protein folding, chaperonins, protein splicing, role of ER resident proteins, golgi etc.

Enzymes:
Multienzyme complexes and their significance, membrane bound enzymes, supramolecular organization, non-aqueous enzymology.
Bioenergetics:
Energy transduction, biological oxidation / Reduction, electron transport

Code: BS608: MOLECULAR BIOLOGY

Basics on DNA Structure and replication
Change in structure and topology of DNA in response to microenvironment change, prokaryotic and eukaryotic genomes size and content. Basic differences in the mechanisms underlying chromosomal, plasmid, phage and mitochondrial DNA replication. Regulation of DNA replication in prokaryotes and eukaryotes. Control of plasmid Copy Number and incompatibility. Mechanism of genome segregation in bacteria and eukaryotes.

Regulation of Gene Expression:

Transcription: A brief outline of catabolic and anabolic operon regulation in bacteria (one example each). Structure of typical regulatory cis elements modules in bacteria and eukaryotes. Chromatin structure, remodeling and implication in regulation of gene expression.
Posttranscriptional processing of transcripts: Different types of RNA splicing mechanisms and alternative splicing, and RNA editing.
Translation: A brief outline of protein synthesis in bacteria and eukaryotes. Mechanisms of ribosome processivity and regulation of translation fidelity at various steps of protein synthesis.

Understanding RNA biology
A brief outline of structure and function of tRNA and rRNA, Secondary and 3D structures of RNA their roles in synthesis and stability of RNA and proteins. Noncoding RNA, RNA trafficking, tRNA maturation, Biogenesis of RNA protein complexes including telomerase function. RNA interference, RNA aptamers and the SELEX protocol, SnRNA, MicroRNA and SiRNA and their possible uses in research in biology.

DNA Damage and Repair

DNA damage produced by ionizing and non-ionizing radiations and chemical mutagens, its detection and repair mechanisms in prokaryotes and eukaryotes. DNA repair deficiency syndromes. Kinetics of DSB repair during post irradiation recovery in bacteria.

Basic tools in molecular biology
DNA protein interaction. Experimental approaches for studying genetic redundancy in genomes maintenance.

Code: BS603: CELL BIOLOGY

Signal Transduction in Animal Systems

Receptors (membrane linked and cellular) receptors with enzyme activity, G proteins, tyrosine kinase related transduction, preview of three modes of signaling (MAP kinase pathway, NFκB pathway and JAK/STAT signaling)
Radiation induced signal transduction and cell death
Cytoprotective and cytotoxic pathways activated By radiation, Cross communication. Bystander effects

Cell Cycle and apoptosis

Predivision stages, G1, S and G2 phases and their significance. Genetic regulation of cell cycle, Oncogenes and tumor suppresors. Detection of changes in cell cycles, apoptosis. Activation of radiation damage sensors and alarm signals. Mechanisms of radiation induced apoptosis. Techniques used in detection of apoptosis, flow cytometry.

Immunology

Innate and acquired immunity; Dichotomy in immune response; Immunocompetent cells and their sub populations; Cell cooperation. Antigen presentation T cell and B cell activation; Cytokines; Tolerance and autoimmunity

Antibodies structure and diversity; Affinity and Avidity; Hybridomas; T cell receptor, structure and diversity; MHC structure and polymorphism; MHC restriction; Immuno defficiency; vaccines and immunotherapeutics

Animal Biotechnology

Stem cell therapy (stem cells identification and asymmetric division), cancer stem cells, characterstics, methods of identification, isolation and characterisation, role in cancer relapse after chemo/radiotherapy, ways to target CSC, gene therapy, pharmacogenomics

Code: BS604: CROP SCIENCE

Linkage, Recombination & Genetic map in crop improvement
Mendelian genetics, Gene interaction, linkage, recombination and linkage maps, mapping functions, linkage/genetic maps vs. physical maps. Cytoplasmic inheritance**.** Chromosome engineering and crop improvement

Quantitative Genetics
Multiple factor hypothesis, transgressive segregation, analysis of quantitative traits, components of variance, heritability, population genetics, Hardy-Weinberg principle, changes in gene frequency

Plant Breeding

Hybridization of Crop Plants: Pedigree method, back cross methods. Male sterility and hybrid seed technology,

Principles of mutation breeding: use of induced mutations for crop improvement with emphasis on achievements in DAE; methodology and protocol for testing and release of cultivars for commercial cultivation.
Disease resistance: Mechanism, sources, screening methodologies and strategies for resistance breeding.
Quality Improvement: Different traits, genetic control, sources and analytical methods, Improvement in quality traits like protein, oil, anti-nutritional factors and vitamins
Abiotic stress: drought, salinity and heat stress tolerance. Basics of abiotic stress tolerance, consequences and mitigation strategies

Crop Management

Plant pathology
Principles of plant pathology, evolution of parasitism, host-parasite interactions and plant immunity, economically important pathogens, plant disease management

Radiation in Insect Pest control: Insect resistant crop plants, use of radiations in pest control - radiosensitivity of insects - SIT and F1 inherited sterility - IPM concepts

Pesticides for crop protection:
Pesticide and their role in crop protection,
environmental issues associated with pesticides applications, pesticide residues analysis

Soil Science
Types of soil, manure, fertilizer, testing and analysis

Plant Tissue culture

Methods in plant cell, tissue and organ culture, regeneration pathways – organogenesis and somatic embryogenesis. Synthetic seeds, apomixis, secondary metabolites in *in vitro* cultures

Code: BS607: MICROBIOLOGY & BIOTECHNOLOGY

Microbial Diversity, Nutrition, Growth
Identification of bacteria: taxonomy and molecular phylogeny, media requirement (enriched and mineral media) and culture techniques.
Antibiotic resistance: mechanism and challenges

Growth kinetics &factors affecting growth, chemostat and continuous cultures, synchronous cultures and their utility, single cell culture, VBNC, concept of microbiome.

Biofouling
Biofilms, biofouling and biocorrosion

Industrial Microbiology
Types of fermentation/ fermentors with examples

Bacterial and Viral Genetics
Genetics of representative phages – lambda, P1, filamentous, retroviruses. Genomic organization, integration into host genome, packaging.

Transformation, transduction and conjugation, kinds of recombination. Basic concepts including gene conversion; Models of recombination, genetics and biochemistry of recombination, site specific recombination, transposons; Rearrangement and amplification of genes.

Gene Mutation
Molecular basis of mutagenesis and mutator genes. Random versus directed mutations, conditional mutations, nonsense mutations and suppressors.
CRISPR: different phases of CRISPR immunity (adaptation, expression and interference), biomedical and other applications of CRISPRs.

Code: BS606: HUMAN GENETICS

Cytogenetics
Constitutional anomalies: Numerical and structural, causes and their implications in human health. Chromosomal disorders.

Molecular Genetics
Mendelian genetics, polygenic and multifactorial inheritance, variability in expression, non-Mendelian inheritance of single gene disorders, monitoring and screening of human population, genetic polymorphisms: VNTRs, SNPs, copy number variations, association studies, pharmacogenetics

Genome Mapping: Physical and genetic mapping, low and high resolution mapping: somatic cell hybrids, radiation hybrids, contigs, chromosome walking, linkage maps, genetic markers, polymorphism information content (PIC), expressed sequence tags (EST), sequence tagged site, (STS), human genome project, and ethical Issues, human genome diversity project.

Next generation sequencing (NGS) and different platforms, paired end sequencing, pyrosequencing, exome sequencing, miRNA and small RNA sequencing, transcriptome sequencing.

Code: BS602: BIOINFORMATICS

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Introduction to Databases
Biological databases including primary and derived databases.

Sequence Analysis/Alignment techniques
Pair wise sequence alignment: local and global alignment, consensus sequence (sequence logo), frequency matrices (PAM, BLOSUM), log odds score, penalty, introduction to graphical, dyanamic programming and heuristic methods, database similarity searches-BLAST/FASTA algorithms

Multiple sequence alignment: clustering, dendogram/tree construction, molecular phylogeny

Genomics, Structural and Functional Analysis
Methodologies for high throughput analysis including microarrays and, application of bioinformatics in genomics

Bioinformatics applications in proteomics: introduction to mass spectrometry based proteomics, MASCOT, protein sequence database and their use, gel based and gel free quantitative proteomic approaches, interpretation and validation of proteomics results, functional proteomics.

Structural Biology and Structural Bioinformatics
Theory and practices of protein crystallography, introduction to the protein structural databases (PDB, CATH, SCOP etc.),
Instrumentation: structural/functional genomics initiatives, evolution of structural motifs and molecular evolution (convergent/divergent evolution), structure prediction methods with particular focus on homology/comparative modelling, structural validation approaches, protein structures in biotechnology (drug design/protein engineering etc.)

Code: BS609: RADIATION BIOLOGY

Introduction to Radiation Biology
Radiation and Life, concept of radiation dose, stepwise development of radiation injury, targets of radiation damage. Concept of RBE and LET. Dose-effect relationships.

Radiation Protection standards , units and concepts:
Introduction, objectives of radiation protection, radiation units, radiobiological data base for radiation protection standards, criteria and standards. Low dose effects and concept of radiation hormesis.

Free Radical Biology and Radioprotection
Biological effects of free radicals, biological defense against free radicals. 0_2 effect, acute radiation syndromes – bone marrow syndrome, gastrointestinal syndrome and CNS syndrome. Sub-lethal and potentially lethal damage and recovery physical, chemical and biological factors modifying radiation damage. Chemical radio-protectants

Radio-Sensitization and Radiotherapy of Cancer:
Basic Concepts, chemical radiosensitizers. Their applications in radiotherapy of cancer. Hyperthermia and modification of radiation injury. Properties of tumor cells relevant to radiotherapy, end points for *in vitro* and *in vivo* cell survival. Dose fractionation, biologically effective dose for teletherapy and brachytherapy, MFD and CHART. Radiosensitivity of tumor cells.

Genetic Effects of Radiation
Dose response relationship, utero exposure, risk estimation of genetic diseases and malformations, Biological dosimetry: partial and whole body exposure, Calibration curves, Cytogenetic and molecular end points: dicentrics, translocations, CBMN assay, pancentromeric, telomeric and whole chromosome FISH, premature chromosome condensation, HPRT assay, comet assay, gamma-H2AX.

Radiation and Immune System:
Radiation effects on immune system. Radiosensitivities of different cell populations. Cytokines and radiation injury. Low dose radiation effects in immune system and their mechanisms. Radioadaptation.

Radiation Dosimetry:
Basic concepts definition and areas of dosimetry, ionisation methods of radiation dosimetry of internally deposited radionuclides, personal monitoring devices and radiation survey instruments.

Operational Monitoring:
General principles and techniques of monitoring, assessment and control of radiation hazards in nuclear fuel cycle facilities with special reference to metallurgical, radiochemical, radioisotope facilities and fuel reprocessing plants including safety aspects of their design and operation, criticality safety

Environmental Aspects of Nuclear Fuel Cycle Operation:
Environmental release, management of solid, liquid and gaseous wastes, tritium hazards from PHWRs
Radiation Emergency Preparedness:
Discussion of type of incidents/accidents likely to be encountered, procedures for handling such events

Code: BS605 : FOOD TECHNOLOGY

Food Chemistry

Physical & chemical properties, macro & micronutrients, food colours, flavours, and additives

Chemical changes, nutritional qualities and functional properties of radiation processed foods

Nutraceuticals properties of food

Food Microbiology

Spoilage and pathogenic microbes, radiation microbiology, fermentation and enzymes

Food processing

Radiation processing: Applications and wholesomeness

Conventional methods for food preservation, emerging concepts in food processing (hurdle technology, HACCP, high pressure processing (HPP) Ohmic heating, ultrasonic treatment), food packaging

Sensory analysis and detection methods for irradiated food

Food irradiation plants: Engineering, process control and economic aspects

Code: BS592 :RESEARCH METHODOLOGIES

3.1) Cell Biology Techniques
Chromosomal analysis with mammalian cells metaphase preparation, micronuclei, G-banding, chromosomal aberrations, cytogenetic effects of radiation.
Immunology:, ELISA, isolation of lymphocytes from lymphoid tissues and peripheral blood, immunophenotyping of T and B cells, E-rosettes and PFC assays, tissue culture methods, blast transformation, cytokine assays. Flow cytometry
Radioimmunoassay and related procedures and tracer distribution in animals

3.2) General techniques
Confocal microscopy

TLC, GC-MS, mass spectrometry, ESR,
NMR/ FT-NMR, IR, UV-VIS spectroscopy

Protein purification, isolation of enzymes, enzyme kinetics, ion-exchange and gel filtration, polyacrylamide gel electrophoresis.

Electrophoretic resolution of proteins (1D & 2D), *in vitro* radiolabeling and autoradiography, western blotting & immunodetection.

Enzyme and cell Immobilization, permeabilization and bioreactors

3.3) Molecular Biology and Microbiology
Transduction, conjugation, repair of UV induced damage, screening of markers

Isolation and purification of DNA from plants & labeling of DNA, Southern hybridization, mRNA Isolation and Northern hybridization

Cloning: screening and reporter assay

Isolation, purification and quantification of DNA and total RNA from peripheral blood and Mammalian Cells, polymerase chain reaction, amplified fragment length polymorphism (Amp-FLP) analysis and silver staining in PAGE, cDNA synthesis, quantitative real time –PCR

Microbiology: Enumeration of bacteria – plating techniques Isolation & identification of Salmonella, MPN for coliforms, radiation survival curve

3.4) Radiation Techniques

Radiation Biology & Radiation Measurements:
Radioisotope tracer techniques and radiation measurements, GM counting system, counting statistics; half life, absorption and scattering, isotope dilution, crystal scintillation counting

Chemical dosimetry & ESR

Food Irradiation
Hurdle technology (water activity, antioxidants, packaging & gamma irradiation), analysis (microbial, chemical & sensory)

Code: BS594 SEMINARS

This module is designed for cultivating the art of communication and presentation in the trainees and helps towards value addition to the professional ability and personality development of the trainees

4.1 Paper Seminar

Seminar on a selected paper published by reputed scientists. The purpose of the paper seminar is to prepare the trainee to acquire skills in the presentation of published research work. Aspects such as analysis of the experimental data, details discussion on the results and hypothesis presented and drawing of meaningful conclusions are expected to be inculcated during the process. In addition, the trainee is encouraged to point out the strengths and lacunae if any in the publication and suggest feasible steps to enhance the quality of the publication.

4.2 Review Seminar

Seminar on a review to be presented by trainees. Broad areas/ processes/topics/concepts of current research interest are communicated to the trainees for choosing a topic for review. The seminar committee allocates the review topic to the trainee from amongst the topics submitted by him/her based upon the suitability, interests and aptitude of the trainee. The trainee is expected to review as many papers as feasible on the specified topic and submit a brief summary on the review topic assigned followed by an open defense. A senior HBNI faculty in Biosciences is assigned as a mentor to each trainee to guide them.

AUDIT LECTURES

Reactor Science

Basic concepts of nuclear energy
Properties of nuclei, binding energy, cross section, nuclear fission process and energy release, fission products, fission product activity, fission gammas, Neutron flux
Interaction of neutrons with matter
Neutron reactions, production of neutrons, nuclear reactions with thermal and fast neutrons
Concept of a nuclear reactor
Chain reaction, multiplication factor, four factor formula, nuclear reactor materials, fissile, fertile, fissionable nuclides, fuel, moderator, coolant, structural materials, concepts of irradiation, burn up, criticality
Exposition to different reactor systems
Indian nuclear power programme, thorium utilisation (AHWR)

Biosciences
Bio safety and animal ethics

Scientific Research & Documentation
Preparation of manuscript for publication: research & review papers, thesis writing, patent filing etc.

Intellectual Property Rights

Occupational safety, health and environment at work place

Syllabus
Regulatory framework of BARC, Atomic Energy Act 1962, Atomic Energy Factory Rules, Radiation Protection Rules
Surveillance of occupational health, medical care and management of Internal contamination
Preparedness for fire safety 1. Fire process 2. Fire detectors and alarms 3. Fire extinguishers 4. Fire protection systems 4. Do's and don's during fire emergency
Non-ionizing radiation safety
Chemical safety
Basic of radiation and sources of radiation, interaction of radiation with matter, radiation quantities and units, principles of radiation detection and measurement, effects of radiation, fundamentals of radiation protection

BS701 - BS714: ELECTIVE COURSES

Code	Title
BS701	Advances in enzyme technology
BS702	Assessment of health effects from exposure to low levels of ionizing radiation
BS703	Biology of stress and adaptive response in bacteria
BS704	Challenges for sustainable and clean environment
BS705	Food borne pathogens
BS706	Immunological methods in biochemical and chemical analysis
BS707	Molecular markers and genomics for crop improvement
BS708	Oxidative stress and redox modifiers in disease management
BS709	Cancer- hallmarks, pathogenesis, microenvironment and therapeutics (previously *Overview of cancer*)
BS710	Plant genetic engineering
BS711	Advances in genome biology
BS712	Principle and practices in structural biology
BS713	Advanced instrumentation for bioanalysis and imaging
BS714	Molecular biology methods in tuberculosis and thyroid cancer

Annexure-II

COURSE STRUCTURE - BIOSCIENCES

FOUNDATION COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Chemistry & Radiochemistry	BS 501	20	2	75
2	Physics, Maths & Statistics	BS 502	40	4	150
	FOUNDATION TOTAL		**60**	**6**	**225**

CORE COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Biochemistry	BS 601	15	2	75
2	Bioinformatics	BS 602	30	3	125
3	Cell Biology	BS 603	25	3	100
4	Crop Science	BS 604	30	3	125
5	Food Technology	BS 605	20	2	75
6	Human Genetics	BS 606	15	2	75
7	Microbiology & Biotechnology	BS 607	25	3	100
8	Molecular Biology	BS 608	25	3	100
9	Radiation Biology & Health Physics	BS 609	30	3	125
	CORE TOTAL		**215**	**24**	**900**

ELECTIVES (any 4)

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advances in enzyme technology	BS 701	20+2W*	4	125
2	Assessment of health effects from exposure to low levels of ionizing radiation	BS 702	20+2W*	4	125
3	Biology of stress and adaptive responses in bacteria	BS 703	20+2W*	4	125
4	Challenges for sustainable and clean environment	BS 704	20+2W*	4	125
5	Food borne pathogens	BS 705	20+2W*	4	125
6	Immunological methods in biochemical and chemical analysis	BS 706	20+2W*	4	125
7	Molecular markers and genomics for crop improvement	BS 707	20+2W*	4	125
8	Oxidative stress and redox modifiers in disease management	BS 708	20+2W*	4	125
9	Cancer- hallmarks, pathogenesis, microenvironment and therapeutics (previously *Overview of Cancer*)	BS 709	20+2W*	4	125
10	Plant genetic engineering	BS 710	20+2W*	4	125
11	Advances in genome biology	BS 711	20+2W*	4	125
12	Principle and practices in structural biology	BS 712	20+2W*	4	125
13	Advanced instrumentation for bionalysis and imaging	BS 713	20+2W*	4	125
14	Molecular biology methods in tuberculosis and thyroid cancer	BS 714	20+2W*	4	125
	ELECTIVES TOTAL		**80+8W**	**16**	**500**

* One week (6hrs *5 days=30 hrs.) of Lab Work (equivalent to 1 Credit)

	THEORY TOTAL	**355+8W**	**46**	**1625**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	Viva Voce (Mid-Term & Final)	BS 591	6	200
2	Research methodologies and experimental work $	BS 592	20(7+13)	550
3	Seminars	BS 594	4	200
		TOTAL	**30**	**950**

$ (70 lectures equivalent to 7 credits; 67 days *6 hrs.=402 practical hours equivalent to 13 credits)(2*70+ 20*7= 280; 13*20=260; 280+260= 540; so 550 marks taken total out of which ;200 marks for lab viva; 350 marks written test at the end of each practical)

Total Contact Hrs : 355; Total Credits: 75; Total Marks: 2575

Note: Credit Requirement for Ph.D: 60

Marks are calculated using the formula (As per BOS decision)
2*Hours + 20*Credits (Nearest multiple of 25)

BARC

PGD in Physical Science
(Program Code: PHYS00)

SYLLABUS

PHYSICAL SCIENCES

Course work for Training School Officers (OCES)

The course work structure is divided into 5 foundation courses (A1-A5), 9 core courses (B6-B14), 3 experimental and laboratory courses (C15-C17) and 2 elective courses (D18, D19), as given in Table-1. The topic ‘Research methodology’ is explicitly included as a part of the course work (C16) as per the requirement of UGC. Total lecture hours are 490 + 75 tutorials and 7 weeks duration for a mini project (C17). Total credits are 60 as per the requirement of HBNI. Detailed course structure for individual subjects is provided separately. Some specific issues are as follows:

Research Methodology and methods of Experimental Physics

The course work includes specific topics related to ‘research methodology’ that are not covered elsewhere in the syllabus. These include design, analysis and presentation of scientific projects, objectives and planning of research, literature survey, statistical methods, mathematical modeling, documentation and presentation, laboratory safety and research ethics. Other topics in are related to the experimental techniques in areas such as vacuum, low temperature, X-ray, neutrons, spectroscopy, lasers and accelerators.

Mini Project

As regards the Mini Project (C17), it is understood that the project will be carried out after the completion of the trimester and allotment of trainees to various units of the DAE. The mini project will run concurrently with the elective courses.

Elective Courses

The elective courses are organized under five broad groups as shown in Table-2, which also provides the list of Divisions of BARC involved in closely related R&D activities. This grouping has been done so as to help a TSO to select an elective course that will help him/her to obtain advanced training required for the R&D work to be carried out in the division where he/she is allotted. Such grouping will ensure minimum number of students opting for a given elective course.

It is recommended that the two elective courses in respect of a TSO will be chosen in the following manner:

Elective-1: This elective will be from the group to which the Division of joining of a TSO belongs to (*cf.* Table-2).

Elective-2: This elective can be chosen from any of the other groups depending on the interest of the TSO.

Training School Physics Committee will advise the TSOs on the selection of the elective courses.

COURSE STRUCTURE- PHYSICS

FOUNDATION COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Mathematical Physics	PH 501	30 + 5*	3	125
2	Quantum Mechanics	PH 502	30 + 5*	3	125
3	Statistical Physics	PH 503	30 + 5*	3	125
4	Electromagnetic Theory	PH 504	30 + 5*	3	125
5	Computational Physics	PH 505	30 + 5*	3	125
	FOUNDATION TOTAL		**150+15***	**15**	**625**

CORE COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Nuclear Physics	PH 601	30 + 6*	3	125
2	Atomic, Molecular & Laser Physics	PH 602	30 + 6*	3	125
3	Plasma Physics & Technology	PH 603	30 + 6*	3	125
4	Physics of Materials and Surfaces	PH 604	30 + 6*	3	125
5	Reactor Physics & Technology	PH 605	30 + 6*	3	125
6	Accelerator Physics & Technology	PH 606	30 + 6*	3	125
7	Astrophysics	PH 607	15+ 3*	2	75
8	Electronics	PH 608	30 + 6*	3	125
9	Health Physics and Radiation Detectors	PH 609	30 + 6*	3	125
	CORE TOTAL		**255 +51***	**26**	**1075**

EXPERIMENTAL AND LAB COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Engineering Drawing & Workshop Practices	PH 610	15	2	75
2	Research Methodologies and Methods of Experimental Physics	PH 611	30 + 50 (Lab Hours)	8	325
	TOTAL		**95**	**10**	**400**

ELECTIVES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Elective 1	PH 701-731	20 + 4*	2	75
2	Elective 2	PH 701-731	20 + 4*	2	75
	ELECTIVES TOTAL		**40+ 8***	**4**	**150**

	THEORY TOTAL	**540**	**55**	**2250**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	Viva Voce	PY 591	6	200
2.	Mini Project	PY 593	9	300
		TOTAL	**15**	**500**

*** Tutorials**

Total Contact Hrs: 540; Total Credits: 70; Total Marks: 2750

Note: Credit Requirement for Ph.D: 60

Marks are calculated using the formula (As per BOS decision)

2*Hours + 20*Credits (Nearest multiple of 25)

Course work for Training School Officers (OCES)

The course work structure is divided into 5 foundation courses (A1-A5), 9 core courses (B6-B14), 3 experimental and laboratory courses (C15-C17) and 2 elective courses (D18, D19), as given in Table-1. The topic 'Research methodology' is explicitly included as a part of the course work (C16) as per the requirement of UGC. Total lecture hours are 490 + 75 tutorials and 11 weeks duration for a mini project (C17). Total credits are 60 as per the requirement of HBNI. Detailed course structure for individual subjects is provided separately. Some specific issues are as follows:

Research Methodology and methods of Experimental Physics

The course work includes specific topics related to 'research methodology' that are not covered elsewhere in the syllabus. These include design, analysis and presentation of scientific projects, objectives and planning of research, literature survey, statistical methods, mathematical modeling, documentation and presentation, laboratory safety and research ethics. Other topics in are related to the experimental techniques in areas such as vacuum, low temperature, X-ray, neutrons, spectroscopy, lasers and accelerators.

Mini Project

As regards the Mini Project (C17), it is understood that the project will be carried out after the completion of the second trimester and allotment of trainees to various units of the DAE. The mini project will run concurrently with the elective courses.

Elective Courses

The elective courses are organized under five broad groups as shown in Table-2, which also provides the list of Divisions of BARC involved in closely related R&D activities. This grouping has been done so as to help a TSO to select an elective course that will help him/her to obtain advanced training required for the R&D work to be carried out in the division where he/she is allotted. Such grouping will ensure minimum number of students opting for a given elective course.

It is recommended that the two elective courses in respect of a TSO will be chosen in the following manner:

Elective-1: This elective will be from the group to which the Division of joining of a TSO belongs to (*cf.* Table-2).

Elective-2: This elective can be chosen from any of the other groups depending on the interest of the TSO.

Training School Physics Committee will advise the TSOs on the selection of the elective courses.

FOUNDATION COURSES

PY 501: Mathematical Physics

Symmetries and groups: Point groups, abelian and non-abelian groups, characters, representations of simple groups, Lie groups, symmetric groups, braid group

Functions of a complex variable: Analytic and multi-valued functions, Cauchy residue theorem and complex integration, Riemann surfaces, applications to fluid mechanics and quantum mechanics.

Ordinary differential equations (ODE): Linear and nonlinear first-order equations, classification of ODEs, linear independence and Wronskian, singular points, Frobenius series solutions for second-order differential equations, Green function, system of ODEs, phase portraits, hypergeometric and confluent hypergeometric equations, relation with special functions

Partial differential equations: Classification, characteristics, method of integral transforms, Green functions for Poisson equation, diffusion equation, wave equation, Helmholtz equation

Integral equations: Fredholm, Volterra, Abel integral equations, solutions by Liouville-Neumann, Fredholm method, Hilbert-Schmidt theory, Sturm-Liouville problems

References

1. Groups and Symmetry: A Guide to Discovering Mathematics, D. W. Farmer (Universities Press, 1998).
2. Mathematical Methods in Physics, J. Mathews, R. L. Walker (Addison-Wesley, 1971).
3. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag (Springer, 2010).
4. Elements of Green's Functions and Propagation, G. Barton (Clarendon Press, 1989).
5. Mathematical Methods for Physicists, Seventh ed., G. B. Arfken, H. J. Weber, F. E. Harris (Elsevier, 2013).
6. Fundamentals of Mathematical Physics, E. A. Kraut (McGraw-Hill, 1967).

PY 502: Quantum Mechanics

Background: Recollection of the experimental facts exposing limitations of the classical theory; Bohr model: Quantization of angular momentum, Schrodinger's approach to building a new theory leading to Schrodinger equation; Wavefunction, Statistical Interpretation; Probability, Normalization.

Formalism: Postulates of quantum mechanics: Representation of a state as a vector in Hilbert space; Scalar products; Dirac's bra and ket notation, Schwarz's inequality and linear operations on Hilbert space; representation of observables as hermitian operators; adjoints, eigenvalues and eigenvectors; hypothesis of measurement; Uncertainty relation as a consequence of Schwarz's inequality and the concept of minimum uncertainty states. Quantum mechanics in coordinate and momentum space representations and their relationship.

Quantum mechanics in 1-dimension: Free particle and wave packet, phase and group velocities, completeness; Uncertainty principle, minimum uncertainty, Ehrenfest's theorem; Step potential, transmission and reflection coefficients, transfer matrix;Particle in a well/box, density of states; Simple Harmonic Oscillator potential, creation and annihilation operators.

Quantum mechanics in 2-dimensions; Simple harmonic Oscillator potential, isotropic and non-isotropic.

Quantum Mechanics in 3-dimension: Angular Momentum; Angular momentum algebra; Free particle in 3-d; Particle in central potential; Hydrogen atom; Virial theorem, Feynman-Hellmann theorem;

Identical Particles: Two particle systems; Pauli's principle, Fermions and Bosons; Spin of an electron

Approximation methods: Wentzel-Kramers-Brillouin (WKB) method, Time-independent perturbation theory for non-degenerate as well as degenerate Hamiltonians; Variational method; Time-dependent perturbation theory.

Scattering theory: Lippmann-Schwinger equation, Born approximation, optical theorem, Eikonal approximation, method of partial waves.

References

1. *Introduction to Quantum Mechanics*, D. J. Griffiths, 2nd Edition (Pearson, 2005).
2. *Quantum Mechanics*, B.H.Bransden and C.H.Jochain, 2nd Edition (Pearson, 2000).
3. *Principles of Quantum Mechanics*, P.A.M. Dirac, 4th Edition (Oxford University Press, 2004).
4. *Modern Quantum Mechanics*, J.J.Sakurai (Pearson, 1994).
5. *Quantum Mechanics*, E. Merzbacher (Wiley, 2011).
6. *Mathematical Methods of Quantum Optics* (Chapter 1), R.R.Puri, (Springer-Verlag, Heidelberg, 2001).
7. *Quantum Mechanics* (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz, 3rd Edition (Elsevier, 1981).

PY 503: Statistical Physics

Background: Revision of main results of thermodynamics

Formalism: Introduction to micro-canonical, canonical and grand canonical ensembles with examples for each, derivation of Fermi-Dirac and Bose-Einstein distribution for a quantum ideal gas, Specific heat of a degenerate Fermi gas, Blackbody radiation, Bose-Einstein Condensation.

Phase transitions: Introduction to phase transitions, notion of continuous and discontinuous transitions, Landau Theory-Mean field and Gaussian fluctuations.

Monte Carlo Techniques and applications: Introduction to Monte Carlo methods, Metropolis algorithm, Application to numerical integration, application to Ising Model.

Applications: BBKGY equations, Vlasov equation, Saha ionization formula, Statistical nuclear physics

Irreversible processes: Master equation, Brownian motion and Langevin equation, Fluctuation-Dissipation theorem and calculation of friction constant

References

1. *Statistical Mechanics*, K. Hunag, 2nd Edition (Wiley, 1987)
2. *Statistical Mechanics*, R. K Pathria, 2nd Edition (Butterworth-Heinemann, 1996)
3. *Fundamentals of statistical and thermal physics*, F. Reif, 1st Indian Edition (Levant Books, 2000)
4. *Principles of Condensed Matter Physics*, P M Chaikin and T C Lubensky, 1st paperback Edition (Cambridge University Press, 2000)
5. *Reports on Progress in Physics* 60, 487 (1997), K Binder
6. *Saha Equation*, Hale Bradt, (soft copy available)
7. *Saha and his Formula*, G. Venkataraman, 1st Edition (Universities Press India Ltd., 1995)
8. *Statistical Models for Nuclear Decay*, A. J. Cole (IOP Publishing Ltd, 2000).
9. *Treatise on Heavy Ion Science*, R. Stokstad, Ed. D. A. Bromley (Plenum, New York, 1985), Vol. 3, p. 83.

PY504 : Electromagnetic Theory

Background: Overview of EM theory and revision of basic concepts. Role and scope of EM theory and its applications.Laws of induction.Induced fields.Displacement current.Maxwell's equations in vacuum and media.

Electrostatics and Magneto-statics: Boundary value problems. Separation of variables Numerical methods.Finite difference representation of Poisson's Equation. Relaxation methods and Successive Over Relaxation Method (SOR)

Maxwell's equations: General solutions of Maxwell's Equation and Electromagnetic radiation. Electromagnetic waves in free space. General time dependent solutions of Maxwell's Equation: Wave-guides and cavities. Microwaves.Dipole Radiation.Bremsstrahlung.Cyclotron.Radiation as a diagnostic tool.

Propagation of electromagnetic waves through matter: reflection of waves in bounded media. Phase velocity; group velocity; wave equation; continuity theorem; Brilliouin diagram for empty cavity, etc.; Generation of modes in a cavity/waveguide; TEM, TE, TM modes; mode creation and identification. Boundary conditions; Generation of an electric field in an empty cavity; dispersion relation; frequency mode evaluation, etc.

Potentials and Fields: Gauge transformations. Retarded potentials.Lienard-Wiechert potentials.

Relativistic electrodynamics: Lorentz Transformations. Four Vectors.Covariant and contravariant tensors.Electrodynamics in Tensor Notation.Relativistic Potentials.Invariance.

Dynamics of charged particles in Electromagnetic fields: Orbit theory. Drifts (ExB, grad B perpendicular and parallel to B).Adiabatic invariance.Magnet mirror.

References:

1. *The Feynman Lectures on Physics*, Vol.2, R.P. Feynman, R.B. Leighton and M. Sands, 1st edition, (Addison-Wesley Publication Company, 1963).
2. *Introduction to Electrodynamics*, D.J. Griffith, 3rd Edition (Prentice Hall India, 2000).
3. *Classical Electrodynamics*, J.D. Jackson, 2nd Edition (John Wiley & Sons, 1975).
4. *Electrodynamics of Continuous Media*, Vol. 6 of Course of Theoretical Physics, L.D. Landau and E.M. Lifshitz, 2nd Edition (Butterworth Heinemann, 1998).

PY 505: Computational Physics

Computer Programming: Introduction to Linux, Programming in Fortran, Introduction to C and Parallel Processing, Hands on experience at the computer, Data plotting using programs such as gnuplot.

Numerical Methods: Errors in Numerical Methods, Data Statistics & Curve Fitting, Interpolation and Extrapolation, Integration of Functions, Solution of System of Linear Equations, Solution of Nonlinear Equation or Root Finding, Solution of Ordinary Differential Equations, Solution of Partial Differential Equations, Solution of Integral Equations.

Project Assignments: various realistic physics problems to be solved using numerical algorithms coded into programs to be run on the computer.

References

1. *Computer Programming in FORTRAN 90 and 95*, V. Rajaraman (Prentice-Hall of India Private Limited, 2006).
2. *Upgrading to FORTRAN 90*, C. Redwing (Springer-Verlag New York, 1995).
3. *C: The Complete Reference*, H. Schildt (McGraw-Hill, 1987).
4. *Computer programming in C*, V. Rajaraman (Prentice-Hall of India Private Limited, 1994).
5. *C++ : The Complete Reference*, H. Schildt (Tata McGraw-Hill, 2003).
6. *Numerical Recipes – The Art of Scientific Computing* : W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery (Cambridge University Press, 1996).
7. *Numerical Algorithms: Computations in Science and Engineering*, E. V. Krishnamurthy and S. K. Sen (East-West Press, 1986).
8. *Numerical Methods for Engineers - A Programming Approach*, D. V. Griffiths & I. M. Smith (Chapman and Hall, 2006).
9. *Numerical Methods for Scientists and Engineers*, H. M. Antia (Birkhauser, 2002).

CORE COURSES

PY 601: Nuclear Physics

Background: Basic properties of nuclei, systematic of nuclear ground states (low lying states) properties, size, shape, electric and magnetic moment, nuclei away from the line of stability, isomers, nuclear decay, symmetries.

Nuclear Forces: Phenomenological description of nuclear forces, deuteron problem, N-N scattering, microscopic description, meson theory of nuclear forces, N-B interaction with fundamental degrees of freedom, nuclear resonances, quarks and gluons, QCD and chiral symmetry, colour quantum number, standard model, GUT.

Nuclear structure: Multipole composition of radiation, transition matrix, selection rules for multipole transitions, collective and single particle excitations, shell and collective models, giant resonances, high spin states and shape deformations, relativistic mean field theory, Fermi gas model, weak interaction, beta decay, neutrino interaction and oscillations.

Nuclear reactions: Definition of cross-sections, phase shifts, low energy behavior and astrophysics, compound nucleus theory, optical model, statistical model, direct reactions, heavy ion reactions and fission, semiclassical description of nuclear reactions, impact parameter representation, Galuber model, relativistic heavy ion collisions, energy density and rapidity, equation of state of QGP and hadronic matter phase transition, QGP in RHIC, LHC, experimental signatures.

Applied nuclear physics: RBS, NRA, NAA, AMS etc.

References

1. *Introductory Nuclear Physics*, Kenneth S. Krane (Wiley, New York, 1988).
2. *Introductory Nuclear Physics*, Samuel S.M. Wong (Wiley Interscience).
3. *Basic Ideas & Concepts in Nuclear Physics*, K. Heyde (3rd Ed. Taylor & Francis 2004).
4. *Particles and Nuclei*, B.Povh, K.Rith, C.Scholz and F.Zetsche, 5th Edition (Springer 2006).
5. *Introduction to Elementary Particle Physics*, E. Griffiths (Wiley, New York 1987).
6. *Introduction to High Energy Heavy Ion Collisions*, Cheuk-Yin Wong (World Scientific).

PY 602: Atomic, Molecular and Laser Physics

Atomic and Molecular Physics

Background of atomic and molecular structure: Energy level structure, effect of external electric and magnetic fields, Rydberg and autoionizing levels, Nuclear effects: hyperfine structure and isotope shifts, Radiative and non-radiative

processes, Born-Oppenheimer approximation, Vibrational, rotational and electronic spectroscopy of diatomic molecules including selection rules and intensities. Frank-Condon principle, Rotational and vibrational, Raman spectroscopy.
Molecular symmetry and group theory: Groups, Symmetry operations, Point groups, Character tables, Application to molecular problems.

Polyatomic molecules: Rotational energy levels and nuclear spin statistical weight effect, Vibrational spectra of polyatomic molecules: normal modes, energy levels and selection rules, types of bands, group theoretical treatment, inversion, torsional vibrations, etc. Designation of electronic states of diatomic molecules, coupling cases, Molecular orbital theory.

Accelerator based atomic/molecular physics: Spectroscopy with Synchrotron radiation: VUV and soft X-ray spectroscopy of atoms and molecules, photo-ionization /dissociation/ fragmentation, inner shell processes, techniques of electron spectroscopy, Beam foil spectroscopy and Collinear fast beam spectroscopy with ion accelerators.

Laser spectroscopy: Atomic/molecular beam and vapour sources, Theory and practice of Doppler-limited spectroscopic techniques: absorption, fluorescence, opto-galvanic, opto-acoustic spectroscopy. Non-linear and Doppler-free laser spectroscopy: Saturated absorption, polarization and two-photon spectroscopy. Multi-photon and multi-step processes and spectroscopy: Multi-step Resonance excitation/ionization, Multi-photon absorption/ionization.

Applications of laser spectroscopy: Trace analysis, Laser isotope separation, Laser cooling and trapping, Ion traps.

Laser Physics

Theory of Optical Resonators: Resonator modes, Stability criterion, Gaussian beams and their propagation.
Principles of laser oscillation: Pumping mechanisms, Rate equation for three/four level laser systems, Population inversion, Gain coefficient and threshold population inversion, Gain clamping, Single mode and multimode oscillations, Spatial and spectral Hole burning.

Intense and ultra-intense lasers: Techniques for generation of short laser pulse, Q-switching and mode-locking including active/passive schemes, Chirped pulsed amplification.

Types of Lasers: Solid state lasers- Nd:YAG, Ti:S; Gas and metal vapour Laser, Dye lasers, Semiconductor lasers and Diode pumped solid state lasers.

Non-linear Optics: Classical theory of nonlinear response, Wave propagation in nonlinear media, General properties of polarizability tensor, Three wave mixing– Second harmonic generation, Phase matching condition, Sum and difference frequency generation, Optical parametric oscillator and amplifier, Four wave mixing: Third order non linearity, Intensity dependent refractive index, Third harmonic generation, Elementary treatment of stimulated Raman scattering, Stimulated Brillouin scattering, Self phase modulation, and Optical phase conjugation.

Laser Applications: Laser Fusion, Laser accelerators, Laser material processing

References

1. *Atomic Physics*, C.J. Foot, Oxford Master Series in Atomic, Optical and Laser Physics (Oxford University Press 2008).
2. *Laser Spectroscopy Basic Concepts and Instrumentation*, W. Demtröder, 3rd Edition (Springer-Verlag 2003).
3. *Spectra of Atoms and Molecules*, P.F. Bernath, 2nd edition (Oxford University Press 2005).
4. *Modern Spectroscopy*, J.M. Hollas, 4th Edition (Wiley India Pvt. Ltd.
5. *Fundamentals of Molecular Spectroscopy*, C.N. Banwell and E.M. McCash, 4th Edition, (Tata McGraw Hill, 2010).
6. *Laser Fundamentals*, W.T.Sylfvast, 2nd Edition (Cambridge University Press , 2004).
7. *Photonics*, Ralf Menzel, 2nd Edition (Springer, 2007).

PY 603: Plasma Physics and Technology

Background: Introduction to Plasma, the fourth state of matter, collective behaviour, charge neutrality, space and time scales. Concept of plasma temperature, Debye length, plasma frequency, plasma parameters. Debye shielding, plasma sheath and dielectric properties, plasma in nature and laboratory: elementary concepts of thermal, nonthermal plasmas, laser produced plasmas, non-neutral plasmas.

Basic processes in plasmas: Collisions in plasmas, significance of small angle scatterings, ionisation, recombination, concepts of diffusion, mobility, ambipolar diffusion. Thermal ionisation and the Saha equation, LTE and equilibrium models.

Plasma Theory: Fluid theory of plasmas, single & multi fluid approximations, generalized Ohm's law. MHD equations, Waves and instabilities in plasmas.

Plasma production and diagnostics: Various plasma production techniques, Electrical breakdown in gases using dc, rf, microwave and high frequency fields, Glow and arc discharge. Langmuir probes, magnetic probes, spectroscopic diagnostics, active and passive techniques.

High temperature plasma applications: controlled thermonuclear fusion, Introduction to thermonuclear fusion, fusion reactions, cross sections, radiative processes in plasmas, energy loss, Lawson criterion, break even and ignition, magnetic and inertial confinement scheme and devices, emission of X rays and neutrons, fusion plasma diagnostics.

Low temperature plasma applications: plasma processing of materials, Physics of high and low pressure plasma sources and applications to materials processing, brief review of plasma based surface coatings in low pressure and high pressure plasmas Plasma applications to metal cutting, melting, spraying and waste processing in nuclear, space and semiconductor industries.

References

1. *Plasma Physics: An Introductory Course*, Ed. R.O. Dendy (Cambridge University Press 1995)
2. *Introduction to Plasma Physics* (Plasma Physics Series) by R.J. Goldstan, P. H. Rutherford (Institute of Physics, 1995)
3. *Principles of Plasma Physics*, N.A. Krall and A. W Trivelpiece (McGraw Hill, 1973)
4. *Introduction to Plasma Theory*, D.R. Nicholson, (Wiley, 1992)
5. *Principles of Plasma Diagnostics* by I.H. Hutchinson (Cambridge University Press, 2002)
6. *Thermal Plasma Diagnostics* ,A.A. Ovsyannikov (Cambridge International Science Publishing, 2001)
7. *Inertial Confinement fusion*, J.J. Dudesrstadt and G.A. Mosses, (Wiley, 1982)
8. *Fusion: An introduction to the Physics and Technology of Magnetic Confinement Fusion*, W. M. Stacy (Wiley, 1984)
9. *Industrial Plasma Engineering*, J. Reece Roth (IOP Publications, 2000)

PY 604: Physics of Materials and Surfaces

Background: Symmetry, nature of bonding, crystalline structure and classification, 2D and 3D lattice types, symmetry tables, constraints on physical properties by symmetry, diffraction for structure studies, nuclear and magnetic scattering, small angle scattering.

Lattice vibrations and phonons: Debye model, dynamical matrix, acoustic and optical branches, outline of experimental techniques, like neutron inelastic scattering, Raman and Brillouin scattering; special features in phonon spectra like softening, Kohn anomaly, etc.

Molecular dynamics simulation technique: simulations as a function of pressure and temperature.

Electron states, independent particle picture and periodic boundary conditions, metal-insulator-semiconductor bands, Fermi surface, relation to many electron system and total energy, exchange-correlation terms, relation to experiments like photoemission, optical absorption, etc.

Magnetism: Magnetic materials, types of magnetic ordering and interactions, principles of adiabatic demagnetization and cooling, magnetic domains, linearized spin waves in ferromagnets.

Superconductivity: Meissner effect, energy gap, London equation, type-I and type-II superconductors, vortices, tunneling junctions, outline of modern superconductivity theories, new superconducting materials.

Semiconductors: Intrinsic and extrinsic semiconductors, p-n junction and its applications, heterostructures and semiconductor superlattices.

Dielectrics and Ferroelectrics: Dielectric relaxation and loss, ferroelectric and related materials, comparison with ferromagnets.;

Introduction to surface structures, stability and reactivity.Surface reconstructions and relaxation.Surface processes: Physisorption and chemisorptions.

Surface modification techniques: Physical vapor deposition (thermal evaporation, electron beam, laser ablation, sputtering, molecular beam epitaxy), chemical vapor deposition. Self-assembled monolayers, Langmuir-Blodgett techniques.

Surface characterization techniques: Morphology (optical, scanning electron, atomic force, scanning tunneling and tunneling electron microcopies); Structure (low energy electron diffraction, high energy reflected electron beam diffraction, grazing x-ray diffraction); composition (X-ray photoelectron spectroscopy, energy dispersive X-ray analysis, Rutherford back scattering, secondary ion mass spectrometry).

References

1. *Solid State Physics*, N.W. Ashcroft and N.D. Mermin (Saunders College, 1976)
2. *Introduction to Solid State Physics*, C. Kittel 8th edition (Wiley, 2004)
3. *Solid State Physics*, A.J. Dekker (Macmillan India Limited, 2000)
4. *Physics of Surfaces and Interfaces*, *H. Ibach* (Springer, 2006)

PY 605: Reactor Physics and Technology

Basics Neutron Physics Concepts: Fission process, Definition of flux, current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section. International Nuclear Data files & processing for reactor application.

Steady State Neutron Transport Equation: Transport equation : Differential & integral forms, Diffusion approximation, One speed neutron diffusion theory, Boundary conditions, Source-sink problem, Sub-critical reactors with flux independent source, K-infinity, four factor formula, Critical reactor and concept of K, Separation of space and energy.

Homogeneous Reactor: Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector savings.

Slowing Down and Energy Dependence: Elastic scattering, Inelastic scattering, Anisotropy, average energy loss per neutron, Concept of lethargy. Fermi age theory, age of neutron, Logarithmic energy decrement, Slowing down spectra, Slowing down in hydrogen, Definition of resonance integral, Shape of thermal neutron-Maxwell spectrum.

Resonance Absorption: Resonance cross sections, Resolved and unresolved region, Spatial and energy self shielding, Narrow resonance and intermediate resonance approximation, Concept of potential scattering cross section, Resonance integral in homogeneous media, Doppler broadening of resonance.

Multi-group Diffusion Theory: Energy group and group fluxes, Flux weighted group constants, One group theory for thermal neutrons, Two group theory, Two group two region model core with reflector.

Reactor Kinetics: Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, One group delayed neutrons, One dollar of reactivity, Prompt criticality.

Reactor Control: Cold start-up, Hot power operation, Temperature loads, Effects of burnup and fission products. Function of control rods. Theory of control rods, Xenon load during operation, Xenon iodine concentrations after shutdown, Xenon override, Xenon poison out condition, Samarium poisoning. Temperature coefficient of reactivity, Density temperature coefficient.

Experimental reactor physics aspects: Neutronic Instrumentation (source and power range monitors/detectors); Neutron Sources - requirement vis a vis reactor type (eg external localised sources in LWRs & Fast Reactors; internal distributed spontaneous fission/photo neutron sources in PHWRs) ; Approach to criticality in different reactors; different steps of initial start up in different reactors (research and power reactors); Low power experiments for validation of reactor physics evaluations - subcritical and critical experiments; experimental determination of reactivity coefficients; General methods of flux measurement - foil/wire activation methods; spectrum unfolding; differential measurements for reaction rates; Dynamic methods for reactivity evaluation - power run-down experiments and period measurements; Process parameter measurements using neutronics - eg., coolant flow measurement with N-16 gamma signals; Delayed neutron and noble gas fission

Nuclear Fuel Cycles: Uranium-Plutonium, Uranium-Thorium. Brief Description of Nuclear Reactors like PHWRs, AHWR,VVER, HTR and FBR. Brief discussion of Accelerated Driven Subcritical System (ADSS)

References

1. *The Elements of Nuclear Reactor Theory*, Samuel Glasstone and M.C.Edlund, (Van Noostrand, 1952).
2. *Nuclear Reactor Theory*, Lamarsh J.R., (Addison-Wesley, 1966).
3. *Nuclear Reactor theory*, Duderstadt and Hamilton, (Wiley, 1976).
4. *Nuclear Reactor Engineering*, Glasstone and Sesonske , (Reprint CBS Publishers, 2004)
5. *The Physical Theory of Neutron Chain Reactors*, Weinberg A. M. and Wigner E.P., (Chicago Press, 1958).
6. *Nuclear Reactor Theory*, Bell and Glasstone (Van Nostrand Reinhold Co., 1970).
7. *Physics of Nuclear Reactors*, Jakeman D. (American Elsevier, 1966).
8. *Physics of Nuclear Reactors*, Garg, Feroz Ahemad and Kothari L.S. (Tata McGraw Hill, 1986).
9. *Nuclear Reactor Physics*, Weston M. Stacey, (Wiley, 2001).

PY 606: Accelerator Physics and Technology

Basic Accelerator Physics

Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons; intersecting storage rings; ion sources.

General equations of motion in a combined electric and magnetic field, in Cartesian co-ordinate system; in cylindrical co-ordinate system; beam rigidity; relativistic expressions.

Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.

Expression for vertical betatron frequency; expression for horizontal betatron frequency; weak focusing principle; stop bands.

Tunes and Resonances in betatron oscillations; imperfection resonances; sum and difference resonances; non-linear resonances; tune diagram; working point of an accelerator; general design of a cyclic accelerator.

Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;

Matrix techniques in beam optics; first order transfer matrix of dipole/quadrupole, transfer matrix of a drift space; quadrupole doublet; condition for double focusing; other focusing conditions; aberrations; second order transfer matrix; matching and design of beam transport systems.

Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters

Strong focusing principle; analysis of betatron frequencies using matrix technique; condition for strong focusing; lattice design.

Momentum compaction; Longitudinal stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.

Physics of synchrotron radiation sources; spectrum of emitted radiation; Schwinger's expressions; brilliance of a source; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators, FEL; fundamental wavelength.

RF Linacs

Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.

Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac

Transit time factor and the energy gained in a linac.

Longitudinal stability; stability criteria; separatrix ; synchronous oscillation with small and large amplitudes; longitudinal wave vector; time period; phase damping; acceleration through v=c traveling wave linac and damping phenomena; acceleration conditions therein etc.

Transverse stability; stability criteria; impulse due to radial field; focal strength of a radial defocusing impulse.

Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.

General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature structures; superconducting structures (SC); general advantages of SC systems over room temperature ones; Breakdown mechanisms in SC cavities.

Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac

Introduction to space charge effects.Linear space charge and KV envelope equations.

Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Applications: Accelerator Driven Systems.

High power DC and pulsed electron accelerators

Electron emission processes; thermionic cathodes; field emission; explosive field emission.

Pulse power systems; Marx generators; Tesla transformer, transmission line spark gaps; induction linac.

Relativistic electron beam generation, propagation and applications in generation of microwaves, neutrons, ion beams and X-rays.

Industrial DC electron accelerators.

References

1. *Principles of RF Linear Accelerators*, T. P. Wangler (John Wiley & Sons Inc., 1998)
2. *Introduction to Accelerator Physics,* Arvind Jain (Macmillan India 2007)
3. *Electron Beam Technology*, S. Shiller, U. Heisig and S. Panzer (John Wiley & Sons, 1982)
4. *An Introduction to the Physics of Particle Accelerators*, M. Conte, W.W. Mac Kay (World Scientific Publishing Company, 2008)
5. *Handbook of Accelerator Physics and Engineering*, A. Chao, M. Tigner (1999)

6. *Particle Accelerator Physics*, Vol 1 and 2, Helmut Widemann (Springer 1999 & 2012)
7. *Principles of Charged Particle Acceleration*, Stanley Humphries (Wiley-Interscience, 1986)
8. *Fundamentals of Beam Physics*, James Rosenzweig (Oxford University Press, 2003)
9. *An Introduction to Particle Accelerators*, E. J. N. Wilson (Oxford University Press, 2001)
10. *Accelerator Physics*, S. Y. Lee (World Scientific Publishing Company, 2004)
11. *The Physics of Particle Accelerator:An Introduction*, Klaus Wille (Oxford University Press, 2001)
12. *The Principles of Circular Accelerators and Storage Rings*, Philip Byrant (Cambridge University Press, 2005)

PY 607: Astrophysics

Introduction to Astrophysics and Astronomy: Celestial sphere, coordinate system, time references, cosmic-rays, multi-wavelength observations.

Astrophysical Objects: Stars, clusters, galaxies, x-ray binaries, pulsars, supernova remnants, active galactic nuclei etc.

Non Thermal Universe: Cosmic-ray spectrum and composition, Cosmic emissions at keV-TeV energies, first order and second order Fermi acceleration, diffusive shock acceleration.

Experimental Techniques in Astronomy: Gas filled detectors, solid state detectors, satellite based experiments, ground based experiments, extensive air showers, simulation studies, atmospheric Cherenkov technique.

Fundamentals of Radiative Transfer: Electromagnetic spectrum, radiative flux, specific intensity and its moments, basic equations of radiative transfer, bremsstrahlung, synchrotron and inverse Compton process, proton-proton collision, neutral pion decay, proton-photon interaction.

Theory of Accretion: Spherical accretion, Eddington luminosity, disc accretion and its basic equations, equations for structure of discs and their standard solution.

Jets and Outflows: Microquasars, Blazars and Radio Galaxies, radiation emission from jets, Doppler boosting, Lorenz transformations, observed spectra and spectral models.

References

1. *High Energy Astrophysics*, Vol 1 & 2, M.Longair (Cambridge University Press, 2004).
2. *Very High Energy Gamma-Ray Astronomy*, Trevor Weekes (IOP Publishing, 2003).
3. *Radiative Processes in Astrophysics*, G.B.Rybicki and A.P.Lightman (John Wiley & Sons, 1979).
4. *Accretion Power in Astrophysics*, J.Frank, A.King, D.Raine (Cambridge University Press, 2003).

Note: First four topics (with first three references) constitute the regular 15 lecture course (See Table-1) while all the topics together constitute the 30 lecture course (see Table-3).

PY 608: Electronics

Digital Electronics

Overview of Digital Integrated Circuits: Boolean Algebra and Truth Tables, Integrated circuit Families and their applications, Digital Gates, Flip-Flops, Counters, Multiplexer, Memories.

Number system: Binary, Octal, Hexadecimal with examples. Conversion from one to the other.

Half Adder, Full Adder, 4 bit Adder/Subtractor.

Digital Computer Systems: Basics of Digital computers, 8085 microprocessor architecture and interfacing of memory and I/O peripheral devices.

Buses: Synchronous, Asynchronous. Basics of ISA and PCI buses

Interface standards: RS232, USB; basic protocol, voltage levels, data transfer rate, length etc.
SCADA – Overview

Analog Electronics

Overview of Electronic Devices and Circuits: Diodes, Zeners, Transistors and FETS. Switching Circuits.

Linear Integrated Circuits: Characteristics of OP AMP, Applications of OP AMP (Amplifier, Integrator, Differentiator etc) and Comparator.

Power Supplies: Linear and Switch Mode Power Supplies, High Voltage and Power supplies.

Data Converters: Sampling Theorem, Analog to Digital Converters, Digital to Analog Converters, Sample and Hold Circuits

Reference

1. *Modern Digital Electronics,* R. P. Jain, 3rd Edition (Tata McGraw-Hill Publishing, 2003).
2. *Microprocessor Architecture, Programming, and Applicationswith the 8085,* Ramesh Gaonkar, 5th Edition (Prentice Hall, 2002).
3. *Electronic Principles,* A. P. Malvino, 7th Edition (Tata McGraw-Hill Publishing).

PY 609: Health Physics and Radiation Detectors

Part-I: Nuclear and Radiation Detectors

Interaction of radiation with matter: Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe-Bloch formulae), Cherenkov radiation.Energy loss of electrons and positrons: Electronic stopping and energy loss by bremsstrahlung radiation,Interaction of photons: Photoelectric absorption, Compton scattering, pair production, Electromagnetic shower in high energy photon and electron interaction with matter**,** Interaction of Neutrons: elastic scattering, radiative capture, positive Q-value reactions such as (n,p), (n,a), (n,fission) and hadron shower production at high energies.

Radiation detectors: General characteristics of detectors: efficiency, response in energy, time, position and corresponding resolutions, recovery time or count rate handling capability**,** Gas detectors: Basic processes, Q-V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter. Large area MWPC, PPAC.Semiconductor detectors: Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium detectors (planar and cylindrical geometry). Photovoltaic cells, charged coupled devices.Scintillation detectors: Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes**,** Compton suppressed high purity germanium detectors for high-resolution gamma spectroscopy,Miscellaneous detectors:Cryogenic detectors, thermal detectors, channeltrons and microchannel plates, plastic track detectors, hybrid detectors.

Experimental techniques: Electronics modules for pulse processing: Preamplifiers(charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), timing discriminators(leading edge and constant fraction types), gate and delay generators, coincidence(fast and slow) units, linear gate and stretchers, scalers and rate dividers, SCA, TAC, ADC, QDC, TDC, MCA, computer based data acquisition systems (DAQ). Particle identification methods (dE-E telescope, pulse shape discrimination, Cerenkov radiation), time of flight technique, magnetic spectrometers including recoil mass separator.Monte Carlo simulation of detectors.

Part-II: Health Physics

Introduction: Radiation sources, quantities and units: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given). Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given), Exposure dose relationship, Bragg-Grayprinciple.

Biological effects, Radiation Protection and Regulation: Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell.Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Importance of radiation protection programme in DAE. Types of exposure (natural, occupational, medical and public).National and International regulatory bodies, their role and responsibilities. Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems).Latest recommendations of ICRP-103.Fundamentals of ICRP respiratory model (only basics), entry through ingestion, GI track model (only basics).Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Radiation protection and measurement (External and Internal): Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources.Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area monitoring, air monitoring. bioassay, whole body counting and Liquid Scintillation Spectrometry (LSS) techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures: Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation.

Nuclear Accidents, Emergency Preparedness and Management: Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

Industrial Safety (Non radioactive): Principles of industrial safety and industrial hygiene; legislation related to health and safety and major hazard control.

References:

1. *Radiation Detection and Measurement*, G.F. Knoll, 4th edition (John Wiley & Sons, New York, 2010)
2. *Techniques for Nuclear and Particle Physics Experiments*, W.R. Leo, 2nd Edition. Springer International Student Edition (Narosa Publishing House, New Delhi, 1995).
3. *Introduction to Health Physics*, Herman Cember, 4th Edition (McGRAW-HILL, 2009)
4. *Physics for Radiation Protection*, James E. Martin, 2nd Edition (Wiley-VCH Verlag GmbH, 2006)
5. *IAEA Regional Basic Professional Training Course on Radiation Protection* (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
6. *Nuclear Radiation Detection*, W.J. Price, 2nd Edition, (McGRAW-HILL,1964)
7. *Radiobiology for radiologists,* Eric J. Hall, 7th Edition, (Lippincott Williams & Lippincott, 2012)
8. *Accident Prevention Manual for Industrial Operation*, Vol. 2, National Safety Council, 11th Edition, (National Safety Council, USA, 1997).

PY 610: Engineering Drawing and Workshop Practices

Overview of Engineering Drawing

Drawing Instruments, Standards and Codes: Introduction; Drafting Instruments-Drawing board, T-square, Set-square, Compass, Dividers, Scales, French curves and Drafting machines; Various Indian and International standards and codes related to drafting.

*Sheet Layout and Sketching***:** Sheet layout; Sheet sizes; Scales and scale drawing.

*Types of drawing***:** Assembly drawing- General assembly drawing, Schematic assembly drawing, Exploded assembly drawing; Sub assembly drawing; Part drawing; Production drawing; Drawing for manual and catalogue.

*Lines, Lettering and Dimensioning***:** Introduction; Types of lines; Types and sizes of letter; Dimensioning- Types, Terms and notations, Placing of dimensions, Unit of dimensioning, general rules and practical hints on dimensioning.

*Orthographic Projection***:** Introduction, principle of projection; Methods of projection, Orthographic projection, Planes of projection, First angle projection, Third angle projection, B.I.S. code of practice and conventions employed.

Sectional Views: Introduction; Cutting plane line; Types of sectional views- Full section, Half section, Partial or broken section, Revolved section, Removed section and Offset section; Sectioning conventions; Hatching or section lines and conventions of section lines.

*Tolerances, Limits and Fits:*Introduction;Linear and angular tolerances; Tolerance zone – limits and deviations; Tolerance sizes, Standard tolerance grades; Geometric tolerances; Classification of fits – Clearance, Transition and Interference; System of fits – Hole basis and Shaft basis.

Surface Parameters: Surface texture; Surface irregularities; Surface roughness assessment methods; Roughness grades – symbols, values and grade numbers; Principle reasons for controlling the surface texture; Factors affecting the surface roughness; Disadvantages of excessive roughness; surface roughness achievable from different manufacturing process.

Computer Aided Drafting: Introduction; Benefits and limitations of CAD; Hardware and software of CAD system; AutoCAD–Brief introduction; Drawing environment, layout and sketching; How to access commands;Getting help; Starting a drawing**-**Existing drawing & New drawing**;** Basic settings – Units, Scale, Limits**,** Grids, & Snap**;** Elements of drawing-Line, Multi-line, Rectangle, Polygon, Curve, Circle, Donut, Points, Sketch, Spline, Ellipse, Hatch & Fill;Object Properties - Line type, Colour and Layer; Undoing mistakes;Drawing accurately; Viewing and Editing commands– Zoom, PAN, Move, Align, Rotate, Copy, Mirror, Array, Offset, Trim, Extend, Chamfer, Fillet and Erase;Text; Dimensioning and Printing / Plotting of drawing. Brief introduction of Solid modeling software and its command.

Threads and fasteners: Introduction; Parts of threads; Forms of threads; Single and multiple start threads; LH & RH threads; Brief introduction of bolts, studs, screws, plain & spring washers, set screw and split pin.

Overview of Workshop Practices

Manufacturing Process: Introduction; Classification of manufacturing process- Machining, Joining and Forming.

Metal Cutting using machine tools: Introduction; Theory of metal cutting; Process of metal cutting; Single point and Multipoint cutting tools; Tool signature; Machine reference system; Commonly used metal cutting machines, its parts and related operations / processes viz. Turning, Drilling, Boring, Milling, Shapers, Planer, Grinding etc.

*Unconventional machining operations***:** Introduction; Various types of machines and its operations viz. AJM, USM, ECM, EDM, EBM, and LBM.

*Metal Cutting using hand tools***:** Introduction; Various types of hand tools, its parts and related machining operations viz. saws, Files, Hand drills, Taps, and Reamers.

*Metal Forming***:** Introduction; Various types of forming tools, its parts and related forming process viz. Rolling, Bending, Spinning and Drawing.

*Joining Methods***:** Introduction; Various metal joining tools and related processes viz. Soldering, Brazing and Welding; Various types of demountable joints, flanges and coupling.

References

1. *Engineering Drawing Practice for Schools & Colleges (SP 46:2003)*, Bureau of Indian Standards.
2. *Geometrical and Machine Drawing*, N.D. Bhatt, V.M. Panchal, **(**Charotar Publishing House, Anand 2000).
3. *Manufacturing Science*, A. Ghose, A. Mallik (Tata McGrow Hill, 1997).

PY 611. Research Methodology and Methods of Experimental Physics

Research Methodology: Definition and characteristics of research,Objectives, importance and planning of research, types and stages of research, scientific methods, accessing scientific literature, *Experimental design*: control of errors, calibration of instruments, data analysis,*Statistical methods*:Definition of precision, accuracy, systematic and random errors**,** propagation of errors in experimental data and their estimation, estimation of confidence level.*Mathematical modeling*: measurement of functional relationships, order of magnitude analysis, function fitting, *Documentation*: preparing scientific papers/reports and presentations, *Laboratory safety*: Safe practices, *Research ethics:* acknowledgment of the source of ideas, awareness of plagiarism and other scientific misconducts.

Vacuum Techniques: Definition of Vacuum, Basic theory of Gas dynamics**,** Importance of Vacuum for various experiments, Low temp, Accelerators etc.**,** Flow Regimes in vacuum systems**,** Line Conductance, Calculation of pump-down time**,** Pumps and their ranges: Rotary vane pumps, Diffusion pumps, Ion pumps, Cryo-pumps, Sorption pumps, Gettering pumps**,** Vacuum Gauges in various ranges: Thermal Conductivity gauges, Ionization gauges, Ultrahigh vacuum gauges**,** Vacuum valves**,** Design of vacuum systems**,** Leak detection

Low Temperature Techniques: Requirement of Low Temperature *techniques* for experiments, Heat transfer mechanisms at low *temp*: conduction, convection and radiation, Thermal properties of materials at low temp: Sp. Heat, Thermal conductance etc.Thermodynamic properties of liquid cryogens, Liq. $N_2$and Liq. He, Low *temp* thermometry, Design of small scale laboratory cryostats: Material selection, their properties, Vacuum components, type of measurements, Superconducting magnets, Various inserts, Experiments at low temp: Transport properties, Magnetic properties, Faraday balance, Vibrating Sample magnetometer, SQUID, A.C. Susceptibility, Torque magnetometry

X- ray and Neutron Techniques for Condensed matter studies: Neutrons and X-rays as probes for condensed matter. Complementarities of the techniques**,** Neutron and X-ray sources: Nuclear reactors, Spallation Neutron Sources, Laboratory X-ray sources, Synchrotron X-ray sources**,** Elastic scattering of neutrons and X-rays. Experiments and examples**,** Inelastic scattering of neutrons. Dynamics in solids**,** Possible inelastic experiments in synchrotron sources using X-rays

Laser-Raman and Infrared spectroscopy: Theory of Raman spectroscopy, Laser Raman spectrometer, Molecular symmetry and Raman active modes, Some typical examples, Theory Infrared spectroscopy, Fourier Transform IR (FTIR) Instrument, Typical examples. Comparison with Laser-Raman spectroscopy, IR experiments in synchrotron sources

Laser and Laser spectroscopy Techniques: *Laser diagnostic techniques*: measurement of energy/intensity/power, pulse width, bandwidth, polarization etc. Synchronization of laser pulses, optical alignment. *Laser spectroscopy*: Techniques of some laser spectroscopy experiments in brief i.e. Intracavity laser absorption spectroscopy, CRDS, fluorescence, Saturation absorption spectroscopy, optical pumping and double resonance techniques, Design and implementation, maximization of signal, calibration of frequency

Plasma Physics and Technology: Understanding operation of plasma torches: construction of plasma torches, I-V characteristics of arcs, requirement of I-V characteristics of power supplies for plasma torches, gases suitable to be used for production of plasma, method of ignition of plasma, water cooling systems, interlocks etc. Determination of temperature in thermal plasma jets by spectroscopy techniques.

Experiments in accelerator physics and nuclear physics.

Reference

1. *Research methodology for science*, M.P. Marder (Cambridge University Press 2011).

ELECTIVE COURSES

Elective Courses in General Physics

PY 701: Special topics in Mathematical Physics

Difference equations: Homogeneous linear difference equations (constant-coefficient equations, linear independence, initial and boundary-value problems, Euler equations, generating functions, eigenvalue problems); Inhomogeneous linear and nonlinear difference equations

Local analysis: Singular points, local behaviour of solutions at irregular singular points of homogeneous linear equations, inhomogeneous linear equations, asymptotic relations, asymptotic series, approximate solutions of nonlinear differential equations, nonlinear autonomous systems, singular points of difference equations and local behaviour of solutions, regular and singular perturbation theory, perturbative eigenvalue problems

Global analysis: Boundary layer theory (examples, mathematical structure, simple boundary layer problems), Multiple-scale analysis (resonance and secular behaviour, formal theory, examples), Floquet theory of stability, Mathieu equation, Fermi-Pasta-Ulam problem

Reference

1. *Advanced Mathematical Methods for Scientists and Engineers*, C. M. Bender, S. A. Orszag (Springer, 2010).

PY 702: Selected Topics in Classical Mechanics

Basic concepts: Principle of least time, connection with Huygens principle, optics-mechanics analogy – the basic ideas of Hamilton's mechanics, Euler-Lagrange equations and Hamilton's equations, applications

Transformation theory of mechanics: Generating functions, contact transformations, canonical transformations, canonical group, motion in phase space, Poincaré-Cartan invariant, action-angle variables, adiabatic invariance, examples

Integrable systems: One degree of freedom, Liouville-Arnold theorem, dynamical systems, more than one freedom, noncanonical variables

Canonical perturbation theory: Resonances, classical perturbation theory, adiabatic perturbation theory, secular perturbation theory, applications

Near–integrable systems: KAM stability, three-body problem, applications to celestial mechanics, plasma physics

References

1. *Regular and chaotic dynamics*, A. J. Lichtenberg and M. A. Lieberman (Springer, 1992).
2. *Chaos in dynamical systems*, E. Ott (Cambridge University Press, 2001).
3. *Classical dynamics - a contemporary approach*, J. V. Jose, E. J. Saletan (Cambridge University Press, 2002).

PY 703: Chaos and Nonequilibrium Statistical Mechanics

Introduction: Laws of mechanics and the law of large numbers, Boltzmann ergodic hypothesis, Gibbs' mixing hypothesis, problems in modern nonequilibrium statistical mechanics

Boltzmann and Liouville equation: Derivation, H-theorem, Kac ring, diffusion, BBGKY heierarchy, Poincare recurrence theorem, Birkhoff ergodic theorem, mixing systems, distribution functions

Green-Kubo formulae: Linear response theory, van Kampen's objections, Green-Kubo formula for diffusion

Nonlinear maps: Baker map, Boltzmann equation for Baker map, Bernoulli sequences, irreversibility, Arnold cat map, Kolmogorov-Sinai entropy, Pesin's theorem, Markov partitions, Frobenius-Perron equation

Open systems: Smale horseshoe, escape-rate formalism, thermodynamic formalism for chaos, transport coefficients, deterministic diffusion, Sinai-Ruelle-Bowen measures, entropy, Gallavotti-Cohen fluctuation formula

Dynamical foundation of Boltzmann equation: Lorentz gas, Sinai formula, Lorentz-Boltzmann equation

References

1. *An introduction to chaos in nonequilibrium statistical mechanics*, J. R. Dorfman (Cambridge University Press, 1999).
2. *Chaos, scattering, and statistical mechanics*, P. Gaspard (Cambridge University Press, 1998).

PY 704: Nonlinear Dynamics

Introduction to Nonlinear Dynamics: Introduction to nonlinear dynamical systems (continuous-time): local and global bifurcations, Explanations of Feigenbaum sequence and other routes-to-chaos through standard maps. Characterization of chaos: fractal dimension and other measures; Feigenbaum universal constants. Nonintegrable Hamiltonian dynamics: KAM theorem, Transition from regular to chaotic state, KAM Torus Breakdown.

Instabilities and chaos of periodically forced nonlinear oscillators: Harmonic and various subharmonic resonances. Period doubling, tripling, quadrupling, n-tupling bifurcations, Synthesis of bifurcation structure: recurrent features. Multistability and basins of attraction; Crises of chaotic attractors.

Examples of bifurcations and chaos in laboratory-scale systems: Feigenbaum sequence, multistability and crises in lasers, Instabilities and chaos in electronic circuits, Fluid dynamical instabilities in natural circulation thermal hydraulics and in plasma. Dynamical diseases: cardiac and neurological. Introduction to soliton wave propagation.

Control and synchronization of nonlinear phenomena: Control of Chaos-theoretical concepts, Control of multistability and multi-state hopping intermittency, Coupled nonlinear dynamical systems: various modes of synchronization, secure communication.

Experiments and Numerical projects: Hands-on experience on analyzing various types of bifurcations, crises, chaos, multistability, noise-induced intermittency etc with nonlinear electronic circuits. Computations of subharmonic bifurcation curves of the periodically forced nonlinear systems.Analysis of nonlinear phenomena in the case of autonomous nonlinear systems.

References

1. *Nonlinear Oscillations, Dynamical Systems, and Bifurcation of Vector Fields*, John Guckenheimer and Philip Holmes (Springer Verlag, New York, 1983).
2. *Chaos*, Hao Bai-Lin (World Scientific, 1984).
3. *Universality in chaos*, P. Cvitanovic' (Adam Hilger Ltd, Bristol, 1984).
4. *Deterministic Chaos*, H G Schuster (Springer-Verlag, 1984).
5. *Nonlinear Dynamics and Chaos*, J M T Thompson and H B Stewart (Wiley, 1986).
6. *Chaotic Vibrations –An Introduction for Applied Scientists and Engineers*, F. C. Moon, (John Wiley & Sons New York 1987).
7. *Chaotic and Fractal Dynamics*, F C Moon (J Wiley, 1992).
8. *Chaos in Dynamical Systems*, E Ott (Cambridge Univ Press,1993).
9. *Introduction to Nonlinear Dynamics for Physicists*, H D I Abarbanel, M I Rabinovich and M M Sushchik, (World Scientific,1993).
10. *Nonlinear Dynamics and Chaos*, S H Strogatz (Addison Wesley, 1994).
11. *Applied Nonlinear Dynamics, Analytical, Computational, and Experimental Methods*, A. H. Nayfeh and B. Balachandran, (John Wiley \& Sons, Inc New York 1993).
12. *Nonlinear Spatio-temporal Dynamics and Chaos in Semiconductor*, E. Scholl, (Cambridge Univ Press, 2001).
13. *Handbook of Chaos Control*, Ed. H. G. Schuster, Wiley-VCH 271(1999).
14. *Elementary Stability and Bifurcation Theory*, G. Iooss and D. D. Joseph, (Springer-Verlag New York Heidelberg Berlin), 1990.
15. *Nonlinear Oscillations in Physical Systems*, Ch. Hayashi (McGraw-Hill: New York San Francisco Toronto London, 1964).
16. *Chaotic motions in Nonlinear Dynamical Systems*, (CISM Courses and Lectures 298), W. Szemplin'ska-Stupnicka, G. Iooss and F. C. Moon (Springer-Verlag, Wien New York, 1988).
17. *Perturbation Methods*, A. H. Nayfeh (Wiley: New York Chichester Brisbane Toronto, 1973).
18. *Nonlinear Oscillations*, A. H. Nayfeh and D. T. Mook (Wiley: New York Chichester Brisbane Toronto Singapore, 1979).
19. *Multiple Attractors in the self-similar bifurcation-structure*, B. K. Goswami, Rivista del Nuivo Cimenta, Vol. 27, 2005.

PY 705: Advanced Computational Physics

ScientificProgramming: Introduction to ComputerProgramming, Familiarization with Unix andWINDOWS,Computerarithmetic, High Level Languages, FORTRAN&CstatementsandimplementationonPCs,Sampleassignmentstowriteprogramsforscientificcomputation.

NumericalMethods: Solutionofnon-linearsystemofequations.Curvefittingsofgivendata.Numericalintegration Solutionoflinearsystemsandeigenvalueproblems.Solutionofordinaryandpartialdifferentialequations, MonteCarloMethods.

Physicsproblemsand solutions basedonscientificprogramming: Scatteringbyacentralpotential,Partialwavesolutionofquantumscattering, ASchematicshellModel,Thedynamicsofmanyparticlesystems,(moleculardynamics,deterministicmethod),Optimizationmethods, Neutrontransmissionthroughashield(MonteCarloMethod). Multi-dimensionalMonteCarlointegration,importancesampling,randomwalkmethods,Theapproachtoequilibrium(MonteCarlomethod),Microcanonicalensemble,CanonicalensembleandMetropolisalgorithm.

References:

1. *NumericalRecipesinFortran*,W.H.Presset.al., (CambridgeUniv.Press, 1992)
2. *NumericalMethodsforEngineeringApplication*,J.H.Ferziger, (JohnWiley, 1998)
3. *TheMonteCarloMethod*,I.M.Sobolov (MIRPublishers,1971).
4. *AnIntroductiontoComputerSimulationMethods*, H.GouldandJ.Tobochnik,Part-1&2 (Addision-Wesley, 1988)
5. *ComputationalPhysics*,S.E.Koonin (Addision Wesley, 1986)
6. *TheoreticalPhysicsonthePersonalComputers*,E.W.Schmidtet.al (Springer-Verlag,1988).

PY 706: Stochastic Physics

Classical theory of Brownian Motion*: Langevin's Formulation***:** Motion of a particle in a fluid; Continuum theory of viscous drag; Molecular fluctuations- resolution into mean and fluctuating force; Langevin's equation for a free particle; Force correlations and ensemble averaging; Approach to equilibrium; fluctuation dissipation theorem; implications; Stochastic motion of a harmonically bound particle. *Random-walk Model*: Markov process; Simple Markovian random-walks; position distribution using Fourier transforms; Levy flights; asymptotic law of root mean square displacements; continuous time random walks; random walk with memory; Monte-Carlo techniques of random walk simulations. *Passage to Differential equation*:Concept ofTransition probability;Constraints on moments;Integral formulation; Derivation of phase space Fokker-Planck equation (FPE); special solutions. *Diffusion approximation***:** Moments Equations of FPE; Closure problem; Reduction to diffusion equation; Discussion on boundary conditions.

Nucleation and Coagulation theory: *Homogeneous nucleation theory*: Thermodynamics of phase equilibrium; Free energy of a spherical drop; concept of critical size; Free energy barrier; cluster size distribution; detailed balancing; derivation of nucleation rate-Becker-Doring theory; Zeldovich Factor; Lifshitz-Slozov theory; Experimental studies on homogeneous nucleation rates; multi-component and ion-induced nucleation. *Mathematical theory of coagulation*: Onset of irreversibility post nucleation; The absorption condition; Derivation of formulae for Kernels; Smoluchowski's formulation of colloid coagulation; Integro-differential formulation; scaling theory; self-preserving distributions; Classification of Kernels; Gelation condition; numerical approaches; Practical examples in aerosols. *Escape over barrier*: Transition state theory; Kramer's rate formula.

Growth Models: *Aggregation theory*: fractal concepts; compact and fractal aggregates; mathematical and statistical fractals; Ballistic Aggregates; Eden clusters. *Fractal aggregates:*Diffusion limited growth; Mullins-Sekerka instability; Diffusion Limited Aggregate (DLAs); Witten-Sanders Model; spectral, walker and chemical dimensions; Current state of understanding of DLAs; Cluster-cluster aggregation Model; Relation to coagulation problem; dynamic scaling theory. *Numerical simulation techniques*: Lattice and off-lattice simulations; Monte-Carlo techniques.

References

1. *Stochastic problems in Physics and Astronomy*, S. Chandrasekhar**,** Rev. Mod. Phys. **15**,1-89 (1943).
2. *Noise and fluctuations: An Introduction,* D.K.C. MacDonald (Wiley 1962).
3. *The Fokker-Planck Equation*, H Risken, ed. H. Haken, (Springer-Verlag 1984)
4. *Wonderful world of random walks*, E.W. Montrol and M.F. Shlesinger in *Studies in Statistical mechanics, Vol XI*: Eds. E.W. Montrol and J.L. Lebowitz (Elsevier1984).
5. *Homogeneous Nucleation Theory*, F.F. Abraham (Academic 1974).
6. *Nucleation*, A.C. ettlemoyer (Ed.) (Marcel Dekker, 1969).
7. *Homogeneous nucleation theory and Experiment: A survey*, J.L. Katz, Pure and Appl. Chem. **64**, 1661-1666 (1992).
8. *Nucleation theory*, D.T. Wu in Solid-state Physics: Advances in Research and Applications **50**, 37 (1997).
9. *A general mathematical survey of the coagulation equation,* R.L. Drake, in International Reviews in Physics and Chemistry, Vol.3, Eds. G.M. Hidy and J.R. Brock (Pergamon1972).
10. *The effect of coalescence on the surface area of a coagulating aerosol,* W. Kochand S.K. Friedlander, J. Colloid & Interface Sci. 140, 419 (1990).
11. *Kinetics of clustering in irreversible aggregation*, M.H. Ernstin Fractals in Physics, (Eds.) L.Pietronero and E. Tossatti, (North Holland 1986).
12. *Diffusion limited aggregates-a kinetic critical phenomenon*, T.A. Witten and L.M. Sander, Phys. Rev. Lett. 47, 1400 (1981).
13. *Fractal growth phenomena*, T. Vicsek (World Scientific 1989).
14. *Scaling of kinetically growing cluster,* M. Kolb, R. Botet and R. Jullien, R, Phys. Rev. Lett. **51**,1123 (1983).
15. *Kinetics of aggregation and gelation*: F. Family and D.P. Landau, (North_Holland 1984).

Elective Courses in Nuclear and Accelerator Physics

PY 707: Selected Topics in Nuclear Physics

Brief introduction to heavy ion fusion reactions: General features, Energy dependence at low energy, Limitation at high energy

Decay of the compound nucleus and the statistical model analysis: Bohr hypothesis and Hauser-Feshbach evaporation model, Optical model, Transmission coefficients, Nuclear level densities (NLD)

Particle evaporation spectra and nuclear level densities: Evaporation spectra of neutron and charged particles, Experimental measurements, Extraction of NLD from evaporation spectra

Electromagnetic decay of excited nuclei: Electromagnetic interaction in nuclei – a brief introduction, Single particle and collective gamma transition

Brief introduction to giant resonances in nuclei: Giant resonances – definition, Energy and width systematic, Macroscopic and microscopic description – brief treatment, Giant Dipole Resonance (GDR) in deformed nuclei

Giant Dipole Resonance in excited nuclei: Brink-Axel hypothesis, GDR on excited states in proton capture reactions, GDR in hot nuclei formed in heavy ion reactions

Properties of GDR from high energy gamma spectra using statistical model: Inclusion of GDR emission in statistical model, Measurement of high energy gamma spectra – detectors, experimental procedures, Extraction of GDR information from measured spectra using statistical model, Shape evolution and fluctuation of hot rotating nuclei

Experiments with radioactive Ion Beams (RIB) and future directions: Production of RIB – different methods, GDR in exotic nuclei

References

1. *Treatise on Heavy-Ion Science*, Vol. 2, 3, ed. D. A. Bromley
2. *Nuclear Structure* (Vols. I and II), A. Bohr and B. R. Mottelson (Benjamin, Reading, Massachusetts, 1969 and 1975)
3. *Introductory Nuclear Physics*, S.S.M. Wong (Prentice Hall of India, 1990)
4. *Theoretical Nuclear Physics*, A. de Shalit and H. Feshbach (Wiley, NY 1974)

PY 708: Advanced Accelerator Physics & Technology

Proton and Heavy Ion Accelerators:DC Accelerators, Linacs, Cyclotrons, Synchrotrons etc,Positive and negative ion sources, Ionization, Recombination, Charge transfer and other processes in ion sources, Beam extraction, Low energy beam transport - matching to an accelerator, Radio Frequency Quadrupole, DTL, CCDTL and CCL, High Current Accelerators, Introduction to ADS Systems, Linacs for ADS. Normal and Superconducting accelerator structures, Space charge effects, Waveguide resonators etc.

Gigawatt Pulsed Power and Industrial Electron Accelerators: Electron emission processes and technology of cathodes, Electron gun design and related areas. Gigawatt to Terrawatt power pulsed electron guns, beam transport, HPM generation, Flash X Ray generation and applications. DC and RF Industrial Electron Accelerators- sub systems and applications

Beam Dynamics and advanced accelerators: Beam emittance, Liouville's theorem, Beam transfer lines, FODO cells, quadropole triplet, phase space matching, emittance dilution, Synchrotrons & Storage Rings, Synchrotron Radiation (SR) Sources, Linac Based SR Sources.
New Accelerators: Free Electron Lasers, Laser Acceleration, Plasma Beat Wave Accelerators

References

1. *Introduction to Accelerator Physics,* Arvind Jain (Macmillan India 2007)
2. *Electron Beam Technology,* S. Schiller (John Wiley & Sons Inc 1982)
3. *Industrial Electron Accelerators and Applications,* E.A. Abramyan (Springer 1988)
4. *Accelerator Physics,* 2nd ed., S.Y. Lee (World Scientific, 2004)
5. *Free Electron Lasers*, C. A Brau, (Academic Press, Oxford, 1990)

PY 709: Introduction to Neutrino Physics

The course is intended to introduce the basics of neutrino physics. By the end of the course it is hoped that one will be able to appreciate the intense activity worldwide in thisfield. A brief exposition of a non-invasive method of monitoring fissile materials using neutrinos will also be given.

Present understanding of fundamental particles and their interactions: neutrinos and their properties. Weak decays such as nuclear beta decay, muon and pion decay. Higher order processes such as double beta decay in nuclei.

Neutrino sources: Stellar (including the sun and supernovae), atmospheric, natural radioactivity, reactors and particle accelerators

Interactions of neutrino with matter: charged and neutral current processes, quasielastic and deep inelastic scattering

Neutrino oscillations: two flavour oscillations in vacuum and matter, three flavor oscillations

Some key experiments in neutrino physics: discovery experiments of ν_e,ν_μ,ν_τetc.; what has been learnt and what we do not yet know; ongoing and planned experiments

References

1. *Neutrino Astrophysics*, J.N. Bahcall, (Cambridge University Press, Cambridge, England, 1989).
2. *Massive Neutrinos in Physics and Astrophysics*, R. N. Mohapatra and P.B. Pal, (3rd Ed. World Scientific, 2004)
3. *The Neutrino Matrix*, APS Multidivisional Study Group report (2004)

PY 710: High Energy Astrophysics

Introduction to Astrophysics and Astronomy: Celestial sphere, coordinate system, time references, cosmic-rays, multi-wavelength observations.

Astrophysical Objects: Stars, clusters, x-ray binaries, pulsars, supernova remnants, active galactic nuclei etc.

Non Thermal Universe: Cosmic-ray spectrum and composition, Cosmic emissions at keV-TeV energies, first order and second order Fermi acceleration, diffusive shock acceleration.

X- ray and Gamma-ray emission: Observed spectra from galactic and extragalactic sources, bremsstrahlung, synchrotron and inverse Compton scattering, IC spectra from optically thin and thick sources, electron-positron pair physics, thermal electrons and radiation, non-thermal electrons and radiation, gamma-rays from proton-proton and proton-photon interactions.

Theory of Accretion: Spherical accretion, Eddington luminosity, disc accretion and its basic equations, a alpha prescription of viscosity, equations for structure of discs and their standard solution.

Jets and Outflows: Microquasars, Blazars and Radio galaxies, radiation emission from jets, Doppler boosting, Lorenz transformations, observed spectra and spectral models.

Experimental Techniques in Astronomy: Satellite based experiments, ground based experiments, extensive air showers, simulation studies, atmospheric Cherenkov technique.

References:

1. *High Energy Astrophysics*, Vol 1 & 2, M.Longair (Cambridge University Press, 2004).
2. *Very High Energy Gamma-Ray Astronomy*, Trevor Weekes (IOP Publishing, 2003).
3. *Radiative processes in Astrophysics*, G.B.Rybicki and A.P.Lightman (John Wiley and Sons, 1979).
4. *Accretion Power in Astrophysics*, J.Frank, A.King, D.Raine (Cambridge University Press, 2003).

Elective Courses in Atomic, Molecular, Laser and Plasma Physics

PY711: Synchrotron Radiation and its Applications

Production and properties of SR: Physics of production of SR, general properties and advantages of SR, Storage rings, properties of bending magnet radiation, important relations/equations, Radiation from insertion devices (Wiggler, undulator), FELs, Historical development and current scenario, overview of Indus-1 & Indus-2.

Basics of Beamline Instrumentation: Considerations in optical design of beamlines, Special requirements in VUV, Soft-X-ray, Hard X-Ray, IR, types of monochromators, Mirrors, gratings, detectors, vacuum systems, electronics etc.

Experimental Techniques: Overview of typical experiments carried out at synchrotron facilities, brief introduction to various techniques, Spectroscopy (VUV, soft X-ray/hard X-ray spectroscopy, PES, ARPES, IR, THz), Scattering (Diffraction, crystallography, small angle scattering, Inelastic X-ray scattering, etc), Imaging (X-ray imaging, IR imaging, Microscopy, Lithography), Special techniques utilizing the polarization or time structure of SR

Atomic, Molecular & Cluster Physics using SR: Physics of autoionisation, Rydberg states, superexcited states, chemical dynamics, advantages of using SR to study these phenomena. Techniques: Photoabsorption, photoionization, fluorescence, PES (incl. ZEKE, MATI, etc.), Laser + SR, coincidence experiments, etc: Basic principles, design of experimental stations, information obtained. Recent developments & current status of the field internationally. Currently available facilities & ongoing research programs of AMPD at Indus-1(PPBL, HRVUV, photoabsorption studies of stable gases/free radicals, matrix isolation spectroscopy, etc.; Beamline & experimental stations planned at Indus-2.

References:

1. *Introduction to Synchrotron Radiation*, Giorgio Margaritondo (Oxford University Press, 1988).
2. *Soft X-Rays and Extreme Ultraviolet Radiation*, David Attwood *(*Cambridge University Press, 1999).
3. *Synchrotron Radiation: Production and Properties*,Philip John Duke, Oxford Series on Synchrotron Radiation 3 (Oxford 2008).
4. *Handbook on Synchrotron Radiation, Volume 1a*:Ernst-Eckhard Koch (Ed.)(North Holland, 1983).
5. *Handbook on Synchrotron Radiation, Volume 2*: *Vacuum Ultraviolet and Soft X-ray Processes*:G.V. Marr (Ed.) (North Holland, 1987).

PY 712: Selected Topics in Atomic and Molecular Physics

Coherent spectroscopy: Transition from Doppler to sub-Doppler to natural linewidth to sub-natural linewidth, theory and practice of sub-natural linewidth spectroscopy, atomic frequency stabilization techniques, error signals and stability, applications of coherent spectroscopy including slow light generation.

Physics with trapped ions and atoms: Techniques ofion-traps (Paul trap, linear quadrupole trap etc) and atom traps (magneto-optical trap, dipole trap), ultra-precision measurements of atomic parameters and fundamental constants, quantum jumps and parity violation in atoms/ions, quantum degenerate gases, ultra-cold molecules.

Atoms and molecules in intense fields: Multi-photon processes in atomic and molecular systems, cross-sections, Intense and super-intense laser-atom/molecule interaction, pondermotive force, Keldysh parameter, above threshold ionization, high harmonic generation, atomic stabilization, theoretical techniques involving Floquet and split operator methods, experimental techniques. Atoms in high magnetic fields.

R**eferences**

1. *Laser spectroscopy: Basic Concepts and Instruments*, W. Demtroder, 2nd Edition, (Springer Verlag, 1996).
2. *Atomic Physics*, C.J. Foot, Oxford Master Series in Atomic, Optical and Laser Physics (Oxford University Press 2008).
3. *Laser Cooling and Trapping*, H.J. Metcalf and P. van der Straten, (Springer 1999).
4. *Atomic and Molecular Processes with Short Intense Laser Pulses*, A.D. Bandrauk (Ed.), NATO ASI Series: B Physics, Vol **171**, Plenum Press (1988).

PY 713: Advanced Photonics

Review of wave optics: wave-particle duality concepts and experiments, Maxwell's equations, wave equation for light. Light propagation in conducting and non conducting medium, sources of light, characteristics of light (coherence and polarization), light in bulk materials.

Basics of lasers: emission and absorption of light, Einstein coefficients, population inversion, threshold condition, laser beam characteristics and parameters.

Fiber and non-linear optics: Reflection and refraction at plane wave interface, total internal reflection, TE and TM polarization, Goos-Hanchen shift, modes in optical waveguides, step index and graded index fibers, fiber in optical communication, fiber amplifiers and fiber lasers. Non-linear optics of materials, when and how non-linear response arise, dispersion relations, phase matching conditions, second and third harmonic non- linear optical effects, frequency mixing, Kerr effect and electro-optics effect. Applications of non-linear optics

Introduction to nanophotonics: Optical materials from bulk to nano-scale, why nanophotonics, light scattering mechanism in nano-scale structures, optics of quantum dots, nano-plasmonic crystals, surface plasmons, Fermi-Golden rule, photon density of states, different approaches to fabricate nanophotonic structures, application of nanophotonics.

Meta-materials: What are meta-materials, classes of materials and their exotic properties, photonic band gaps, one, two and three-dimensional band gaps for light, wave equation in photonic crystals, different methods to calculate photonic band structure, origin of band gap, spontaneous emission in photonic band gap, nanophotonics switching, optics of cavities, experimental realization of photonic crystals, different characterization techniques.

References

1. *Optics*, E. Hecht and A. R. Ganesan, (Pearson, 2008)
2. *Laser Fundamentals*, W. T. Silfvast, (University Press, 1996)
3. *Nanophotonics*, P. N. Prasad, (John Wiley & Sons, 2004)
4. *Photonic Crystals: Molding the flow of light, J. D.* Joannopoulos, S. G. Johnson, J. N. Winn and R. D. Meade, (Princeton University Press, 2008)
5. *Nanophotonic Materials: Photonic Crystals, Plasmonics and Metamaterials,* Editor(s): R. B. Wehrspohn, H.-S. Kitzerow, K. Busch, (John Wiley & Sons, 2008)

PY 714: Quantum Optics and Information

Quantum theory of radiation: Quantum states of radiation field, non-classical states, squeezing, photon statistics, correlations, noise properties of light.

Quantum theory of light-atom interaction: Optical Bloch equations, quantum theory of damping and master equation, dressed atom approach, quantum theory of lasers, coherent control, electromagnetically induced transparency.

Ultra-cold atoms and quantum degenerate gases: Laser cooling and trapping of atoms, interactions involving ultra-cold atoms, ultra-cold quantum gases, Bose-Einstein condensation, Gross-Pietavskii equation.

Elements of Atom optics: Atom optical elements, atom interferometry, non-linear atom optics, quantum atom optics.

Elements of Quantum information: Entanglement and its measures, quantum measurement, quantum teleportation, quantum communication, physical realization of quantum computer.

References

1. *Concepts of Quantum Optics*, P.L. Night and L. Allen (Pergamon,1983).
2. *The Quantum Theory of Light*, R. Loudon (Oxford University Press, NY, 1983).
3. *Elements of Quantum Optics*, P. Mystre and M. Sargent III (Springer Verlag 1990).
4. *Laser Cooling and Trapping*, H.J. Metcalf and P. van der Straten, (Springer 1999).
5. *Quantum Computation and Quantum Information*, M.A. Nielsen and I.L. Chuang (Cambridge University Press, 2000).

PY 715: High Power Lasers and Applications

Basics: Coherence, Resonator modes, Gaussian & Non-Gaussian beams, propagation through optical systems, beam quality, focusing, atmospheric propagation effects and adaptive optics techniques.

Nonlinear optical processes: Second Harmonic Generation, Third Harmonic G with pulsed and cavity enhanced CWorking lasers, Parametric generation, SRS, Two-photon absorption, Self-focusing and Self phase modulation, Nonlinear optical effects in optical fibers.

Types of lasers: Excitation techniques & Laser properties in different media: Gas (He-Ne, CO_2, Excimer, Cu Vapor, Chemical), Solid state : (Nd:YAG, Nd:Glass, Yb:YAG), Semiconductor diode, Free Eelectron Laser. Tunable lasers: Dye, Diode, Ti:Sapphire, Optical Parametric Oscillator, Frequency selection & tuning techniques, frequency stabilization.

Laser dynamics & pulse generation: Brief recapitulation of Relaxation oscillations, Q-switching, cavity dumping

Ultrashort pulse generation: Mode locking, Group Velocity Dispersion compensation in Kerr Lens Modelocking cavities, Pulse compression.

Power scaling: Special resonators, Pulsed laser amplifiers (CO2, Nd:YAG/Glass, Dye, CVL, Master Oscillator Power Amplifier chains) – gain saturation, efficiency, spectral narrowing, Injection locking. Diode laser arrays & amplifiers, Diode Pumped Solid State Lasers, Fiber lasers

Ultrashort pulse amplification and compression: Chirped pulse amplification in Ti:S, Opt Para CPA, regenerative amplifier, multipass amplifier – typical system architectures.

Applications: Laser Ionization Spectroscopy – applications in science & technology. Laser requirements and system architecture. Material processing, Reflection, transmission & absorption of laser beams in materials, ultrafast material processing.

High intensity laser interaction with materials: Basic phenomenology of: High intensity effects, High order harmonic generation, production and acceleration of charged particles, laser induced nuclear reactions, X-ray lasers, Laser fusion.

References

1. *Principles of Lasers*, O. Svelto and D C Hanna, 4th edition, (Plenum Press,1988).
2. *Solid State Laser Engineering*, W Koechner, Springer Series in Optical Sciences, 6th revised and updated edition, (Spinger, 2006)
3. *Laser Electronics*, J.T. Verdeyen, 3rd edition (Prentice Hall, 1995).
4. *Dye Lasers*, L.G. Nair, Progress in Quantum Electronics, 7, 153-268 (1982).
5. *Dye Lasers*, K. Dasgupta in Wiley Encyclopedia of Electric and Electronics Engineering (Wiley, New York, 1999).
6. *Fundamentals of Nonlinear Optics*, Peter E Powers (CRC Press, 2011).
7. *High Power Laser Handbook*, H. Injeyan & G.D. Goodno (McGraw Hill, 2011).

PY 716: Laser-Matter Interactions and Applications to Advanced Material Processing

Introduction to Laser Matter Interaction; Basics ofPulsed, Ultrashort and CW lasers typically employed for Laser processing; Mode Locking, Kerr Lens Modelocking, Pulse Compression, Chirped Pulse Amplification

Surface Characterization, Measurement & Diagnostic Techniques: (i). SEM, Optical microscope, X-ray Diffraction Technique (XRD), Atomic Force Microscopy (AFM), X-ray photoelectron spectroscopy (XPS), Electron probe X-ray micro-analysis (EPMA), Auger electron Microscopy (AES) Energy Dispersive X-ray spectroscopy (EDX), Differential Thermal Analysis (DTA) Surface Profilometer Surface hardness, Micro-indentation test

Plasma and Vapour diagnostics: Time of Flight (TOF), Langmuir Probe, LIBS, TRLIF etc.

Laser diagnostics: Short pulse – autocorrelator, FROG (frequency resolved optical gating), SPIDER (spectral phase interferometry for direct electric field reconstruction), Spatial profilometer- array detector

Laser Matter Interaction: Excitation Mechanisms, and Relaxation Times, Multiphoton Excitation, Photochemical Process- Catalytic Effects, Photophysical & Thermal Processes ; Heating & Surface melting, Evaporation

References

1. *Laser Processing and Chemistr*y, D.Bauerle, 4th Edition (Springer, 2011).
2. *Laser Material Processing*, W.M.Steen, 4th Edition (Springer, 2010).
3. *Pulsed Laser Deposition of Thin Films*, D.B.Chrisey and G.K.Hubler (Wiley Interscience, 2007).

PY 717: Computational Plasma Physics: Introduction to Particle in Cell (PIC) Technique

Basics: Necessity for plasma simulation. Approaches to plasma simulation, fluid and kinetic theory methods, examples of physical systems appropriate for each of the different approaches.

Introduction to the PIC method: The mathematical model. The physical model, Principles of finite differencing, Converting Maxwell's equations into their finite difference form.

Solution of Maxwell's equation: Interative methods for solving Poisson's equation, Solution of curl equations using FDTD method, The concept of superparticles, Weighing methods, Shape factor, Realtion between particles and fields.

Self consistent charge and current density: Lorentz force integrator with and without magnetic fields. The computational cycle.Electrostatic programs.Electromagnetic programs.

Sources of errors and stability

References

1. *Plasma Physics via Computer Simulation*, C. K. Birdsall, A. B. Langdon (McGraw-Hill, 2004).
2. *Computer Simulation Using Particles*, R.W Hockney, J.W Eastwood (CRC Press, 1989).
3. *Electromagnetic Simulation using the FDTD Method, D. M. Sullivan (IEEE Press, 2013)*
4. *Numerical Techniques in Electromagnetics,* Matthew N.O. Sadiku (CRC Press, 2009)
5. *The Finite-Difference Time Domain Method for Electromagnetics,* K. S. Kunz, R. J. Luebbers (CRC Press, 1993).
6. *Introduction to Electrodynamics,* D. J. Griffith (Prentice-Hall, 2012).
7. *Classical Electrodynamics, J. D. Jackson (Wiley, 1998)*
8. *Introduction to Plasma Physics, F. F. Chen (Plenum Press, 1974).*

PY 718: Nonlinear Plasma Theory

Basics: Revision of linear theory, including Langmuir waves, ion-acoustic waves, Alfven waves, waves from local pulsed source, Cerenkov emission and Kelvin wakes, wakes in ion-acoustic waves, Vlasov equation, Chandrasekhar equation, cold plasma waves, Landau damping.

Nonlinear waves: beams of non-interacting particles, ordinary progressive waves, waves in weakly dispersive media, Korteweg de Vries equation (KdV), solitons, Analytical solution of the KdV equation, Ion-acoustic wave overturn

Nonlinear wave-wave interaction: Three wave processes, dispersion laws and decay spectra, triads, Manley-Rowe conservation laws and nonlinear superposition, analogy with Euler equations for rigid bodies, resonant interactions between plasma waves, many-wave interaction in random phase approximation, nonlinear explosive instability, Interaction of low-frequency waves with high-frequency waves, plasma turbulence, kinetic equation and instabilities.

Wave-particle interaction: Statistical preliminaries, Random phase approximation, quasilinear diffusion equation in two and three dimensions, single and many waves, quasi-linear theory of some instabilities, non-resonant wave-particle interaction, effect of transverse waves on ions, quasilinear theory of Alfven wave turbulence.

Nonlinear wave-particle interaction: Electron plasma oscillation turbulence, nonlinear theory of the drift instability, and the effect of thermal fluctuations.

Reference

1. *Nonlinear Plasma Theory*, R. Z. Sagdeev and A. A. Galeev (W. A. Benjamin Inc., New York, 1969).
2. *Plasma physics for astrophysics,* R. M. Kulsrud (Princeton University Press, 2004).
3. *Plasma turbulence,* B. B. Kadomtsev (Academic Press, 1965).
4. *Nonlinear resonance analysis,* E. Kartashova (Cambridge University Press, 2010).
5. *Reviews of Plasma Physics,* vol. 7, Ed. M. A. Leontovich (Consultants Bureau, 1979).

Elective Courses in Condensed Matter Physics

PY 719: Modeling and Simulations in Physics

Basics: Modeling in different domains: Continuum, Mesoscopic, Atomistic and Quantum descriptions, Setting up a computer experiment: Starting structure and dynamics length and time scales

Electronic structure Theory: Many-body Schroedinger Equation, Born-Oppenheimer approximation, Hartree-Fock theory and Slater Determinants, Density Functional theory(DFT)
Thomas-Fermi and Exchange and Correlation(and different xc types)

Methods of Solution: Basis sets: Gaussian and Plane Wave, Analytic gradients and Hessians, The potential surface, Geometry optimization, Transition state calculations.

Simulation Methods:***Monte Carlo (MC):***Monte Carlo integration, Averaging procedure in various ensembles, Importance sampling, Metropolis scheme, ***Classical Molecular Dynamics (MD):*** Newtonian, Lagrangean and Hamiltonian dynamics, Basic algorithms, Time averages and ensemble averages, Molecular Dynamics in various ensembles, Interatomic potentials (pair potentials and beyond), Force-fields and their parameterization, Handling long-range forces, Analysis of Simulation results, ***First Principles MD:*** Born-Oppenheimer Molecular Dynamics, Car-Parrinello Molecular Dynamics (CPMD), Mermin functional and Free Energy MD (FEMD), ***Hybrid schemes:*** Combined classical MD and DFT – hybrid QM/MM schemes, ***Reactive schemes:*** General problem in chemical reactions, Path sampling methods, Blue Moon ensemble approach, Metadynamics

Beyond DFT: Time dependent DFT, Dynamical Mean Field Theory, GW-Approximation

Quantum Chemistry Methods: Configuration interaction, Many-body perturbation theory, Moller-Plesset perturbation theory, Multi-Configuration self consistent field theory, Coupled cluster theory

References

1. *Electronic Structure – Basic Theory and Practical Methods*, Richard Martin (Cambridge University Press, 2004).
2. *Electronic Structure Calculations for Solids and Molecules*, Jorge Kohanoff (Cambridge University Press, 2006).
3. *Computer Simulation of Liquids*, M P Allen and D J Tildesley (Oxford Science Publications, 1989).
4. *The Art of Molecular Dynamics Simulations*, D C Rapport (Cambridge University Press, 2004).
5. *Ab Initio Molecular Dynamics - Basic Theory and Advanced Methods*, Dominik Marx and Juerg Hutter (Cambridge University Press, 2009).

PY 720: Selected topics in Condensed Matter Theory

The course will deal with the theory and application of quantum mechanical and atomistic lattice dynamics and computer simulations to model, understand, and predict the properties of real materials. It is designed for students in Physics, Chemistry, Engineering and Materials Science interested in (i) the modeling of the properties of materials with advanced quantum mechanical and atomistic techniques and (ii) experimentalists using theory for the interpretation and analysis of complex experimental data. The course will have a strong focus on applications. However a minimal background in quantum mechanics and solid state physics (or equivalent) will be required.

First principles calculations of the total energies, electronic structure and phonon spectra: Density functional theory, Electronic structure calculations, Lattice vibrations, Theoretical calculations for the interpretation and analysis of experimental Raman, infrared, neutron and synchrotron data.

Lattice dynamics calculations and molecular dynamics simulations of complex solids: Microscopic to Macroscopic: From phonon spectra to thermodynamic properties. Studies of phase transitions, thermodynamic properties and melting at extreme conditions of pressure and temperature.

Project work: First principles calculations of the total energies, Electronic structure Calculations, Calculations of crystal structure, long-wavelength phonons, elastic constants, Calculations of the Phonon density of states, Calculations of the thermodynamic properties

References

1. *Electronic Structure: Basic Theory and Practical Methods*, Richard M. Martin (Cambridge University Press, 2004)
2. *Dynamics of perfect crystals*, G. Venkataraman, L.A. Feldcamp and V.C. Sahni (MIT Press, Cambridge, 1975).
3. *Phonons: theory and experiments*, P. Bruesch (Springer-Verlag Berlin, Heidelberg, New York; 1982)
4. *Computer Simulation of Liquids*, M.P. Allen and D.J. Tildesley (Clarendon, Oxford, 1987)
5. *Simulations for Solid State Physics*, R H. Silsbee, J Draeger (Cambridge University Press, 1997).

PY 721: Organic Semiconductor Devices

Introduction to organic semiconductors: Organic materials: bonding, hybridization, conjugation and origin of semiconducting properties, Comparison of inorganic and organic semiconductors, types of organic semiconductor: molecular and polymeric, donor and acceptor materials, molecular ordering, light absorption and emission, different charge carriers and excitations, charge carrier injection: organic metal contacts and interfaces, charge transport models: tunnelling, Schottky, Poole-Frankel, space charge limited conduction, variable range hopping etc.

Organic thin films and their characterization: ***Preparation techniques***:*Thin/thick film*: Drop casting, doctor blading, spin casting, screen printing, inkjet printing, chemical polymerization, electrochemical polymerization and interfacial polymerization, physical vapour deposition, *Monolayer/multilayer*: Self-assembly, Langmuir-Blodgett and electrografting. ***Characterization techniques***: *Spectroscopic techniques*: UV/Vis, Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy, Auger electron spectroscopy, electron energy loss spectroscopy (EELS) etc. ***Structure and surface analysis techniques***: X-Ray diffraction (XRD), low-energy electron diffraction (LEED), SEM, TEM, AFM, NSOM, confocal microscopy and contact angle measurements. ***Thickness measurements***: x- ray reflectivity (XRR), ellipsometery and profilometer. ***Electrical characterization***: current-voltage measurement and impedance analysis.

Organic devices: ***Molecular electronics***: Basic concepts of molecular electronics, making contact to single molecule molecular and self-assembled monolayer, molecular rectifiers, molecular resonant tunnel diodes, molecular memory, molecular transistors. ***Organic electronics***: Fabrication and characterization of organic field effect transistors and organic light emitting diodes. ***Organic solar cells***:Solar spectrum, interaction of photons with materials, solar cell operational parameters, bulk hetrojunction polymer solar cells, small molecule based solar cells and dye sensitized solar cells. ***Organic gas sensors*:** Gas sensors and their necessity, interaction between toxic gases with organic films, fabrication and characterization of chemi-resistive gas sensors.

References

1. ***Molecular and Organic Electronics Devices*, D.K. Aswal and J.V. Yakhmi (Nova Science, USA, 2010)**
2. *Organic Electronics: Materials, Processing, Devices and Applications*, Franky So (CRC Press, 2010)

PY722: Single Crystal Growth and Devices

Introduction: History, importance, applications and scope of single crystals and related devices.

Transportation, nucleation, growth and thermodynamics: Phase diagram, material synthesis and characterization of synthesized materials.Transportation of reactants to the growth surface.Absorption at the growth surface and nucleation (first order phase transformation) thereafter.Growth of nucleus (minimization of Gibbs free energy due to interplay of entropy and enthalpy).

Single crystal growth techniques: ***Growth from the liquid-phase*****:** From melt**,** Czochralski growth technique**,** Bridgman, Float Zone**, *From solution*:**TSSG (top seed solution growth)**,** Aqueous solution growth**, *Growth from vapour phase***:PVD**,** MBE**,** Thermal evaporation technique**,** Electron-beam evaporation technique**,** CVD**,** MOCVD

Characterization: ***Crystallography***: Symmetry operations and crystal structure determination (single crystal XRD).Orientation and topography (Laue back reflection method).***Crystal defect analysis***: Point defects, Dislocation lines, Sub-grain boundaries.Defect formation during single crystal growth.***Electronic structure and Electrical properties***: Band structure (theory and first principle calculations).Electrical and thermal conductivity.Luminescence properties: Photo-luminescence process**,** Thermo-luminescence process, Scintillation process

Specific single crystals and related devices: ***Scintillator/phosphor single crystals*****:** Doped alkali halides**,** CsI:Tl, NaI:Tl, $LaBr_3$:Ce etc**,** Doped and un-doped Oxide**,** LBO, LSO, BGO, YAP etc**,** Gamma detectors**,** TL readers**. *Optical Window*:** Fluorides, Sapphire**, *Solid state laser crystals***:YAG, Sapphire, Double tungstates**,** Laser cavity (diode pumped)**, Non-linear crystals**: KDP, BBO, LBO etc**,** Second harmonic generation**,** SAW devices**, *Ferroelectric crystals*:** $BaTiO_3$, $LiTaO_3$ etc**,** Remote temperature sensors**, *Semiconductor crystals***: Si, Ge, GaAs etc**. Superconductors:** $YBa_2Cu_3O_{7-\delta}$, $Bi_2Sr_2CaCu_2O_{8+\delta}$ etc

References

1. *Crystal Growth Technology: From Fundamentals and Simulation to Large-scale Production,* Hans J. Scheel, Peter Capper (John Wiley & Sons, 2011).
2. *Kinetic Processes: Crystal Growth, Diffusion, and Phase Transitions in Materials,*Kenneth A. Jackson (John Wiley & Sons, 2010).
3. *Bulk Crystal Growth of Electronic, Optical and Optoelectronic Materials,* Peter Capper (John Wiley & Sons, 2005).
4. *Handbook of crystal growth,* Govindhan Dhanaraj, Kullaiah Byrappa, Vishwanath Prasad (Springer, 2010).
5. *Fundamentals of Solid State Engineering,* M. Razeghi (Springer, 2009).
6. *Luminescence,* Cees Ronda (John Wiley & Sons, 2008).
7. *Thermoluminescence of Solids,* S. W. S. McKeever(Cambridge University Press, 1988).
8. *Springer Handbook of Electronic and Photonic Materials,* Safa Kasap, Peter Capper (Springer, 2006).
9. *Elements of X Ray Diffraction,* Bernard Dennis Cullity, Stuart R. Stock (Prentice Hall, 2001).

PY 723: Advanced Magnetism and Superconductivity

Magnetism: Types of phase transitions- first and second order; Examples of magnetic and superconducting phase transitions

Type of magnetic exchange interactions: Direct exchange, Indirect exchange, Superexchange, Double exchange, RKKY exchange, D-M interaction, Dipolar interaction, etc.

Classification of magnetic systems: Diamagnetism, paramagnetism, ferromagnetism, ferrimagnetism, antiferromagnetism, superparamagnetism, spin-glass, cluster spin-glass, metamagnetism, modulated spin structures, etc.; Magnetic ordering under external perturbations such as magnetic field, pressure, ion irradiation, quenched disorder, etc

Low dimensional magnetism: 1D, Quasi-1D, 2D, and Quasi-2D.

Spintronics; Magneto-caloric effect; Gaint magnetoresistance (GMR) and colossal magnetoresistance (CMR); Magnetic nanoparticles, molecular magnetism

Superconductivity: Thermodynamics of Superconductors; London Theory–A phenomenological approach to understand Superconductivity; Application of London theory – Electrodynamics of Superconductors; Ginzburg – Landau Theory - Origin of vortex state, vortex structure, flux pinning; Josephson effect

Co-existence of superconductivity and magnetism

Neutron scattering in magnetism and superconductivity

References

1. *Magnetism- Principles and Applications*, Derek Craik (Wiley, New York 1995)

2. *Magnetism in the Solid State: An Introduction*, Peter Mohn, 2nd Edition (Springer, 2005)
3. *Introduction to Superconductivity*, M. Tinkham (Dover Publications, 1996)

PY 724: Neutron as a Probe of Condensed Matter

The short-range strong interaction of neutron with matter and its inherent magnetic moment of neutron make neutron scattering a unique probe in condensed matter research. The other important advantage of neutrons over other forms of radiation in the study of structure and dynamics on a microscopic level are they are uncharged, which allows them to penetrate the bulk of materials. They interact via strong nuclear force with the nuclei of the material and the scattering cross section varies randomly between various elements and even between isotopes. This allows one to observe light atoms such as hydrogen in the presence of heavier ones and distinguish neighbouring elements in the periodic table easily. One can exploit isotopic substitution and contrast variation methods. Matching wavelength and energy of thermal neutron to the lattice spacing and excitations in condensed matter makes it an indispensable tool to both study structure and dynamics. Over and above neutron has a magnetic moment that suits to study magnetic structures and the fluctuations and excitations of spin systems.

Why neutron scattering? basic properties of neutron; Basics principles of Neutron Scattering, Neutron scattering cross-section, correlation functions, coherent and incoherent scattering, Principle of detailed balance, magnetic scattering, polarized neutron.

Neutron sources: Reactor and spallation, Moderation of neutrons.

Structural study by Diffraction: Cross section, structure factors, Scattering of neutrons by atoms, Diffraction by crystals and polycrystals, Extinction and absorption, Experimental technique for diffraction, Principles of magnetic scattering, Investigation of magnetic materials, Diffraction by gases, amorphous materials and liquids.

Small-Angle Neutron Scattering: Scattering from general Two Phase Systems, Scattering from Fractal Aggregates, Nuclear vs. Magnetic Scattering, Small-Angle Neutron Scattering Instrumentation (Experimental Aspects, Data Treatment), Analysis of Small-Angle Neutron Scattering Data (Model Independent Analysis, Model Dependent Analysis, Contrast Variation),
Applications (Nanomaterials, Colloids, Biological Systems, Porous and Fractal Structures)

Neutron Reflectometery: Theoretical aspects of neutron reflectivity from Stratified Media, specular reflectivity from thin films and multilayers, description of Rough Multilayers, Reflectivity on Non-Magnetic Systems, Neutron Reflectivity on Magnetic Systems, Polarized Neutron Reflectometry on Magnetic Systems, instrumental setup for neutron reflectivity, Off-Specular (diffuse) reflectivity

Dynamics in condensed matter: ***Deterministic***: Basic Lattice Dynamics and Neutron Inelastic Scattering**:** Theoretical lattice dynamics (LD): Debye model, dynamical matrix, acoustic and optical branches. One phonon scattering, phonon dispersion relations: monoatomic and diatomic crystals, Incoherent scattering: phonon density of states, Coherent scattering. ***Stochastic (Diffusion)*****:** Theoretical formalism of quasielastic neutron scattering (QENS), self and distinct van Hove correlation functions. Different kinds of motions and contributions to scattering law, different model for translation motion: continuous diffusion, jump diffusion and localized translational diffusion. Different models for rotational motions:continuous rotational diffusion on a circle, jump rotation among N equivalent sites on a circle and isotropic rotational diffusion on a surface of a sphere.Instruments and methods for quasielastic neutron scattering, general aspects of data analysis, examples of QENS studies.

Reference

1. *Neutron Diffraction, G. Bacon (Clarendon, Oxford 1975)*
2. *Thermal Neutron Scattering, P.A. .Egelstaff (Academic Press)*
3. *Theory of Thermal Neutron Scattering, W. Marshall and S.W. Lovesey, (Clarendon, Oxford 1971)*
4. *Thermal Neutron Scattering, G.L. Squires, (Cambridge University Press, 1978)*
5. *Methods in Experimental Physics, Vol. 23 (eds. D.L. Price, Kurt Skold), (Academic Inc.USA1987)*
6. *Neutron scattering in condensed matter, A. Furrer, J. Mesot, T Strässle (world Scientific)*
7. *Methods of Experimental Physics Ed. D.L. Price and K. Sköld P 99:Neutron Sources J.M. Carpentar and W.B. Yelon,(Academic Press)*
8. *Topics in Current Physics, Vol 6 'Neutron Diffraction' H. Dachs (Springer)*
9. *Structure Analysis by Small-Angle X-Ray and Neutron Scattering, L.A. Feigin and D.I. Svergun (Plenum Press, New York, 1987)*
10. *Neutron, X-Ray and Light Scattering, P. Lindner and T. Zemb (North-Holland, Amsterdam, 1991)*
11. *Neutron Scattering from Polymers, J.S. Higgins and H. Benoit (Clarendon, Oxford, 1994)*
12. *Analysis of Small-angle Scattering Data from Polymeric and Colloidal Systems: Modelling and Least-squares Fitting, J. S. Pedersen, Advances in Colloid and Interface Science 70, 171-201 (1997).*

13. *Small-angle Scattering Studies of Biological Macromolecules in Solution, D.I. Svergun and M.H.J. Koch, Reports on Progress in Physics 66, 1735–1782 (2003).*
14. *X-ray and Neutron Reflectivity: Principles and Applications, Daillant, J., Gibaud, A. (Eds.), Lect. Notes Phys. 770 (Springer, Berlin Heidelberg 2009),*
15. *Theory of reflection of electromagnetic and particle waves, Lekner, J. (Martinus Nijhoff, Dordrecht, (1987) 188*
16. *Coherent inelastic Scattering in lattice dynamics, B Dorner,(Springer 1982)*
17. *Methods of Experimental Physics, Vol 23, Part A, Ed. D.L. Price and K. Sköld P 369: Lattice Dynamics.*
18. *Quasielastic Neutron Scattering, M. Bee (Adam-Hilger, Bristol, 1988)*
19. *Single Particle rotations in Molecular Crystals, W. Press, (Springer, Berlin, 1981)*

PY 725: Structure and Crystallography of Biomolecules

1. Brief introduction to structure and functioning of a bacterial cell.
2. Introduction to important molecular components of the cell.
3. Methods of protein production, purification.
4. Introduction to three dimensional structures of proteins and nucleic acids.
5. Computational and experimental methods of determining 3D structures.
6. X-ray sources and diffraction.
7. Macromoleculer crystallisation and crystal characterization.
8. Methods of diffraction data collection, data processing
9. Phase problem.
10. Current status of the methods for solving the phase problem.
11. Crystallographic refinement.
12. Electron density maps.
13. Structure-based drug design.
14. Laboratory experiments: a) High-throughput crystallization, b) Crystal mounting, diffraction data collection and processing, and c) Interpretation of electron density maps.

References

1. *Structure Determination by X-ray Crystallography*, 4th ed., Mark Ladd and Rex Palmer**,** (Kluwer Academic/Plenum, New York, 2003).
2. *Crystallography Made Crystal Clear, A Guide for Users of Macromolecular Models*, 3rd ed., Gale Rhodes (Complementary Science Series, 2006) .
3. *Protein Structure and Function*, Gregory A Petsko and Dagmar Ringe (Blackwell Science and Sinauer Associates, 2004).

Elective Courses in Condensed Matter Physics

PY 726: Advanced Reactor Physics

Neutron Transport theory: Various formulations of neutron transport theory: Integro-differential equation, Integral equation, surface integral equation, invariant imbedding theory; Transport equations for special geometries; Numerical methods for solution of transport equation: Energy groups and group cross sections, Pn method and diffusion theory, Discrete ordinates and discrete Sn methods, Collision probability and related methods and their applications, Method of characteristics; Adjoint equation, perturbation theory, variational method.

Numerical methods for solution of the Multi-group neutron diffusion equation: Finite difference method and nodal methods

The Monte Carlo method: Random numbers: methods of generation and properties tests for randomness; Methods for sampling distributions; Mechanics of particle transport; Source and criticality problems; Errors and variance reduction methods.

Methods for burnup and control rod worth calculation

Reactor Dynamics: Point kinetics: point kinetics equations, Stability Analysis, Linear Stability theory, Routh's stability criterion, Root-Locus method, Nyquist plot, Non linear stability analysis; Space dependent reactor Dynamics and related topics; Accident analysis for thermal and fast reactors

Reactor Noise and its applications: Stochastic kinetics and zero power Reactor Noise, Power reactor noise, Reactor Noise in Accelerator Driven Systems

References

1. *Nuclear Reactor Theory*, G.I.Bell & S.Glasstone (Van Nostrtand,1970).
2. *Computing Methods in Reactor Physics*, H.Greenspan (Ed.) (Gordon and Breach, 1968).
3. *Dynamics of Nuclear Reactors*, D.L.Hetrick, (University of Chicago Press, 1971).
4. *Random Processes in Nuclear Reactors*, M.M.R.Williams (Pergamon, 1974).
5. *Neutron Fluctuations - A Treatise on the Theory of Branching Processes*, L.Pal and Imre Pazsit,(Elsevier Publishing Company, 2007).
6. *Computational Methods of Neutron Transport*, E.E.Lewis and W.F.Miller, Jr., (Wiley, 1984).
7. *Nuclear Reactor Physics*, W.M.Stacey (Wiley, 2001).
8. *Particle Transport Simulation with the Monte Carlo Method* L.L.Carter and E.D.Cashwell, Report TID-26607 (1975).

PY727: High Energy Density Physics: Theory

This course is intended for those interested in acquiring basic knowledge in the physics of matter existing at very high temperatures and / or densities as occurring in inertial confinement fusion system, astrophysical objects etc.

Introduction to High Energy Density Physics (HEDP): Static and dynamic high pressures, parameters defining High Energy Density, Laboratory generation of HED matter using lasers and particle beams, Basic processes involved in HEDP.
Hydrodynamic and shock waves: Hydrodynamic flow of compressible fluids, Equations of gas-dynamics, Euler and Lagrange formulation, Rarefaction and Compression Waves, Rankine-Hugoniot Relation, Hugoniot curves, self similar solutions, artificial viscosity, numerical methods.
Equation of State and radiation opacities: Thermodynamic properties of Gases, Entropy, Thermodynamic Equilibrium and Equipartition, Specific Heats and Thermodynamic Exponent, Thermodynamics of Condensed Matter, Gamma-Law Equations of State, Matter At High Pressures, Thomas-Fermi Theory, Radiation opacities and emissivities, Rosseland and Planck means, models to calculate opacities.
Radiation Hydrodynamic: Radiation Transfer Equation, Equilibrium Diffusion Limit, Non-equilibrium Diffusion, Marshak Waves, Three-Temperature Model, Radiation matter coupling, Basic radiation hydrodynamic equations, approximate solutions, Numerical Methods
Hydrodynamic Instabilities: Rayleigh–Taylor, Richtmyer–Meskov & Kelvin–Helmholtz Instabilities, Fluid-Dynamics Description, R-T Instability with Two Uniform Fluids, Effects of Viscosity, Effect Density Gradients
Inertial Confinement Fusion: Fusion reaction, Thermonuclear burn and ignition schemes, central hot spot ignition, fusion Energy gain, direct and indirect ICF Schemes.

References

1. *High-Energy-Density-Physics – Fundamentals, Inertial Fusion and Experimental Astrophysics*, R. Paul Drake (Springer Verlag, 2006)
2. *The Physics of Inertial Fusion – Beam Plasma Interaction, Hydrodynamics, Hot Dense Matter*, S. Atzeni, J. Meyer-ter-Vehn (Clarendon Press 2004)
3. *Introduction to Inertial Confinement Fusion*,S. Pfalzner (Taylor & Francis 2006)
4. *Physics of shock Waves and High temperature Hydrodynamic Phenomena*, Zel'dovich YB and Raizer YP (Academic Press, NY 1967)
5. *Inertial Confinement Fusion: The Quest for Ignition and Energy Gain using indirect drive*, J. D. Lindl, (Springer, 1998)
6. *The equations of radiation Hydrodynamics*,G. C. Pomraning (Pergamon Press, Oxford 1973).
7. *Hydrodynamic and Hydromagnetic Stability*,S. Chandrasekhar (Oxford University Press 1968).

PY 728: High Energy Density Physics: Experimental

Physics of High Energy Density Effects in Matter: Tensor representation of strain and strain. Linear and nonlinear waves, ideal shock wave; Rankine Hugoniot relations, Shock representation in x-t and p-u_p plane, p-x and p-t plots, entropy and temperature under shock compression. Interaction of Shock waves, reflection of shock wave from rigid boundary etc. Development of rarefaction waves, interaction involving rarefactions, Negative pressures/ isentropic compression in materials.

Energy Storage Systems, Energetic Materials and Applications: Various Types of Energy Storage Systems and their Characteristics. Ideal detonation (ZND model); Chapman Jouget (CJ) pressure and density; detonation interaction.Concept of reaction zone; effect of diameter on detonation velocity, detonation failure diameter, effect of density/ temperature.Initiation, critical energy fluence, run distance versus pressure, impactor thickness and diameter effect on impact initiation. Wave shaping and lens design. Single stage gas gun, two stage light gas gun, propellant gun; electric gun and, rail gun. Ultra high magnetic field and magnetic pressures using flux compression generators. Pulse radiation, lasers and particle beams. Z-pinch, Gas-Puff and Plasma Focus devices for Thermonuclear Fusion.

Diagnostic Techniques and Data Interpretation: Measurement of shock velocity; particle velocity and stress history; shock temperature, sound velocity behind shock front; shock overtaking experiments. Velocity measurement using Displacement, VISAR, Fabry-Perot interferometers. Macroscopic measurements in shock compressed materials. Inductive Loops, Rogowski Coil, Voltage Dividers, Faraday Rotation. Visible and x-ray spectroscopy, Faraday cup, Thomson Parabola, X-ray, Ion and Neutron Imaging. Determination of equation of state, Hugoniot elastic limit, phase transition pressure and spall from experimental data. *Ab-initio* calculations for determination of isotherm, Hugoniot and phase transition pressures for interpreting the experimental shock wave data.

References

1. *Physics of High Energy Density*, G. E. Duvall (Academic Press, 1971).
2. *High Pressure Shock Compression of Solids*, J. R. Asay and M. Shainpoor (eds) (Springer-Verlag, 1993).
3. *Explosive Engineering*, P. W. Cooper (Wiley-VCH, 1996).
4. *Pulsed High Magnetic Fields*, H. Knoepfel (North Holland Publishing Co. 1970).

PY 729: Nuclear Data Physics for Advanced Nuclear Applications

Introduction to nuclear physics data: Types of Nuclear data, Variation of cross section with energy, Simple nuclear interactions theory, Measurement and model based predictions, Transmission experiment for total cross section, measurement of differential scattering cross section, Time-of-flight method, sources of errors in measurement, Optical model, Statistical model etc., exposition to SAMMY, EMPIRE. Training in online retrieval of data using Indian Mirror Website: www-nds.indcentre.org.in.

Representation of nuclear data : General purpose and special purpose ENDF libraries, Sub libraries for neutron, photon and charged particle interactions, Radioactive decay data, Fission product yields, formats and procedures, Tabulated and parametric representations in ENDF, Mathematical formalisms for Resonance representation viz. , single and multi-level resonance formalisms, Rieche-Moore, R-Matrix formalism, Breit- wigner formalism, interpolations schemes.

Nuclear data processing: Steps for processing evaluated data, linearization, resonance reconstruction, tolerances, Doppler broadening, , importance of target temperature for Thermal scattering data, Group averaging, PREPRO code systems, SIGACE package.

Multi-grouping: Multigrouping techniques, Energy groups and limits, considerations for grouping, , weighting functions: flux and current weighting, self-shielding, anisotropy and Legendre moments, group-to-group transfer cross sections, GROUPIE/GROUPR, transport cross section, group collapsing , Photon production cross section, Photo-atomic interaction cross sections, GAMINR, activation cross sections, coupled neutron-gamma cross section sets,
Continuous energy data for Monte Carlo codes (ACER), Nuclear data for ADSS applications (MATXSR).

Concept of critical facility; AHWR CF, Difference between critical facility and actual reactors, ICSBEP criticality benchmarking, Illustrati ons with benchmarking of KAMINI, PURNIMA-I and PURNIMA-II in the US-DOE ICSBEP International Handbook.

Exposure to Error Propagation and sensitivity studies, Variance-Covariance error matrix in nuclear data, Propagation of errors in assessment of uncertainty margins. Philosophy and mathematics of adjustment of cross sections to fit integral data from critical experiments.

References:

1. *Handbook of Nuclear Engineering,* DanGabriel Cacuci (Springer 2010).
2. *The Elements of Neutron Interaction Theory,* Foderaro, Anthony Harolde(MIT Press 1971).
3. *Handbook of nuclear reactor calculations,* Vols I-III, Ed. Yigel Ronen (CRC Press 1986).
4. *ENDF-6 Formats Manual (2010),* http://www.oecd-nea.org/dbdata/data/manual-endf/endf102.pdf
5. *Manual of Nuclear model code EMPIRE* (http://www-nds.iaea.org/empire218 /manual.pdf)
6. *Special Issues on Evaluated Nuclear Data File ENDF/B-VII.0,* J.K.Tuli, Nuclear Data Sheets, Vol-107 (2006).
7. *ENDF/B Preprocessing codes,* Cullen, D. E., (IAEA-NDS-39, Rev. 10, 2000) http://www-nds.iaea.org/public/endf/prepro/DOCUMENT/PDF/Overview.pdf
8. *Methods of steady-state reactor physics in nuclear design***,** Stamm'ler, and R. J. J., Abbate, M. J., (Academic press, London., 1983).
9. *See: http://www-nds.indcentre.iaea.org.in/~wlup/ WIMS Library Update Project. WLUP.*
10. *Proc. of the workshop on Nuclear Reactors,- Physics, design and Safety,* Eds. A. Gandini, S. Ganesan and J.J. Schmidt,(IAEA publication, 1994).
11. *WIMS-D Library Update,* Leszczynski, F., López Aldama, D. and Trkov, A.(STI/PUB/1264, ISBN 92-105006-2. IAEA, 2007)
12. *Theoretical Nuclear Physics,* John Markus Blatt and Victor Frederick Weisskopf (Wileyand Sons 1952).

PY 730: Advanced Computational Methods for Steady State and Transient Behaviour of Neutron Transport

Solution of transport equation: P_N method (Plane and curved geometries)**,** Discrete ordinates method (Plane and curved geometries, Quadrature sets)**,** Collision probabilities methods Collision probability method in 1-D and 2-D geometries, Interface current method, Characteristics method. Discrete ordinates methods in 1-D, 2-D and 3-D geometries.Diamond differencing scheme.Solution procedures**.**

Neutron thermalization: Neutron scattering laws, Scattering from mono-atomic gas, bound-atom scattering, Liquid moderators, Nelkin model.

Treatment of resonances: NR, IR and WR approximations, Sub-group method

Solution of time dependent transport equation: Differencing of time dependent transport equation, Point kinetic equations, Space-time kinetics, Adiabatic approximation. IQS; explicit andimplicit time differencing methods

Solution of the fuel depletion equations: Formalism of the detailed burnup chain, Formulation of fuel depletion equations, production-destruction of actinides and fission products, branching ratios **,**Solution of the burnup equations, Constant flux and constant power approximations. Solution for decay heat and other potential reactor applications

Monte Carlo methods: Exposition to neutron and particle tracking principles

References

1. *Computational Methods of Neutron Transport,* E.E.Lewis and W.F. Miller (Wiley, 1984) and ANS (1993).
2. *Nuclear Reactor Theory,* G.I.Bell and S. Glasstone (Van Nostrand, 1970).
3. *Nuclear Reactor Analysis,* A.F. Henry(MIT Press, 1975).
4. *Numerical Methods of Reactor Analysis,* M. Clark and K.F. Hansen(Academic Press, 1964).
5. *Nuclear Reactor Physics,* Weston M. Stacey, (Wiley, 2001)
6. *A primer for the Monte Carlo Method*, IIYA, M. Sobol, CRC Press

PY 731: Accelerator Driven Systems

Neutron Source: Various types of accelerator based neutron sources and their properties: Electron accelerator based source, spallation source and fusion source - advantages and limitations.

The spallation process: Theory and mechanism, various types of targets and projectiles. Neutron yield, energy spectrum, angular and spatial distribution in the target. Spallation products; Heat distribution; Codes in use.

Spallation target: Thermal hydraulics of spallation targets: heat removal and suitable coolants; Radiation damage in window and other structural materials; Windowless designs; Radioactivity of coolant / target.

Sub-critical Reactor: Neutron multiplication in sub-critical reactors, source importance, Ks, Keff and reactivity; Power and power distribution in ADS; Considerations in deciding the degree of sub-criticality of an ADS.

Theoretical Techniques and analysis: Transport theory and Monte Carlo methods: computer codes for ADS analysis; Nuclear data requirements and sources; Burnup and its effect on fuel and core properties; ADS kinetics and safety issues – comparison with critical reactors.

ADS related experiments: Measurements of parameters, Reactor noise in ADS.

Comparative study: Breeding in critical reactors and sub-critical ADS, Fuels and fuel cycles for ADS.

Waste transmutation: Issues in waste management, Waste transmutation in different types of reactor systems, Advantages of ADS.

ADS Types: Proposed ADS types for power generation, breeding and waste transmutation.

References

1. *Accelerator Driven Sub-critical Reactors*, H. Nifenecker, O.Meplan and S.David (Institute of Physics Publishing, 2003).
2. *Conceptual Design of a Fast Energy Amplifier*, C. Rubbia et al ReportCERN/AT/95-44 (ET)(1995).
3. *Accelerator Driven Systems and Fast Reactors in Advanced Nuclear Fuel Cycles – A Comparative Study*, *OECD Report,* NEA (2002).
4. *Accelerator Driven Systems in the Nuclear Power Program*, INS NewsVol 6, No. 2 (2009).
5. *One Dimensional Thermal Hydraulic Design Codes for Buoyancy and Gas Driven Window and Windowless Spallation Target Loops of ADS Reactors,* K. Biswas, P.Satyamurthy and A.K.Ray, Report BARC/2003/I-007.

NON-SUBJECT ASSIGNMENTS

PY 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

PY 592:

Experiments

PY593: Mini

Project

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.

IGCAR

PGD in Physical Sciences
(Program code: PHYS00)

Nuclear Reactor Physics

Course Code	Course Name	Hours	Credits
PY1	Mathematical Methods	45	6
PY2	Computational Methods	45	6
PY3	Introductory Reactor Physics and Engineering	35	4
PY4	Nuclear Physics and Nuclear Data	30	4
PY5	Engineering Drawing and Laboratory Practices and Experimental Methods	20	2
PY6	Reactor Materials	30	4
PY7	Radiation Detection and Measurements	20	2
PY8	Reactor Types and Advanced Reactor Concepts	20	2
PY9	Radiation Shielding Design and Protection	40	5
PY10	Reactor Dynamics and Safety Analysis	35	4
PY11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
PY12	Fluid Dynamics and Thermal Hydraulics	25	2
PY13	Advanced Computational Methods in Reactor Physics	35	4
PY14	Experimental and Operational Reactor Physics	35	4
PY15	Design Methods in Thermal and Fast Reactors and Computer codes	35	4
PY16	In Core of Fuel Management	25	2
Total		**505**	**59**

1. Mathematical Methods (PY1) : (45 lectures)

S.No	Course content
1.	Linear vector spaces, linear dependence and independence, basis and dimension. Linear transformations. Inner product, norm, continuity, convergence, completeness. Hilbert spaces.
2.	Fundamentals of matrices, eigenvalues, eigenfunctions, adjoints, inverse etc sparse matrices; diagonal dominance; non-positive and non-negative matrices; positivity theorems; large set of simultaneous equations.
3.	Functions of a complex variable. Rieman surfaces, Analytic functions Cauchy Rieman conditions and harmonic functions. Contour integration and Cauchy's integration formula. Residue theorem and evaluation of integrals.
4.	Ordinary differential equations - Order and degree of a differential equation, appearance and number of arbitrary constants in the solution of a n-th order differential equation, families of curves and orthogonal trajectories, first order homogeneous and exact equations, methods of reduction of order of some specific differential equations, second order linear homogeneous equations, superposition principle, method of finding second independent solution when one solution is known, qualitative properties of the solution, Sturm comparison theorem, operator methods for second order linear equation with constant coefficients, power series solution for second order linear equations, ordinary and regular singular points of a differential equation, indices corresponding to a regular singular points, hypergeometric and confluent hypergeometric equation, explicit example through solution of Bessel's equation.
5.	Partial differential equations – First order partial differential equations, complete integral and general solution, methods of solution of a first order partial differential equation, second order partial differential equations, Laplace's equation, wave equation, diffusion equations, system of surfaces.
6.	Integral equations – Definition, homogeneous, inhomogeneous, linear, non-linear equations, Fredholm and Volterra equations, eigenfuctions, Schmidt-Hilbert method of solutions.
7.	Integral Transforms. Fourier, Laplace Transforms and the inverse transforms, connection to physical problems Other transforms such as Mellin and Hankel transforms, and transforms generated by Green's function. Applications for obtaining solution of ordinary/partial differential equations.

Books suggested

1. Mathematical Methods for Physicists, G. B. Arfkin and H. J. Weber, Academic Press(2001) Also Prism Books, Bangalore
2. Elements of Partial Differential Equations, I. Sneddon, McGraw Hill (1957)
3. Theory of Functions of a Complex Variable, E. T. Copson, Oxford University Press (1935)

2. Computational Methods in Physics (PY2): (35 lectures + 10 Tutorials)

S.No	Course content
1.	**Computers, Computational Physics and Scientific Programming**

a) Introduction to Computational Physics

b) Components of a high performance computer- memory hierarchy, CPU design, Vector processing, Virtual memory, Number representation- Arithmetic of Fixed and Floating

point numbers, Machine precision, Errors and uncertainties in computation Types of errors, Error propagation

c) Computing software basics

d) Computer languages, Programming concepts, Programme design, Structured programming, Introduction to Fortran and C, C & Unix, Dialects of C, Functions and Program structure, Basic Data Types, Arrays, Strings, Expressions and Operators, Precedence of C Operators, C Preprocessors, Control Statements, Pointers, Pointer arithmetic, Arrays handling with Pointers, Functions in detail, Input and Output Operations and C file handling Operations, Structures & Unions in C, Dynamic Memory allocation, Macro definitions, Compilation and Execution of C program, Fortran to C Linking procedures.

e) Introduction to Parallel processing, High performance computing, Profiling and tuning, Visualization of scientific data

f) Highlights of FORTRAN-90 programming language. Programming in MATLAB

2. **Numerical Methods**

Linear algebra

a) Matrices

b) Solution of Linear Algebraic Equations and Singular Value Decomposition

c) Eigenvalue problems, Computing Eigenvalues and Eigenvectors

d) Iterative methods for Linear systems

e) Software for linear systems- LINPACK and LAPACK

Solution of Nonlinear equations

a) Bracketing and Bisection

b) Secant Method, False Position Method, and Ridders' Method

c) Newton-Raphson method

d) Software for nonlinear equations

Interpolation, Extrapolation and Numerical Differentiation

a) Differentiation- Forward, backward and central differences

b) Polynomial Interpolation and Extrapolation

c) Rational Function Interpolation and Extrapolation

d) Interpolation using Splines

Optimization methods

a) Optimization in one dimension

b) Multivariate problems- Steepest descent, Newton and quasi-Newton methods, Conjugate gradient methods. Constrained optimization

c) Maximum entropy and Genetic methods

d) Least square fitting, Non-linear least square fitting, Goodness of fit

e) Software for optimization- energy minimization

Numerical Integration

a) Integration- Newton-Cotes integration formulae, Gaussian quadrature

b) Integral equations

Probability , Random numbers and Monte Carlo methods

a) Uniformly distributed Pseudo random numbers

b) Exponentially and Normally distributed Pseudo random numbers

c) Testing of pseudo random number sequences

d) Simulation of radioactive decay

e) Numerical Integration

f) Monte Carlo simulation techniques

Fourier and Wavelet transforms

a) Fast Fourier Transform- Convolution and deconvolution, Correlation, Filtering, Power spectrum estimation

b) Wavelet transforms- Wavelets, de-noising, de-trending, Texture analysis, Pattern recognition, Image compression

Ordinary Differential equations

a) Initial value problems for systems of ode's

b) Runge-Kutta Method, and adaptive step size control

c) Stiff differential equations

d) Boundary value problems

e) Galerkin method

Partial differential equations

a) Finite difference methods for Parabolic, Hyperbolic and Elliptic equations

b) Truncation errors, consistency, stability

c) Introduction to finite element methods.

Tutorials: Assignments of problems and computations based on these and other methods using FORTRAN-77 / FORTRAN-90/ C++

Books Suggested:

1. Computational physics- Problem solving with computers, Rubin H. Landau, Manuel J. Paez, John Wiley & sons 1997.
2. Numerical Recipes in Fortran-77 / F-90 / C, W.H. Press et. al., Cambridge Univ. Press.(1996)
3. A First Course in Computational Physics, P.L. DeVries, John Wiley and Sons (1994)
4. Numerical Methods for Engineering Application, J.H. Ferziger, John Wiley and Sons (1998)
5. Scientific Computing: An Introduction with Parallel Computing, G. Golub and J.M. Ortega, Academic Press, (1993)
6. Scientific Computing: An Introductory Survey, Michael T. Heath, McGraw-Hill, New York,

2002.
7. Computational Physics, J. M. Thijssen, Cambridge University Press, Cambridge, 1999.
8. Guide to Neural Computing Applications, L. Tarassenko, Arnold Publishers, 1998.
9. Genetic Algorithms in Search, Optimization, and Machine Learning, D. E. Goldberg, Addison Wesley, Reading, Massachusetts, 1989.

3. Introductory Reactor Physics and Engineering (PY3): (35 lectures)

S.No.	Course content
	Part I
1.	Basic nuclear physics concepts. Properties of nuclei. Nuclear forces. Nuclear models. Nuclear decay. Liquid drop model and nuclear stability. Nuclear reactions including fission. Compound nucleus formation. Microscopic cross-section. Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	Chain reaction; four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.
5.	**Reactor Kinetics**: Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.
	Part II
1.	Neutron distribution in a system; assumptions in setting up the neutron balance equation; applicability of Maxwell-Boltzmann statistics; Time dependent neutron balance (transport) equation, with delayed neutrons
2.	**Steady State Neutron Transport Equation:** Transport equation – differential & integral forms, Diffusion approximation, One speed neutron diffusion theory, Boundary conditions, Source-sink problem, Sub-critical reactors with flux independent source, Separation of space and energy.
3.	**Slowing Down and Energy Dependence:** Elastic scattering, Inelastic scattering, Anisotropy, average energy loss per neutron, Concept of lethargy. Fermi age theory, age of neutron, Logarithmic energy decrement, Slowing down spectra, Slowing down in hydrogen, Definition of resonance integral, Shape of thermal neutron-Maxwell spectrum.
4.	**Resonance Absorption:** Resonance cross sections, Resolved and unresolved region, Spatial and energy self shielding, Narrow resonance and intermediate resonance approximation, Concept of potential scattering cross section, Resonance integral in homogeneous media, Doppler broadening of resonance and importance for safety.
5.	**Multigroup Diffusion Theory:** Energy group and group fluxes, Flux weighted group constants, One group theory for thermal neutrons, Two group theory, Two group two region

model core with reflector. Adjoint equation.

6. **Reactor Control:** Cold start-up, Hot power operation, Temperature loads, Effects of burnup and fission products. Function of control rods. Theory of control rods, Xenon load during operation, Xenon iodine concentrations after shutdown, Xenon override, Xenon poison out condition, Samarium poisoning. Temperature coefficient of reactivity.

   Density temperature coefficient.

7. **Fast Reactors:** Fast reactors as breeders, comparison of fast and thermal reactors, role of fast reactors in Indian 3 stage nuclear power program

8. Neutron spectrum in FBR, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, delayed neutron fraction, fuel expansion and bowing, sodium void reactivity effect, Optimisation of blanket thickness. Effect of burnup on fuel composition and reactivity coefficients

9. General features of FBR core, specific power, linear rating, fluence, requirement and choice of core materials (fuel, coolant and structural materials), types of fast reactors – pool and loop type. Optimisation of core height and pin diameter. Salient physics aspects of FBTR and PFBR

Books suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C.Edlund. Van Nostrand, 1952.
2. Introduction to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Nuclear Reactor Engineering, Glasstone and Sesonske, Van Nostrand, 1990
4. The Physical Theory of Neutron Chain Reactors, Weinberg A. M. and Wigner E.P.
5. Nuclear Reactor Theory, Bell and Glasstone, Van Nostrand, 1970
6. Physics of Nuclear Reactors, Jakeman D.
7. A. E. Walter and A. B. Reynolds, “Fast Breeder Reactors”, Pergamon Press, 1981
8. Weston M. Stacey, “Nuclear Reactor Physics”, John Wiley & Sons, Inc., 2001

4. Nuclear Physics and Nuclear data (PY4): (30 lectures)

S.No	Course content
	Part I - Nuclear Physics
1.	Properties of Nuclei; Binding Energy Curve; Stability Curve – neutron rich isotopes; nuclear interactions: neutron scattering, isotropic and anisotropic scattering. neutron capture, (n,xn) reactions; reaction thresholds, fission; Variation of cross-section with respect to (nuclide) material, reaction and incident energy; Resonance (Resolved/Unresolved) and Continuum regions; Mathematical formalisms to represent these data.
2.	**Nuclear models:** Nuclear potential; liquid drop, shell and optical models. Fission process; Fission barrier; (n,f) - thermal and high energy neutron induced fissions; Fission products and decay; FP elemental mass/isotope chains and distribution; prompt fission and delayed fission neutron energy distributions; energy yield per fission; neutron yield in fission with neutron energy (nu-p); photo neutron.
3.	Important neutron reactions with fuel, control and structural materials in reactor systems.

4. High energy proton interactions with heavy metals; spallation process; spallation products; neutron source distribution from spallation.

Part II - Nuclear Data

1. Four major kinds of nuclear data, viz. nuclear constants data, nuclear structure data, nuclear decay data, and nuclear reaction data. Importance to application areas, like therapeutic treatments, agriculture, and nuclear energy. Kinds of data, like neutron interaction data, neutron/gamma production data, gamma-atom interaction data, etc., pertinent to reactor physics applications.

   Measurements and model based predictions; Transmission experiment for total cross-section, measurement of differential scattering cross-section; Time of flight method, sources of errors in measurement – energy resolution; Optical model, Statistical Model, etc.; Examples of model based computer codes.

2. **Nuclear data Evaluation:** Problems of scarcity and/or abundance of nuclear data, need of nuclear data evaluation; Evaluated nuclear data files (ENDF), ENDF/A, ENDF/B,JENDL and JEFF; General purpose and Special purpose libraries; Sublibraries for neutron, photon, and charged particle interactions, Fission product yields and decay data; Problems of multiple evaluations; Formats and procedures; MAT, MF, MT conventions; Representation of different kinds of data, tabulated and parametric representations, single/multi level resonance formalisms in the resolved/unresolved region, BW formulation, partial & total widths, negative resonance energies, interpolation schemes. IAEA-NDS; Related websites.

3. **Nuclear data Processing:** Need for processing of an evaluated data Steps of processing; Simplifying assumptions and tolerances; Precautions on consistency and accuracy. Popular processing cods: PREPRO and NJOY and their modules, Linearisation: Advantages of linearization; interval halving procedure, tolerance (error criterion), probable pitfall – position of maximum deviation; Program LINEAR.

   Resonance Reconstruction. Doppler broadening: Effect of target temperature on cross-sections – for low energies, for resonances and for threshold reactions; kernel broadening approach, submerging small resonances due to broadening. Validation of evaluated and processed cross-sections.

4. **Multigrouping:** Consideration for deciding the number of groups and group limits. Neutron cross-section averaging: conservation of reaction rate, transport cross-sections, flux and current weighting, self-shielding, dilution and temperature dependences, multigroup cross-section set, effective cross-sections, mixture cross-sections, collapsing of cross-sections, group-to-group transfer cross-sections; Anisotropy and Legendre moments. GROUPIE/GROUPR programs; Validation of multigroup cross-sections.

   Photon production cross-sections; photo-atomic interaction cross-sections; coupled multigroup cross-section set; GAMINR program.Activation cross-sections; relevance of residual nuclear levels. Displacement cross-sections; relevance to radiation damage in reactor materials.

Books suggested:

1. Handbook of nuclear reactor calculations: Vols I-III, Yigel Ronen (Ed.) CRC Press, West PalmBeach, Florida (1986).
2. ENDF – 102, Data Formats and Procedures for the Evaluated Nuclear Data for ENDF – VI, M.Herman (Ed.) BNL-NCS-44945-05, (2005)
3. Special Issues on Evaluated Nuclear Data File ENDF/B-VII.0, J.K.Tuli, Nuclear Data Sheets, Vol-107 (2006)
4. Introduction to Nuclear Reactor Theory, Lamarsh J.R., ANS, (2002)

5. Engineering Drawing and Laboratory Practices (PY5 & PY5A): (20 lectures)

S.No	Course content
1.	**Machine Drawings Projections:** orthographic – 1st & 3rd Angles pictorial; Oblique: Perspective.
2.	Introduction; Indian and International standards for drafting and related subjects.
3.	**Line, lettering and dimensioning:** Outline hidden lines, Centre lines, Dimensional lines, Extension/Projection lines, Construction lines, Section lines, Leader/pointer lines, Cutting plane lines, Border lines, Short & long break lines, Representation of welded joints.
4.	**Dimensioning and tolerancing:** Definition and general principles, Arrangement of dimensions - Chain and parallel dimensioning, method of dimensioning common features; Rules for inscription of tolerancing. Limits fits. Tolerances and surface finish.
5.	**Scales, lines and lettering:** Recommended scales; Different type of lines, their illustration and application; Recommended size of letters and numerals.
6.	**Sections:** Full Section, Half section, Partial section, Revolved section.
7.	**Projections:** Orthographic – 1st & 3rd Angles; Pictorial – Oblique and Isometric
8.	**Conventional representation of common features and sections:** Conventional representation of gears and gear assembly, Threads, springs, bearing, welded joints. Hatching, sectioning, cutting planes.
9.	**Fastenings:** Bolts, studs, screw, washers, set screw, split pins.
10.	Brief Introduction of AutoCAD and its use, common drawing and edit commands.

Laboratory Practices:

1. Errors in measurement. Accuracy and precision. Software, data analysis, filtering and plotting.

   Electronic components of detector systems.Analog electronics, Electromagnetic interference, shieldind and grounding of electronic equipments. Measurement of temperature, pressure, mass, volume and flow. Instrument time constant and response time.
   Production and measurement of (low pressures)vacuum and high pressures.
   Production and measurement of high temperature and low temperatures.

   Computer hardware. Intelligent systems, Computer control and automatic data acquisition. User friendly experimental automation with G (graphical) language.

Books suggested:

1. Indian Standard Code of Practice for General Engineering Drawings (Second Revision); Bureau of Indian Standards.
2. Geometrical and Machine Drawing by N.D. Bhatt; Charotar Publishing House, Anand (WR), India

6. Reactor Materials (PY6): (30 lectures)

S.No	Course content
1.	Properties of fuel materials. Uranium metal, Uranium dioxide, Carbide and nitride fuels. Plutonium fuel materials. MOX fuels. Thorium fuel materials. Fabrication of fuel pellets: sintered and vibropacked.
2.	Dispersion type fuels. Inert matrix fuels, Metallic fuels, sol-gel process. Fuel for HTRs – coated particle / TRISO/ spherical fuel balls for high powered systems.
3.	General requirements of structure and clad materials. (neutronic and physical) Aluminum and alloys. SS and low alloy steels. Nickel alloys. Zirconium and alloys. Properties of moderator and coolant materials. Graphite, Beryllium, water and heavy water. Liquid metals. Heat transfer coefficients.
4.	Mechanical properties of materials. Stress-train relationships. Ductile and brittle failure. Ductile to brittle transition, Fatigue failure, Creep and dilation.
5.	Stress analysis, Thermal stress in fuel clad. Thermal stress in hollow cylinder with no heat generation, Thermal stress in hollow cylinder with exponential heat source, Factors affecting thermal stress.
6.	Radiation effects in materials. Atomic displacements. Mechanisms in radiation damage, General irradiation effects in metals. Thermo-physical properties of fuel (pellet) materials; variations with burnup Temperature dependent swelling. Helium embrittlement. Typical limits of irradiation damage
7.	Corrosion of metals. Chemical corrosion, erosion and fretting corrosion, Stress- corrosion cracking, Hydrogen embrittlement. Fuel clad failure process.
8.	Advaced materials for future FBR, ADS and high temperature reactor. Ferritic steels, oxide dispersed steels and carbon based materials

Books suggested:

1. Nuclear Reactor Engineering, Glasstone and Sesonske, Van Nostrand.
2. Fundamental Aspects of Nuclear Reactor Fuel Elements, D.R. Olander, ERDA report, TID 26711-P1 (1976).

7. Radiation Detection and Measurement (PY7): (20 lectures)

S.No	Course content
I	**Interaction of radiation with matter:**
1.	Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe-Bloch formulae), Cherenkov radiation. Energy loss of electrons and positrons – Electronic stopping and energy loss by Bremsstrahlung radiation.
2.	Interaction of photons – Photoelectric absorption, Compton scattering, pair production, Electromagnetic shower in high energy photon and electron interaction with matter.
3.	Interaction of Neutrons – elastic scattering, radiative capture, positive Q-value reactions such as (n,p), (n,gamma), (n,fission) and hadron shower production at high energies.

II **Radiation detectors:**

1. General characteristics of detectors – efficiency, response in energy, time, position and corresponding resolutions, recovery time or count rate handling capability.
2. Gas detectors Basic processes, Q-V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter.
3. Semiconductor detectors Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium detectors (planar and cylindrical geometry). Photovoltaic cells, charged coupled devices.
4. Scintillation detectors. Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes.
5. Techniques and detectors for neutron and spectrum measurements. Fission ionization chambers. Boron filled and coated detectors. Gamma compensation. Self powered neutron detectors.
6. Pulse processing instrumentation, preamplifiers(charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), single channel analyzers, timing discriminators(leading edge and constant fraction types), gate and delay generators, coincidence(fast and slow) units, linear gate and stretchers, time to amplitude converter(TAC), scalers and rate dividers, analog to digital converter(ADC), charge to digital converter(QDC), time to digital converter(TDC), data acquisition systems (multichannel analysers and computer based multiparameter systems).
7. Experimental techniques and simulation - Particle identification methods (pulse shape discrimination, Cerenkov radiation), Compton suppressed high purity germanium detectors for high-resolution gamma spectroscopy, magnetic spectrometers including recoil mass separator. Monte Carlo simulation of detectors.

Books suggested:

1. Techniques for Nuclear and Particle Physics Experiments – W.R. Leo, 2nd Ed. (Springer International Student Edition published by Narosa Publishing House, New Delhi 1995).
2. Radiation Detection and Measurement – G.F. Knoll, 3rd edition (John Wiley, New York 2000)
3. Nuclear Radiation Detectors – S.S. Kapoor and V.S. Ramamurthy (Wiley Eastern Ltd, New Delhi 1986)
4. Radiation Detectors, C.F.G. Delaney and E.C. Finch (Clarendon Press 1992).

8. Reactor Types and Advanced Reactor Concepts (PY8): (20 lectures)

S.No	Course content
1.	**Thermal Reactors:** History. Development of Gas Cooled Reactors (GCR). Reactor types AGR and RBMK. Development of BWR. Development of PWR and VVER. Development of PHWR and SGHWR.
2.	**Fast Reactors:**

History. Development of LMFBR.

3. **Advanced Reactors:**

   Different generation of nuclear reactors. Evolutionary improvements and revolutionary improvements. High Temperature Reactor(HTR) and Advanced Heavy Water Reactor (AHWR).

   Metal fuelled FBR and increased fuel breeding.

   Accelerator driven systems (ADS)

   Fusion Systems. JET and ITER. Concept and need for tritium breeding.

4. **Indian Reactors (Experimental and power producing):** For each type of reactor - brief principles of the reactor; typical Power/ Research reactor system; Fuel cluster/assembly; number of channels; core; coolant/moderator/reflector/blanket and shield as the case maybe; average neutron energy spectrum; control and shut down systems.

   - APSARA/ CIRUS/ DHRUVA
   - PHWR –India (220, 540 and 700 MWe)
   - LWRs
   - BWR (TAPS 1&2, modern BWRs,)
   - VVER (KK)
   - FBTR and PFBR

5. International Initiatives in Advanced Nuclear Systems: INPRO (IAEA) and GEN-IV. US proposal GNEP. International concerns. Nonproliferation, (proliferation indices), NPT, FMCT, CTBT.

Books Suggested:

1. W. Marshall ed. Nuclear Power Technology, Volumes I to IV, Clarendon Press, Oxford, (1984).

9. Radiation Shielding Design and Protection (PY9): (40 lectures)

S.No **Course content**

1. **Basics of radiation physics and dosimetry**

   Radiation sources, its interaction with matter; natural and induced radioactive sources, half-life, decay constant, specific activity; basic interaction mechanisms of alpha, beta, gamma/x-rays and neutrons with matter (*summary only*).

   Definition of various dosimetric terms (exposure, absorbed dose, equivalent dose, effetive dose, concept of radiation and tissue weighting factors and their importance, Activity, Specific activity (SI units and Old units), radiological, biological and effective halflife and their relation and their importance. Concept of ALI and DAC with suitable problems.

   Human Body: cells, tissues and organs, structure of cell, cellular effects. Factors which influence the damage of cell. Interaction of radiation with biological matter. stochastic and deterministic effects. Acute and delayed effects. LD 50/60, Doubling dose. Radiation toxicity, Risk factor.

2. **Radiation Protection**

   Radiation protection philosophy, objectives and principles of radiation protection ALARA, stochastic and deterministic effects, justification, optimization and dose limitation, Dose limits to occupational workers and members of public, Dose constraints, Investigation limits. Types

of exposure (natural, occupational, medical and public).

External and internal exposures; internal routes of intake of radioactive material. Use of personal dosimeters (TLDs, pocket dosimeters). Calculation of dose, Exposure measurement: Free air and air wall chambers (concept of wall thickness should be given), exposure-dose relationship, Fundamentals of ICRP respiratory model, ingestion, Gastro intestinal track model, wholebody counting and bioassay techniques.

Atomic Energy Act, National and international regulatory bodies, their role and responsibilities, Radiation protection rules, Safety during transport of radioactive materials, Radioactive waste classification and management.

3. **Radiation Shielding**

Shielding concepts- gamma shielding- Attenuation factors. Buildup factor concept for homogeneous and multiple layers. Semi-analytical methods for gamma shield design. Dose rates of gamma rays for various source geometries. Gamma energy dependence of dose. Half layer thickness of different materials. Heat generation.

Neutron shielding. Shielding in thermal reactors. Importance of shielding in fast reactors. In-vessel shields and reduction of dose to components and operating personnel. Activation of structural material and heat generation. Shielding in accelerators and fusion systems.

Computational problems. Transport theory methods. Large problem size and large flux attenuation. Importance of anisotropy effects in scattering. Neutron slowing down and need for fine energy treatment. Monte Carlo methods. Streaming through gaps, voids and pipes. Analytical methods. Complementary shielding.

Selection of shield materials. Shielding from mixed sources. Life of shield materials.

4. **Nuclear Emergency management**

Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, countermeasures. Aerosol physics for core disruptive accidents, Atmospheric transport processes, environmental impact studies.

Books suggested:

1. Nuclear Radiation Detection - W.J. Price, McGraw Hill (1964)
2. Radiation Detection and Measurement - G.F. Knoll, John Wiley and Sons (1989)
3. Biological Effects of Radiation – J.E. Coggle, Taylor and Francis (1983)
4. Atoms,Radiation and Radiation Protection by James E.Turner, Wiley (2007)
5. Problems and Solutions in Radiation Protection by James E. Turner et al., Wiley, (1988)
6. Introduction to Health Physics – Herman Cember, McGraw Hill (1996)
7. Introduction to Radiation Protection –Alan Martin and Samuel Harbison, Chapman and Hall (1986)
8. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998.
9. Radiation Shielding- Three volumes of Compendium on Radiation Shielding, O.Sisman and J. Jaeger et.al., ed. (1975)
10. Radiation Shielding Manual T Rockwell et.al ed. AEC-US, (1958).

10. Reactor Dynamics and Safety Analysis (PY10): (35 Lectures)

S.No	Course content
1.	**Reactor Dynamics** Neutron kinetics and thermal effects. Feed back effects. Time constants. Loosely and strongly coupled reactor systems; Reactor size and eigenvalue separation; fundamental and higher modes. Description of main reactor systems. Coolant system behaviour. Plant dynamics (open loop and closed loop). Flow perturbations. Reactivity perturbations. Thermal perturbations. System stability. Linear and non-linear stability analysis; Nyquist critera; Liapunov methods. Xe dynamics equations; spatial and time dependent oscillations and stability. Safety concepts. Defence in Depth (5 levels) Accident Categories / classification: Design basis events (DBE) and Beyond DBE (BDBE). Loss of Regulation Accident(LORA), Transient Over Power Accident(TOPA), Loss of Coolant Accident(LOCA), Loss of Flow Accident(LOFA), cold coolant additions – with shut down action; Anticipated Transients with out SCRAM(ATWS)- Un protected Loss of Flow (ULOF) and Unprotected Transient over Power (UTOP). Accident scenarios in thermal and fast reactors. Brief description of accidents at Three Mile Island, Chernobyl and FERMI reactor. Computer codes for modeling accidents in thermal and fast reactors. RELAP and SAS4A. Kinetics of ADS.
2.	**Safety Systems** Engineered safety systems. Safety Critical Systems (SCS); Safety Groups, SCS, actuation systems, safety support systems. Shut down Systems. Different shut down states; Shut down margins (SDM). Guaranteed shutdown states (GSS). General safety criteria. Examples of safety analysis of PHWR, LWR and FBR.
3.	**Introduction to Reliability and Probabilistic Safety Analysis (PSA)** Probability, random variable, probability distributions used in Reliability Analysis; uniform, exponential, Weibull, Normal and χ^2 distributions, Central Limit Theorem. Basic component reliability models, definition and other measures of reliability such as Availability, failure frequency, dependability, fail safe design, safe failures/unsafe failures. Reliability Block Diagram, series and parallel systems, minimal cutsets, Combinatorial (Fault Tree / Event Tree) and State Space methods (Markov Models), Binary Decision Diagram. Common Cause Failures, Human Reliability Analysis: Models of Common Cause failures and Human Reliability Analysis, independence, redundancy, diversity. Probabilistic Safety Assessment of Nuclear reactor, measures of risk, core damage frequency, Level-1, Level-2, Level-3 PSA (introduction).

Books suggested:

1. Fast Reactor Safety, John Graham, Academic Press (1972).

2. The Technology of Nuclear Reactor Safety, Vol-I and II, T.J.Thompson and J.G.Beckerley, MIT Press (1971).
3. Reactivity Coefficients in Large Fast Power Reactors, H.H.Hummel and D.Okrent, ANS (1970).

11. Fuel Cycle Physics and Introduction to Fuel Cycle (PY11) : (30 lectures)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.
8.	Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9.	U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10.	Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11.	Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12.	Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13.	Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14.	Isotopic separation operation of bred uranium in thorium cycles to remove U-232. MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:
1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Fluid Mechanics and Thermal Hydraulics PY12 (25 lectures)

S.No	Course content
1.	**Fluid Mechanics** Fluid continuum – Properties of fluids – Methods of describing fluid motion – Kinematics of fluid streamlines, streak lines, path lines – equation of Continuity, Euler's equations of motion – Navier Stokes equations. Hydrostatics – Manometry – Fluid force on planes and curved surfaces, – Aerostatics – variation of pressure, temperature and density with altitude – stability of atmosphere – Fluids subjected to uniform linear acceleration and uniform rotation. Analysis of fluid motion in integral form – Concept of a system and a control volume – equations of continuity, energy, linear momentum and angular momentum as applied to a control volume in fluid flow and their applications to propellers, pumps and turbines. Dimensional analysis, similitude and model testing – Laminar and turbulent flows – Viscous effects – Boundary layer – Separation phenomena – Losses in pipes.
2.	**Thermal hydraulics** **Conduction:** Steady state conduction in one and two-dimensional systems – One dimensional unsteady state conduction; analytical and numerical methods. Heat generation in cylindrical and plate fuel elements; Steady state heat transfer from fuel to coolant; concept of $\int KdT$; Axial temperature distribution in the fuel element; Maximum clad surface temperature. **Convection:** Basic equations, Boundary layers; Forced convection: External and internal flows, correlations, Natural convection. Natural circulation cooling during pump trip transients; flow coastdown; decay heat removal; natural circulation in advanced reactor concepts, flow instabilities. **Radiation heat transfer:** Basic laws, Properties of surfaces, view factors, network method and enclosure analysis for gray – diffuse enclosures containing transparent media, Engineering treatment of gas radiation. **Boiling heat transfer:** bubble nucleation; transition and film boiling (a) pool boiling and (b) flow boiling; heat transfer coefficients in pool and flow boiling. Horizontal and vertical surfaces. Two-phase flow; flow regimes; mixture quality; void fraction; mixture density; pressure drop. **Concept of pressure drop in nuclear channels:** objectives and methods of flow orificing; orificing in BWRs and FBRs. Hot spot factors; classification; determination of subfactors; overall hot spot factor-statistical and multiplicative approaches. **Condensation:** Surface tension- bulk Condensation – Dropwise condensation on solid surfaces, Film condensation, Nusselt's theory. **Critical heat flux:** mechanism of dryout and Departure from Nucleate Boiling (DNB); thermal margin – MCHFR; MDNBR; critical power concept.

Books Suggested:

1. Thermal Hydraulic Fundamentals, Neil E. Todreas, Hemisphere (1990).
2. Fluid Mechanics, F. Dougles et al., Pearson Education, 2006.

3. Heat Transfer, J.P. Holman, Eighth Edition, McGraw Hill, 1997.
4. F.P. Incropera and D.P. Dewitt, "Fundamentals of Heat and Mass Transfer, John Wiley and Sons, Fourth Edition, 1998.
5. Fast Breeder Reactors, Waltar A.E. and Reynolds A.B, Pergamon Publishers, New York, 1981.

13. Advanced Computational Methods in Reactor Physics (PY13): (35 lectures)

S.No.	Course content
1.	**Methods of solving neutron Diffusion equation:** Finite differencing of diffusion equation. Centre and corner mesh differencing schemes. Rectangular and triangular (hexagonal) meshes; Inner and outer iteration schemes. Acceleration methods for inner iteration scheme. Spectral radius and determination of acceleration parameter. Acceleration methods for outer iteration scheme. Power iteration and dominance ratio.
2.	Modern nodal methods. General weighted residual methods. Finite element method- its advantages and disadvantages. Coarse mesh rebalancing.
3.	Estimation of fundamental and higher harmonics; subtraction methods
4.	**Methods of solving neutron transport equation** **(i) Lattice:** (a) P_N method (b) Discrete ordinates method (c) Collision probabilities methods Collision probability method in 1-D and 2-D geometries. Interface current method. (d) Characteristics method.
5.	**(ii) Core and Shield:** Discrete ordinates methods in 1-D, 2-D and 3-D geometries. Diamond differencing scheme. Computer code ATES-3. Monte Carlo methods for core calculation; deep penetration problems. Computer code MCNP.
6.	Detailed burnup chain with all minor actinides. Solution of the burnup equations. Constant flux and constant power approximations. (ORIGIN
7.	Differencing of kinetic equations in time. Approximate solution of point kinetic equations. Space time kinetics. Adiabatic approximation. IQS; explicit and implicit time differencing methods.

Books suggested:

1. E.E.Lewis and W.F. Miller, Computational Methods of Neutron Transport, Wiley (1984) and ANS (1993).
2. G.I.Bell and S. Glasstone, Nuclear Reactor Theory, Van Nostrand (1970).
3. A.F. Henry, Nuclear Reactor Analysis, MIT Press (1975).
4. M. Clark and K.F. Hansen, Numerical Methods of Reactor Analysis, Academic Press (1964).

14. Experimental and Operational Reactor Physics (PY14): (35 lectures)

S.No	Course content
	I. Experimental Reactor Physics (10 hrs)
1.	Source and power range neutron detectors; Neutron sources- requirement vis-à-vis reactor type-External localised sources in LWRs and FBRs - internal distributed spontaneous fission / photo-neutron sources in PHWRs. Different steps of initial start-up in different research and power reactors.

2. Moderator experiments-measurement of diffusion length, age, migration length. Exponential experiment-Alpha dieaway (decay) experiment. Subcritical multiplication experiments-Critical mass measurements.

3. Low power experiments at criticality for validation of reactor physics evaluations-Measurement of neutron flux-Thermal and fast-Activation analysis-cadmium ratio-General methods of flux measurement- foil/wire activation methods, Measurement of buckling, power peaking and power distribution.

4. Neutron spectrum unfolding; differential measurements for reaction rates.

5. Dynamic methods of reactivity evaluation Reactor Period measurements-Measurement of reactivity-control Rod Calibration-power run-down experiments-reactivity coefficients measurements –Temperature and void coefficients measurements. Dose and shielding experiments-cross-section measurements.

6. Reactor noise methods- Process parameter measurements using neutronics-coolant flow measurement with N-16 gamma signals- failed fuel detection using delayed neutrons and noble gas fission products.

7. **Critical Facilities:**

   Thermal – ZERLINA, AHWR-CF, PURNIMA (1,2,3) ZED-2

   Fast – GODIVA (US), ZEBRA (UK), ZPPR (US), MASURCA (France), BFS (Russian).

8. **Subcritical Facilities with source:** MUSE, YELINA, PURNIMA-SCF, AHWR-C with source.

II. Operational Reactor Physics (20 hrs)

1. First Approach to Criticality; low power physics experiments; control requirements; general control schemes (auto or manual control as the case may be); spatial power control; nominal operation, power rise schemes; set-back and step back (as applicable); Reactivity balance in operating reactors.

2. Thermal power estimation using secondary and primary parameters – station heat balance. Assembly/ Bundle power, channel power, Linear Heat Rating (LHR): operational and safety limits; Bundle power envelops in PHWRs.

3. Failed fuel detection – delayed neutron monitoring; Fission Product (FP) gammas and volatile-gaseous FPs Back ground activities in the coolant.

4. Research Reactors: APSARA/CIRUS/DHRUVA – application. FBTR operation and applications. KAMINI operation and applications

5. Power Reactors: Operation of 220 and 540 MWe PHWRs : Incore flux mapping system BWR (TAPS- 1&2), PWR / VVER , PFBR

Books Suggested:

1. Experimental Reactor Physics, A.Edward Profio, John Wiley and Sons.

15. Design Methods in Thermal and Fast Reactors including Computer Codes (PY15): (35 lectures)

S.No **Course content**

I. Thermal Reactors

1. Popular multigroup nuclear data libraries and their group structure.
2. Spatial heterogeneity in different thermal reactors. Wigner-Seitz cell approximation. Self shielding effects in space and energy. Neutron transport treatment. Computer codes MURLI and CLUCOP.
3. Fuel assembly heterogeneity and supercell concept. Neutron transport treatment. Computer codes –SUPERB, CLUB, CASMO. Analysis of plate fuel assemblies. Special treatment of burnable absorbers and control rods.
4. Treatment of hexagonal lattices, EXCEL, TRIHEX.
5. WIMS Methodology ; HELIOS Computer code
6. Generation of cell and assembly parameters as a function of burnup and boron concentration in moderator.
7. Core computations. Core follow up and refueling. Computer codes DIF3D, VENTURE and COMESH. Core simulation codes TRIVENI and COMETG.

II. Fast Reactors

1. Popular multigroup libraries and their group structure.
2. Treatment of slowing down and energy self shielding. Heterogeneity effects in absorber rods. Computer code COHINT.
3. Breeding ratio and its variation with core material geometry. Radial and axial heterogeneous designs. Oxide, carbide and metal fuel and their effect on core safety parameters.
4. Hexagonal geometry effects. Optimisation of blanket thickness. Sodium void reactivity effects. Fuel burnup modeling.
5. Fuel management schemes in FBTR and PFBR. Effects on breeding ratio and power distribution. Computation of peak linear heat rating from measured outlet temperature distribution.
6. Computer code FARCOB. Code system ERANOS.

Books suggested:

1. R.J.J. Stammler and M.J.Abbate, Methods of Steady State Reactor Physics Nuclear Design, Academic Press (1983).
2. Handbook of nuclear reactor calculations: Vols I-III, Yigel Ronen Ed. CRC Press, West Palm Beach, Florida (1986).

16. In Core Fuel Management (PY16): (25 lectures)

S.No **Course content**

1. General in-core fuel management schemes. Advantages and dis-advantages of on-line and batch fuelling. Initial and equilibrium core concepts.

   PHWR: Online fueling; refueling strategies; core burnup - power distribution optimization; time average and snap shot evaluations; theory of computer code TAQUIL. Average exit burnup. Core followup; theory of TRIVENI code. Channel Power Peaking Factor (CPPF). Rules of channel selection. Fuelling in PHWRs: (220 & 540) Discharged bundle data – Pu production & Pu-vector.

2. **BWR:** Initial fuel loading; equilibrium cycle Batch fueling concepts; different core loading concepts – checker board, out-in, sector symmetric. Cycle length and Haling principle. SDM demonstration. Control rod pattern. Power distribution optimization. Core followup computer code COMETG. Minimum Critical Heat Flux Ratio (MCHFR).
3. **PWR and VVER:** Initial loading, equilibrium loading. Boron poison management. Fuel enrichment change and use of burnable absorber. Departure from Nucleate Boiling Ratio (DNBR).
4. **AHWR:** Basic principles of fuelling
5. **HTR:** Basic principles of fuelling

suggested:

1. P. Silvennoinen, Reactor Core Fuel Management, Pergamon Press (1976).
2. R.G. Cochran and N. Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

BACK TO MAIN

GOVERNMENT OF INDIA

BHABHA ATOMIC RESEARCH CENTRE

M.Tech
(PROGRAM CODE: ENGG01)

SYLLABUS

Orientaion Course for Engineering Graduates and Science Post Graduates (OCES)

BARC Training School, Mumbai

HUMAN RESOURCE DEVELOPMENT DIVISION

MUMBAI 400085

PREFACE

The Department of Atomic Energy (DAE) has the multi pronged mandate of the utilisation of the power of the atom towards generation of power, development of advanced technologies, directed research in various scientific and engineering disciplines, production of radioisotopes for societal applications in medicine and agriculture and towards national security. In order to become self reliant and self sustaining in this high technology area, the need for generating highly skilled manpower and ensuring its continuous availability was indispensable. Thus in 1957, the BARC Training School (BARCTS) was established as a centre for in house training of professionals. These professionals today form the backbone of the Nuclear Power Programme. More than 9000 trainees have graduated from BARC TS over the last 61 years and provide the technological leadership in DAE for all its important programmes. Over the last five and a half decades, the BARCTS has grown into a model institute, recognised internationally as a school of excellence.

The academic activities of BARCTS are carried out by the Human Resource Development Division (HRDD) from its campus situated at Anushakti Nagar, well away from the hustle and bustle of Mumbai, nestling between wooded hills and sylvan surroundings, close to the BARC premises. This crucible of learning has been a focus of attraction to many a bright young talent, eager and willing to learn, guided and mentored by an academia drawn from the pool of experts available within DAE. Hailing from some of the best universities in India, they are nurtured with care and concern, by means of a holistic approach to training and personality development. A judicious mix of academics, practical training and soft skills training is imparted at the Training School and at the state of the art laboratories of BARC. A well equipped hostel with sports, recreation, and internet facilities provides the right environment needed for wholesome development. The lure of a professionally challenging career with opportunities for upgradation of skills, an objective merit recognition based career growth pattern and attractive compensation packages have attracted the best talents to BARCTS.

The BARCTS has two principle programmes, the One-Year **Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)** and the **DAE Graduate Fellowship Scheme (DGFS)**

Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)

OCES is the flagship programme of the BARC Training School and its affiliates. Under this scheme, engineering graduates from eight engineering disciplines- Mechanical, Chemical, Metallurgy, Civil, Electrical, Electronics, Instrumentation & Computer Science and Science Post-Graduates from Physics, Chemistry & Biological Sciences are selected and imparted a

rigorous one year training in the field of Nuclear Science and Technology. In addition to the above 11 disciplines, selected post graduate candidates from the Physics and Chemistry disciplines are also inducted into a course specifically designed for the purpose of providing a holistic training in all aspects of radiological safety. This course has been named as “Radiological Safety Engineering’ course.

The curriculum provides multidisciplinary training in topics relevant to the nuclear industry, frontier areas of science and technology and some super specialized areas. Training is imparted by adjunct faculty comprising the scientists and engineers working in various projects of DAE. In this manner, not only the objective of training but also the greater task of seamless and effective knowledge transfer from the expert to the acolyte is carried out successfully. The scheme also ensures the retention of the trained manpower within the Department thereby maximising the benefits of the training programme to the Department.

A total of about 150 courses in the above disciplines comprising more than 4000 lectures are delivered by more than 500 adjunct faculty members from BARC and other educational institutes during this period.

OCES Training Objectives: It involves one year of academic and training programme at the BARC Training School. The training programme aims to ensure that the selected candidates are provided with the necessary facilities and opportunities to acquire knowledge and develop skills for meeting the challenging technological goals of the country in the field of nuclear S&T. The training courses are organized in a structured manner as detailed below

- Foundation courses impart multidisciplinary training in the topics relevant to the nuclear industry.
- Core courses bring all selected candidates from different universities to the same or common level of understanding in the core subjects of the respective disciplines.
- Elective courses impart training in few specialized areas in respective disciplines.

OCES graduates are also eligible for the award of Post Graduate Diploma in Nuclear Science/Engineering & Technology of HBNI. After joining the DAE, the eligible OCES graduates can undertake one year project work leading to the award of M.Tech./M.Phil. Degree of the HBNI.

DAE Graduate Fellowship Scheme (DGFS)

In order to meet the requirement of highly specialised professionals in specific areas, DAE initiated the DGFS Programme for inducting engineers at MTech level in collaboration with the six IITs viz. Bombay, Delhi, Kanpur, Kharagpur, Madras, Roorkee and BHU in addition to some other elite institutes such as NIT Rourkela and ICT, Mumbai. The scheme strengthens the research-education linkage with premier institutes of the country in the areas of interest to DAE and provides useful synergy between the nuclear sector and the academia

Under this scheme, trainees selected for the OCES programme as well as one of the above institutes pursue the M.Tech degree under the sponsorship of DAE. On completion of the MTech degree, the candidates are absorbed into DAE as a Scientific Officer with advance increments. These Fellows then undergo a 4-month Orientation Course for DGFS Fellows (OCDF) after successful completion of M.Tech.

Orientation Course for DGFS Fellows (OCDF)

Several topics of interest to the Department do not form part of the MTech curriculum. To provide an exposure to such topics, the DGFS Fellows undertake a four months orientation course in the BARC Training School **(Orientation Course for DGFS Fellows- OCDF)** after successful completion of their MTech. Programme.

This document furnishes the course structures of all disciplines and syllabi of the courses conducted by the BARC Training School under each discipline.

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SYLLABUS

ENGINEERING SCIENCES

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REVISED CREDITS
FOR
COURSES IN ENGINEERING
SCIENCES

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (MECHANICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for PVP	EN610	60	6	250
2	Computational fluid Dynamics and Heat Transfer	EN611	50	6	200
3	Finite Element Method	EN621	30	4	125
4	Fracture Mechanics	EN622	40	4	150
5	Mechanics of Solids	EN624	40	4	150
	Core Total		**220**	**24**	**875**

ELECTIVES (MECHANICAL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Machine Design	EN711	25	2	100
4	Material Science in Nuclear Engineering	EN712	25	2	100
5	Multi-scale material modelling	EN715	30	4	125
6	Nuclear Emergencies	EN716	35	4	150
7	Reliability Engineering	EN718	25	2	100
8	Vibration	EN721	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CHEMICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25	2	100
2	Advanced Mass Transfer	EN604	25	2	100
3	Code design for PVP	EN610	30	4	125
4	Computational Fluid Dynamics and Heat Transfer	EN611	50	6	200
5	Nuclear Chemical Engineering	EN628	35	4	150
6	Process Dynamics and Control	EN634	45	6	200
7	Process Modeling, Simulation and Optimization	EN635	45	6	200
	CORE TOTAL		**225**	**30**	**950**

ELECTIVES (CHEMICAL) – Any 3 Courses - 9 CREDITS

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Material Science in Nuclear Engineering	EN712	20	2	75
4	Membrane Technology	EN714	35	4	150
	ELECTIVES TOTAL (APPROX)		**90**	**8-10**	**350**

	THEORY TOTAL	**535**	**62-64**	**2175**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 535; Total Credits: 106-108; Total Marks: 2775

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - METALLURGY

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (METALLURGY)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	2	75
2	Extractive Metallurgy	EN620	40	4	150
3	Mechanical Metallurgy	EN623	30	4	125
4	Nuclear Materials	EN628	50	6	200
5	Nuclear Metallurgy	EN629	30	4	125
6	Physical Metallurgy	EN630	40	4	150
7	Process Control & Instrumentation	EN631	25	2	100
		CORE TOTAL	**230**	**26**	**925**

ELECTIVES (METALLURGY) Any 3 Courses- 9 Credits

S.No.	Subject Title		Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Image processing and Machine Vision	EN710	30	4	125
4	Materials Characterization	EN713	20	2	75
5	Multi scale Material Modeling	EN715	30	4	125
6	Nuclear Chemical Engineering	EN628	35	4	150
7	Nuclear Emergencies	EN716	35	4	150
8	Welding Science & Technology	EN723	25	2	100
		ELECTIVES TOTAL (APPROX)	**90**	**8-12**	**350**

	THEORY TOTAL	**540**	**58-62**	**2150**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 540; Total Credits: 102-106; Total Marks: 2750

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (CIVIL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1	30	4	125
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2	30	4	125
3	Design Basis Hazards & Geotechnical Engg	EN621	40	4	150
4	Earthquake Engineeing & Structural Dyanmics	EN609	45	6	200
5	Finite Element Method	EN626	30	4	125
6	Mechanics of Solids	EN624	40	4	150
		Core Total	**215**	**26**	**875**

ELECTIVES (CIVIL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Struct Dynamics & Earthquake Engg	EN724	30	4	100
2	Construction Materials, Management & Quality	EN614	30	4	100
3	Safety & Reliability of Civil Engineering	EN722	25	2	100
4	Project Management	EN717	25	2	100
	ELECTIVES TOTAL (APPROX)		**80**	**8-10**	**300**

	THEORY TOTAL	**515**	**58-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 520; Total Credits: 102-104; Total Marks: 2600

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECRICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	20	2	75
2	Computer Based System Design I	EN612	25	2	100
3	Electrical Systems for Nuclear Power Plants	EN618	30	4	125
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**195**	**22**	**800**

ELECTIVES (ELECTRICAL) Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design II	EN702	25	2	100
2	Artificial Intelligence and its Applications	EN703	30	4	125
3	Computer Based System Design II	EN704	25	2	100
4	Digital Signal Processing & Image Processing	EN706	30	4	125
5	Image Processing & Machine Vision	EN710	30	4	125
6	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
7	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**525**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECTRONICS)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	4	125
2	Advanced Nuclear Instrumentation	EN605	40	4	150
3	Embedded & Computer Based Sys. Design	EN619	45	6	200
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**200**	**28**	**825**

ELECTIVES (ELECTRONICS) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Embedded Electronics Software	EN707	25	2	100
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**60-66**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 104-110; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (INSTRUMENTATION)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40	4	150
2	Computer Based System Design I	EN612	25	2	100
3	Modern Control Systems Design and Simulation	EN625	35	4	150
4	Reactor C&I and Human Machine Interface	EN636	40	4	150
5	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
6	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		EN639	**20**	**775**

ELECTIVES (INSTRUMENTATION) Any 3 Courses-- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	125
2	Computer Based System Design II	EN706	25	2	100
3	Digital Signal Processing & Image Processing	EN707	30	4	125
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**8-12**	**350**

	THEORY TOTAL	**525**	**54-58**	**2075**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-102; Total Marks: 2675

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25	2	100
2	Computer Graphics & Visualisation	EN613	35	4	150
3	Distributed Computing	EN616	45	6	200
4	Networking & Information Security	EN6627	40	4	150
5	Reactor Control Engineering	EN637	15	2	75
6	Software Engineering and Formal Methods	EN640	40	4	150
	CORE TOTAL		**200**	**22**	**825**

ELECTIVES (COMP. SCIENCE AND ENGINEERING) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Data Base Management System & Web Technology	EN705	30	4	100
3	Digital Signal Processing & Image Processing	EN706	30	4	125
4	Embedded Electronics Software	EN707	25	2	100
5	Feedback Control System	EN708	25	2	100
6	Image Processing & Machine Vision	EN710	30	4	125
	3 ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

FOUNDATION COURSES

EN501: Accelerator Physics and Technology

Basic Accelerator Physics (5)

- Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons;
- Ion sources.
- General equations of motion in a combined electric and magnetic field, beam rigidity; relativistic expressions, weak and strong focusing principle; condition for strong focusing.
- Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.
- General design of a cyclic accelerator.
- Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;
- Matrix techniques in beam optics; first order transfer matrix of dipole, quadrupole, transfer matrix of a drift space; quadrupole doublet;
- Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters
- Introduction of normal (room temperature) DC and pulsed magnets, construction features. Superconducting coils, magnets and their construction features.
- Momentum compaction; Phase stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.
- Synchrotron radiation sources; spectrum of emitted radiation; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators.

RF Linacs (12)

Introduction to Linacs

- Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.
- Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac
- Transit time factor and the energy gained in a linac.
- Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.
- General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature RF structures.

Proton Linac

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.
- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
- Introduction to Space charge effects.
- Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Accelerator Driven Systems & RF electron accelerators

Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.

Accelerator Technology (13)

General

- Material selection for Accelerator components
- Mechanical Design and fabrication issues; tolerances, surface finish, etc
- Thermal management in accelerator systems
- Alignment requirements of accelerator magnets and RF structures, methods and instruments for alignment and surveying in accelerators.

Ultra High Vacuum Systems

Basic concepts in Vacuum

- The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
- Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
- Basics of low pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, Sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.

Cryogenics Systems

Introduction to Cryogenic Engineering

- General and basics, Cryogenic properties, Basic cycles
- Large Cryogenic Systems for Accelerators

Cryogenic Equipments

- Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

References

1. Principles of RF Linear Accelerators, T. P. Wangler, (John Wiley & Sons Inc., 1998)
2. Introduction to Accelerator physics – Arvind Jain
3. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer, (John Wiley & Sons Inc., 1982)
4. An Introduction to the Physics of Particle Accelerators - M. Conte, W.W. Mac Kay.
5. Handbook of Accelerator Physics and Engineering - A. Chao, M. Tigner.
6. Particle Accelerator Physics (Vol 1 and Vol 2) - Helmut Widemann.
7. Principles of Charged Particle Acceleration – Stanley Humphries.
8. Fundamentals of Beam Physics - James Rosenzweig.
9. An Introduction to Particle Accelerators - E. J. N. Wilson.
10. Accelerator Physics - S. Y. Lee.
11. The Physics of Particle Accelerators, An Introduction - Klaus Wille.
12. The Principles of Circular Accelerators and Storage Rings - Philip Byrant.
13. Introduction to Vacuum Technology-Compiled by K.G. Bhushan, BARC

EN 502:Engineering Maths-I (15) (All Engg)

- Overview of arithmetic errors in computations
- Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
- Linear systems solutions by direct methods, iterative methods and acceleration techniques.
- Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
- Linear systems: Eigen values.
- Non -Linear systems: Newton-Rapson & Successive Approximation methods
- Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
- Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
- Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and
Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 503: Engineering Maths-II (20) (ME Group)

- Introduction to discretization methods and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations, wave equation
- Formulation of the matrix methods by equilibrium concepts (1D-heat conduction, 2D-truss and 1D-hydraulic flow examples).
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's methods, Piecewise approximations. Basis of Finite Element Method, energy principles in structural mechanics and principles of minimum potential energy, assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit methods.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.
- Finite element formulation for laminar and turbulent flows.
- Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
- Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
- Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
- Response Surface Method 2K+1, factorial design, 3k factorial design
- Monte Carlo Method
- Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Artificial Intelligence and Genetic Algorithm
- Artificial Neural Network
- Gram-Schmidtt Orthogonalization
- Transformation of matrix

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
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6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.
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14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 504:Engineering Maths-II (20) (MT)

Applications in Materials Science:

- Use of matrix in crystallography. Stereographic analysis, lattice correspondence, orientational relationship, applications to twinning and martensitic. transformations,
- Tensor analysis in phase transformation and deformation studies
- Analysis of diffusion data, Solutions of diffusion equations - error function and Eigen value analysis, Polynomial fitting of diffusion profiles.

Application in thermodynamics of metallurgical systems:

- Temperature dependence of thermodynamic quantities, graphical and analytical integration of Gibbs-Duhem equation. Introduction to database for thermodynamic tables
- Analysis and synthesis of phase diagrams, introduction to first principles calculations of phase diagrams with computer demonstration, cluster variation and Monte Carlo methods

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wilev, 1966.
2. Todd R.J. "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods.
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McCraw-Hill Book Co. 1983.
6. Rajaraman V,, "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C. "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis

1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B,, "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers. 1968.
11. Conte S.D,, "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo,McGraw Hill. 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G,, "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis". Addison Wesley, 1984.
15. Rajsekaran S,, "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987; •
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation' Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.-• •
19. Acton, "Numerical Methods That Work"
20. Forsythe et. al,, "Computer Methods for Mathematical Computations"
21. Forsythe et. al,, "Computer Solution for Linear Algebraic Systems"
22. Golub Gene H., "Matrix Computations"
23. Griffiths D. V., "Numerical Methods Engineers: A Programming Approach"
24. Williams P. W,, "Numerical Computation.
25. Strang G,, "Applied Mathematics"
26. Crank J,, "Mathematics of Diffusion"
27. Worked Examples in the Geometry of Crystals: MKDH Bhadesh
28. Materials Science & Technology, Vol.4; Rudman.

EN 505: Engineering Maths-II (20)(EE Group)

- Transforms: Laplace & solution to ODE, Bilinear & Z transforms, Discrete cosine transforms & compression, Entropy & Haufman coding for compression
- Solution of Matrix Differential Equation: Existence & uniqueness of solutions, Solution of Non-Linear continuous time state equation, Solution of Linear time varying continuous time state equation, Solution of linear time invariant continuous time state equations
- Basic Procedure for Designing Conservational Logic: Quine McCluskey method, Iterative consensus method, Design example
- Design of Sequential Circuit Using Sequential Machine Flow Chart: Sequential machine flow chart, Reading reduced dimension maps, Output function synthesis, Next state function synthesis, State assignment & design examples
- Counting Statistics and Error Prediction: Statistical models -Binomial, Poisson and Gaussian distributions, Application of statistical models: Error propagation, Optimization of counting experiments, Limits of detectability, Distribution of time intervals

References:

1. F R Grantmacher, "The Theory of Matrices", New York: Chelsea Publishing Co., 1960.
2. R Bellman, "Introduction to Matrix Analysis", II ed., New York, McGraw Hill, 1970.
3. E Kreyszig, "Advanced Engineering Mathematics, 5th ed., Wiley Eastern Ltd., 1985.
4. Paul R Halmos, "Finite Dimensional Vector Spaces", and New York: D Van Nostrand Co. Inc., 1965
5. Bajpei et.al, "Numerical Methods for Engineers and Scientists"
6. Dahlquist et.al, "Numerical Methods"
7. G Strang, "Applied Mathematics"
8. Golub Gene H, "Matrix Computations"
9. Numerical Methods for Scientists and Engineers, By H.M.Antia, Hindustan Book Agency,New Delhi.
10. Numerical Methods for Mathematics, Science and Engineering, Mathews(IInd Ed), Prentice Hall of India.

EN 506:Health Physics and Radiological & Industrial Safety (20)

Health Physics

Introduction

- Radiation sources, its interaction with matter and units**:** Natural and Induced radioactive sources,
- Units of radioactivity, half-life and decay constant, specific activity.
- Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter.
- Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given).
- Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given),
- Exposure-dose relationship, Bragg-Gray principle.

Biological effects, Radiation Protection and Regulation:

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Importance of radiation protection programme in DAE.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.

- Radiation protection philosophy,
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Principles of radiation detection and monitoring

- Basic operating principles ofa) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type ofRadiation monitors/Radioactivity measurement methods adopted for radiation protection should be taught.

Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management.
- Personal monitoring, area-monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures:

- Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper),
- Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation, Protective equipments

Nuclear Accidents, Emergency Preparedness and Management:

- Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

INDUSTRIAL SAFETY ASPECTS

Introduction:

- Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques

Hazards due to physical agents:

- UV and IR radiation, Lasers, Microwave radiation; noise, heat

Chemicals hazards:

- Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals

Evaluation:

- Instrumental methods, air sampling methods, liquid effluent monitoring

Occupational exposure limits:

- Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50

Handling, storage and control:

- Engineering control measures and safety features,
- Safety management techniques such as safety audit, Personal/ administrative control, and Medical control

Fire and explosion hazards:

- Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits,
- USNFPA Classification of Flammable/combustible liquids: flammable gases;
- Engineering safety for prevention of fire and explosion,
- Hazard area classification, selection of equipment, detection and extinguishing systems.

Hazard identification, assessment and control:

- Hazard identification: Concept of risk and Risk management
- Formal methods of hazard identification and assessment:
- Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies
- Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation.

Management of major hazard Installations:

- Plant Layout and Engineering Design Consideration
- Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic Releases,
- Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment,
- Emergency Planning Guidelines, Development of Emergency Plan

Health and safety regulatory aspects:

- Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate.
- EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

References:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute Of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment And Control; Vol-1, 1996 2 Edition, Frank P Lees.

EN 507:Material Science in Nuclear Engineering (EE) (20)

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction methods --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices.
- Material characterization techniques --- XRD, RBS, SEM, TEM, EDAX, XPS, IR and Raman Spectroscopy.
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials, mechanical properties and measurement techniques, strength and ductility, creep, fatigue and wear testing
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Reactor core materials, Zircalloys, Zr-Nb alloys --- fabrication, properties and applications in reactors
- Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels) --- fabrication, properties and applications.
- Chemistry of fuel materials: Production of Uranium, Plutonium and Thorium.
- Heavy water: Production process, purification, properties and applications.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)
2. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)
3. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)
4. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)

EN 508: Nuclear Fuel Cycle Technology(35)

An overview (1)

FRONT END

Mining, Milling and Associated Processing of Indian Uranium Resources(1)

- General Introduction
- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.

Case Studies (1)

- Jaduguda and Turamdih Uranium Ore Processing
- Tummalapalle Uranium

Metal Purification using Hydro-Metallurgical Processes (1)

- Process, Equipment, Quality control

Metal Production by Metallothermic Reduction Processes (1)

- Process, Equipment, Quality control

WasteManagement and Safety (1)

- Associated wastes, characterisation and management

BACK END

Reprocessing (4)

- Nuclear fuels and generation of Pu239 & U233
- Spent fuel management options.
- Characteristics of spent fuel (RR, PHWR, AHWR ,FBR&LWR).
- Reprocessing by PUREX -Head end operations, solvent extraction cycles including the conversion of nitrates to oxides.
- Reprocessing of AHWR and FBR spent fuels.
- Prevention of criticality in reprocessing plants.

Waste Management (3)

- Waste sources.
- Radioactive waste classification.
- Management of low and intermediate level wastes.
- Vitrification of high level liquid waste.
- Schemes for partitioning of high level waste including recovery of valuable fission products.
- Storage and disposal of radioactive wastes.
- Various decontamination techniques to address alpha bearing materials.

Instrumentation & Control (3)

- Measurement techniques for level, pressure, temperature, interface density and flow Instrumentation and control associated with transfer devices—steam jets, pumps and air lift pots
- Interlocks related to major equipments like pulse column, dissolver, evaporator, joule melter and ion exchange column
- Computerised data acquisition and control system

Radiation Monitoring System (2)

- Area monitoring instruments, stack monitors, criticality alarm systems, effluent monitors,PCW & steam condensate monitors
- Single line diagram for Class-4, Class-3 and UPS
- Earthing, cabling, lightening protection system, VF drives

Civil (1)

Design aspects of back end technology facilities- Design classification and seismic categorization, considerations for external events, Standards/codes for design

Metallurgy (2)

- Corrosion aspects and material of construction for reprocessing and waste management plants.
- Degradation modes of SS 304L in nitric acid.
- Welding techniques, quality assurance and special requirement for in cell equipment.

Mechanical (7)

- Spent fuel transportation- shipping cask design and regulatory requirement.
- Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
- Remote handling system in reprocessing.
- Automation in plutonium powder handling.
- Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
- Sampling system. Transfer devices and valves for radiochemical plants.

Features of Radiochemical Plant (7)

- Layout considerations and design philosophy for back end operation.
- Control of radiation exposure including shielding and barriers.
- Ventilation aspects and Off gas handling and treatment.
- Utilities requirement for back end.
- Mechanical design aspects of metallic and joule melter.
- Radiation shielding windows.
- Remotisation and remote handling in vitrification plants

EN 509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40)

Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulas gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

1. Wakil M.EI, "Nuclear Power Engineering", McGraw- Hill.
2. Strosal and Vapet, "Power Plant Engineering & Economics".
3. Lewis E.E., "Nuclear Power Reactor Safety", Wiley Inter Science.
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von-Nostrand, 1981.

Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time.Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
    - Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio, blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly
    - Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
    - Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination

References:

1. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors", Pergamon Press
2. Yevick J.G., "Fast Reactor Technology", Plant Design, M.I.T, Press.

Module 3:Advanced Reactor Concepts (6)

Introduction(1)

- Need for Advanced Reactors and in what way these are different from conventional reactor
- International initiatives – INPRO, GIF etc.
- Definition of sustainability and INPRO areas of sustainability
- Brief Description of the INPRO Guidelines and Methodology to Evaluate INES
- Basic principles, User requirements, Key Indicators, Allowable parameters etc.

Directions of Development in the World(1)

- GIF and other advanced reactor concepts

Indian Programme on Advanced Reactors and Associated Challenges (2)

- AHWR
- AHWR-LEU
- CHTR, IHTR, MSBR etc.

Reactor Physics Design Challenges(1) ADS and applications(1)

EN 510:Reactor Physics & Engineering (55)

Module 1 :Nuclear Reactor Physics (33)

Properties of Nuclei

Binding energy-formula and interpretation, nuclear forces, nuclear structure.

Fission Process

- Fission rate and reactor power
- Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
- Fissile, fertile and fissionable materials
- Fission product activity after shut down –decay heat.

Interaction of Neutrons with Matter

- Production of neutrons

Concept of microscopic cross section:

- Inelastic and elastic scattering

Variation of cross-section with energy

- Fast, resonance and thermal ranges
- 1/v law of neuron cross-section
- Resonance absorption, Doppler effect.
- Eta vs E curve conversion & breeding concept
- Thorium utilization

Diffusion of Neutrons
- Fick's law and its validity
- Steady state neutron diffusion equation
- Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.

Chain Reaction
- Four Factor formula
- Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
- Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,

Slowing Down Process
- Neutron slowing down
- Slowing down power/ moderating ratio of moderators
- Slowing down with spatial migration
- Fermi age concepts, migration length
- Multi zone reactors
- Ideas of reflectors/blankets, reflector savings, form factor.

Heterogeneous Reactors
- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

Reactor Kinetics
- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

Core Burn Up
- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

Neutron Poisons
- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

Reactivity Coefficients
- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Module 2: Reactor Engineering & Radiation Shielding (22)

Reactor Engineering (14)
- Introduction to reactor system & Indian Nuclear power programme
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems
- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR),
- Fast reactors;
- Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
- Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.

Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.

- Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
- Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.

Nuclear Fuel Cycle (2)
- Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
- Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
- Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
- Advanced fuel cycles

Radiation Shielding (6)
- Source of various neutron & Gamma radiation within the reactor system
- Attenuation of neutrons & gamma rays

- Dose rates for gamma rays for various source geometries
- Buildup factors for homogeneous & multiple layer shields
- Removal diffusion theory for neutron attenuation
- Coolant activation, heat generation
- Streaming of radiation through gaps & void in the shield

CORE COURSES

E601: Advanced Chemical Reaction Engineering (25)

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
- Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
- Reactor design: counter-current moving bed reactors, fluidized bed reactors.
- Advanced topics in reaction engineering- three phase reactors, photochemical reactors, integral reactor-separators, complex systems.
- Examples from nuclear chemical engineering.

References:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

EN602: Advanced Electrical Engineering Design-I (20)

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Methods, Finite Element Methods, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Methods: MFL Technique, Eddy current Technique, Remote Field eddy current Methods. (5)

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronics Circuit Design Techniques (30)

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Programmable Logic Devices: PLD, CPLD and FPGA, Technology architecture (4)
- Hardware Description Languages: VHDL – language details (6)
- Digital Circuit Design using VHDL: Design methodology and optimization, Design of a multiplexer, counter, finite state machine etc., test bench (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. Actel HDL Coding Style Guide, 2009 edition, Published by Actel Corporation, Mountain View, CA 94043. Free softcopy available on Actel website (www.actel.com).
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles

10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25)

- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Rate based approaches for design.
- Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors.
- Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors.
- Adsorption and ion exchange equipment.
- Membrane separation and other advanced mass transfer processes.
- Process intensification approaches.

References:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)

EN605: Advanced Nuclear Instrumentation (40)

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and methods of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems ,Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.

Reactor Instrumentation:

- Fundamental Considerations / Philosophies, requirements, and scope.
- Measurement ranges of reactor neutron flux and considerations
- Types of neutron detectors FC,10B, BF3, CIC and SPND for in-core and out-of-core use.
- Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR,LR, Lin, LinR and ρ)
- Noise reduction techniques, considerations and practice: EMI Interference, Grounding and shielding.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma Monitors, Neutron Monitors, Contamination Monitors, including networking and RADAS.

References

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

EN606: Advanced Operating Systems (25)

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Processs Subsystem : Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem : Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Interprocess Communication : Message Queues, Shared Memory, Semaphores, Mailboxes, Sockets, Fundamentals of Socket Programming, Remote Procedure Calls [1][6]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing, Features of distributed Unix, Logical time, Concurrency Control [1][5]
- Unix Shells: Unix Shell Commands & Fundamentals of Shell Programming [1][2]

- Linux: Packaging and Distribution, Loaders, Virtual Terminals, Internal and External Drivers, Threads, Interfaces, X Window System, Hard Disk Partitions, File System Enhancements, Extended File Systems, Virtual File System, System Tuning. [3, 9, 10]

References:

1. The Design of Unix Operating Systems : Maurice J. Bach, Prentice Hall
2. Unix Programming Environment : Kerninghan & Pike, Prentice Hall
3. Linux Internals : Rubini, O'Reilly & Associates
4. Operating Systems Concepts: Silberschatz, Galvin, John Wiley
5. Distributed Operating Systems : Tanenbaum, Prentice Hall
6. Unix Network Programming : W. Richard Stevens, Prentice Hall
7. Xlib Programming : Adrian Nye, O'Reilly & Associates
8. Inside Windows NT , David A. Solomon, Microsoft Press
9. Demblon & Spitzner, http://learnlinux.tsf.org.za/courses/build/internals/internals-all.html
10. Tigran Aivazian, http://www.faqs.org/docs/kernel_2_4/lki.html or http://students.mimuw.edu.pl/SO/Linux-doc/LinuxKernel-2.4.pdf

EN607: Applied Process Instrumentation (40)

- Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables:
- **Flow**: Differential pressure flow elements: Orifices , venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters. Applications and limitations of various flowmeters. Two phase flow measurements.
- **Pressure**: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.
- **Level**: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
- **Temperature**: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
- **Temperature transmitters**- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
- **Analytical Instrumentation**: Conductivity, pH, ORP and Turbidity measurement.
- **Other Measurements**: Relative humidity; viscosity and density measurement
- **Control valves:** Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
- **Instrument Impulse lines and instrument fittings**: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
- **P & I Diagrams, loop and hook up diagrams:** P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

EN 608 Civil Engineering Design of Concrete and Steel Structures

EN 608.1Civil Engineering Design of Concrete and Steel Structures-I (30)

Introduction to various structures of nuclear facilities Classification of structure and design basis

Radiation protection objectives, defense in depth, safety functions, safety classification, seismicclassification, quality classification, design classification, design for natural and man induced events.

Design Loads:

- Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
- Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
- Severe Environmental Loads: operating basis earthquake,severe windincluding gust effect and aerodynamic instability, design basis flood load,tsunami.
- Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind- induced missile

Design of RC structures:

- DesignofRC structures as per IS456,AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 ,designloadcombinations,design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies

Design for shrinkage, creep & heat of hydration:

Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies..

Foundation design

- Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
- Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
- Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

EN 608.2 Civil Engineering Design of Concrete and Steel Structures-II (30)

Introduction to Prestressed Concrete structures

Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.

Design of lined and unlined containment structures

Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.

Design of steel structures of nuclear facility

Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections,design of embedded parts and anchor boltsas per AERB and ACI standards, case studies.

Design of water-retaining structures

Design of overhead and underground tanksusingun-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.

Design of cooling towers

Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

References

1. IS 456 (2000) "Plain and Reinforced Concrete – Code of Practice ".
2. ACI 318 (2014) "Building code requirements for structural concrete".
3. ACI 349 (2013) "Code requirements for Nuclear Safety related concrete structures".
4. RCC-G "Code of Practice for Design of Prestressed Nuclear Containment Structures". 5. ISO 14000
6. Raju, N. K. (2006), "Prestressed concrete", Tata McGraw-Hill Education.
7. ACI 207 (1995) "Effect of restraint, volume change and reinforcement on cracking of massive structures".
8. Bowles, J. E. (2001) "Foundation analysis and design", Tata McGraw-Hill Education.
9. Rao, N.S.V.K. (1988),"Vibration analysis & foundations dynamics", Wheeler publishing.
10. IS 2974-1, 1984,"Code of practice for design and construction of machine foundations".
11. Arya, S.C., Oneill, M.W. and Pincus, G. (1979), "Design of structures and foundations for vibrating machines", Gulf Publishing Co.
12. Manohar, S. N. (1984) "Tall Chimneys design and construction", Mcgraw-Hill Book Comp.
13. ANSI/AISC N690 (1984), American and National Standard – Nuclear facilities, "Steel safety related structures for design fabrication and erection".

EN 609 Earthquake Engineering and Structural Dynamics(45)

Introduction to Seismology

- Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA),Design Basis Earthquake,Concept of

Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra

- Seismic instrumentation for micro-earthquake and strong motions.

Structural Dynamics

- Introduction to dynamic loading, different types of dynamic loadings, concept of damping,derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
- Single degree of freedom of system (SDOF)–undamped& damped system, free & forced vibration; Response to harmonic and impulse loading,concept of transmissibility and vibration isolation,estimation of damping of structural system using free & forced vibration approach;response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
- Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
- Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies)& eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
- Introduction to dynamics of continuous system

Seismic Response Analysis of Structures

- Seismic response analysis using response spectrum and time history approach
- Modal superposition method, Modal combinations and spatial combinations, missing mass correction
- Time history analysis using direct time integration,
- Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction

Random vibrations

- Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.

Special Seismic Design Considerations

Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain, curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures;Seismic Design Optimization, Principles of performance based design, dynamic response control techniques such as base isolation, dampers etc.

Seismic Requalification of Existing Installations

Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection, review basis ground motion, evaluation of seismic margin capacity, retrofitting.

Case Studies

Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear installments.

References

1. Chopra, A.K. (2007), “Dynamics of structures: Theory and application to earthquake engineering”, Prentice Hall.
2. Clough, R. W. and Penzien, J. (1993). “Dynamics of structures”, McGraw Hill, Inc.
3. Mario Paz and William Leigh (2006), "Structural Dynamics-Theory and Computation", Springer.
4. Thompson, W. T. (1972),“Theory of Vibrations with Applications” Prentice-Hall, Englewood Cliffs.
5. ASCE 4-98 (1998), “Seismic Analysis of Safety related Nuclear Structures and Commentary on standard for seismic analysis of safety related nuclear structures”.
6. AERB/SG/S-11, “Seismic Studies and Design Basis Ground Motion for NPP Sites”.
7. IAEA SAFETY STANDARDS SERIES No. NS-G-3.3 (2002), “Evaluation of Seismic Hazards For Nuclear Power Plants”.
8. IS 1893-1 (2002), “Criteria for Earthquake Resistant Design of Structures”.
9. IS 13920 (1993),“Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces”.
10. Dowrick D.J., “Earthquake Resistant Design”
11. Park and Pauley, “Reinforced Concrete Structures”
12. Pankaj Agrawal, Manish Shrikhande, (2006), Earthquake Resistant Design Of Structures
13. AERB monograph, (2008), SEISMIC SAFETY OF NUCLEAR POWER PLANTS

EN 610: Code Design for PVP (60)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
- Thick cylinder and sphere and derivation of Lame’s equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin- walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
- Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material

and allowable stresses. Design of saddle supports.

- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 and Div.2.
- Difference between metallic pressure vessel and FRP pressure vessels

Nuclear Pressure Vessels and Piping (30)

- Monotonic and Cyclic Stress-Strain Curve, Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Failure modes of pressure vessels, Ratchetting and shakedown.
- Organization of Boiler and Pressure vessel Sec. Ill code. Safety classification and Criterion for selection of ASME sec. Ill classes. Design loadings and service loadings as per NCA 2140.
- Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Definition of B, C and K stress indices.
- Design of Nuclear piping as per Sec. Ill div.1. Design rules for standard support as per NF 3400, Design rule for piping support - NF 3600.
- ASME code rule for component support
- Design rule for Plate and shell- Type support as per NF 3200, Design rule for Linear-type support - NF 3300.
- Design rule for component support - NF 3500, Core support structure Design - NG 3300.
- Fracture Toughness requirements for materials for pressure vessels, pipings and boltings.
- Failure Analysis Diagram.
- Protection against Nonductile Failure - Appendix G, Basis of Low Cycle fatigue Design. Fatigue evaluation of vessels.
- Strain concentration factor ' Ke', Local strain approach: Neubar and Zarka rule, Elastic and elastic-plastic fatigue analysis of nuclear pipings, Leak-Before-Break Design Concept.
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec. Ill.
- NDE requirements, Examination of welds, Acceptance standard.

References:

1. Harvey J.F., “Pressure Vessel Design”, CBS Publication
2. Brownell L.E., and Young E.D., “Process Equipment Design” Wiley Eastern Ltd., India
3. ASME” Pressure Vessel and BoilerCode”, Sec. VIII, Div. I and Div. II, 1985
4. American StandardCode for Pressure Piping”, - B31.1, 1972
5. American Standard Code for Pressure Piping”, - Petroleum, Refinery Piping, B31.3, 1972
6. “Standard of Tubular Exchanger Manufactures Association”, 7th Edition, 1988.

EN 611: Computational Fluid Dynamics & Heat Transfer (50)

Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):

- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme
- Laminar Boundary Layer and Forced Convective Heat (5):
- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
- Convective heat transfer for internal and external flows
- Low and high Prandtl number limits and different thermal boundary conditions
- Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer (5):

- Reynolds decomposition for turbulence
- Prandtl's mixing length theory, Mixing length models
- Structure of turbulent boundary layer over flat plate and through circular cylinder
- Calculation of friction factor and drag coefficient
- Analytical and semi-analytical correlations for calculating heat transfer coefficients
- Analogy between heat and momentum transfer

- Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
- Turbulence Modeling:
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
- Reynolds stress models: algebraic and differential models
- Low Reynolds number models
- Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
- **Natural Convection (3):**
- Basic Equations of natural convection
- Boussinesq approximation
- Derivation of Dimensionless groups from basic equations
- Analytical approximations
- Numerical solution of approximate equations

Numerical Solution of Complete Fluid Flow and Energy Equation (10):

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation
- Streamfunction-vorticity-temperature formulation
- Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
- Primitive-Variable (P-V-T) formulation
- Pressure velocity coupling for incompressible flow:
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
- Simple grid generation techniques for structured grid:
- Elliptic, parabolic and hyperbolic equation method
- Grid adaptation
- Domain decompositions in CFD and heat transfer
- SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer (12):

- Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
- Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.
- Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
- low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
- Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
- Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.
- **Heat Transfer With Phase Change (10):**
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
- Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model)
- Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)
- Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
- Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
- Critical Flow: Models for single – phase and two-phase critical flow.

References for CFD:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.

14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor &Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

EN 612: Computer Based System Design- I (25)

Hardware Design

- Overview of microprocessors and peripherals: 8086, 68000, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications
- Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL)
- Case Study: Design of a single board computer with shared memory interface, I/O board design using ADC, DAC etc with emphasis on signal conditioning and isolation
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues

EN 613: Computer Graphics and Visualization (35)

- Introduction overview, Graphics software/hardware and types of graphics applications (1)
- 2D/3D Geometric Transformations, Affined transformations-Translation, Rotation, Scaling, Shear and reflection. (3)
- Homogeneous coordinates, composite transformations, rotation with qutenion, current transformations and matrix stacks. (3)
- Two dimensional viewing 2D viewing – window, viewport, viewport transformations, clipping operations, line clipping algorithms – Cohen-Sutherland, Liang-Barsky, polygon clippimg algorithm – Sutherland-Hodgman. (4)
- Three dimensional graphics – Planer geometric projections – parallel and perspective, Mathematics for projections, classical three-dimensional viewing, specifying views, viewing transformations, 3D clipping operations. (4)
- Hidden surface removal, object space and image space approach, back face culling, z-buffer algorithm, LOD.(2)
- Illumination and shading – Basic illumination models, light sources, material properties, polygon shading methods – flat, gouraud and phong shading, ray tracing methods. (2)
- Color - Color perception, color models – RGB,CMY,HSV (1)
- Visual Realism – Depth cuing, texture mapping, transparency, shadow, steropsis. (2)
- Curves and surfaces – Representation of curves and surfaces, Algebric and geometric form, Blending functions, interpolation, Hermite, Bezier, B-spline curves and surfaces, Rational polynomials, NURBS (5)
- Modern Graphics Architecture – Graphics Pipeline, GPU, PCI Express (2)
- Case Study – Using OpenGL (3)
- Scientific Visualization – Introduction, Geometry (Structured & Unstructured Grids), Data Representation (Scalar, Vectors), Volume Rendering (Marching Cubes, Ray Casting) (3)

EN 614 Construction Materials, Management and Quality Assurance (30)

Construction Materials

- Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
- Reinforcement: Passive and active (Prestressing)
- Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
- Paints
- Water-proofing materials & membranes

Shuttering/Formwork

Design philosophy, different design requirements, climbing shutter design, slip form work.

Prestressing system

Cable ducts, anchorage and grouting, qualification of Prestressing system

Quality Assurance (QA)

- QA in Civil Engineering design
- QA in materials
- QA in construction
- QA in operation & maintenance
- Inspection during construction, Regulatory inspection

Construction Procedure & Construction Safety

- Dewatering, rock excavation, consolidation grouting

- Construction safety, Job Hazard Analysis.

Contract Management

Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication

References:

1. Singh, K. A. N."ISO 9000-Quality Systems", Dolphin books, New Delhi.
2. Quality systems requirements (QS 9000) – Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 3rd edition
3. Quality system assessment (QSA) Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 2nd edition
4. CPWD Works Manual (2012), Central Public Works Department, Government of India, Published by DIRECTOR GENERAL, CPWD, NIRMAN BHAWAN, NEW DELHI-110 011.
5. Manual of Internal Inspection/DAE Works Procedure (2010), Department of Atomic Energy, Government of India.
6. ATOMIC ENERGY (FACTORIES) RULES (1996), Atomic Energy Regulatory Board, Government of India.

EN 615: Corrosion (15)

- Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables, composition and heat treatment. (3 Lectures)
- Forms of corrosion: uniform attack; corrosion rate measurements, Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion, low temperature sensitization, corrosion of weldments; stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen embrittlement, hydrogen attack, corrosion fatigue; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, failure analysis, specification tests, advanced methods for on-line corrosion monitoring. (7 Lectures)
- General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification. (1 Lecture)
- Corrosion in the nuclear industry – Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. corrosion in fluoride and ammonia containing environments; liquid metal corrosion. low alloy steels, stainless steels and Ni and Cu base alloys, protective magnetite formation on carbon steel, stress corrosion cracking of stainless steels and nickel base alloys. high temperature oxidation and hydriding of zirconium alloys, materials for fast breeder reactor system. Effects of radiation on corrosion (4 Lectures).

References:

1.Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. Corrosion – L.L. Shrier (Ed.) Vol.I & II, 1963.
5. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
6. Modern Electrochemistry, Vol. 1 & 2 – J. O.M. Bockris and A.K. Reddy
7. Corrosion of Stainless Steels – A.J. Sedricks.
8.Stress Corrosion Cracking – Materials Performance and Evaluation – Ed. Russel H. Jones, ASM Int., 1993
9. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN 616: Distributed Computing (45)

Advanced Computer Architecture

- Advances in CPU Architecture
  a. Advancements in CPU architecture – Dynamic Instruction level parallelism, Branch prediction, register renaming
  b. Static instruction level parallelism - EPIC, VLIW
  c. Hyperthreading
- Multi core architectureAdvances in Memory
  a. SDRAM, DDR, DDR-2
  b. Registered ECC, FB-DIMM
  c. CPU – Memory Interfacing techniques - FSB, Hypertransport, Quickpath
- Advances in I/O interfaces
  a. Shared I/O bus
  b. Switched I/O fabric
  c. Serial and parallel I/O bus
  d. Case studies - PCI, PCI-X, PCI-Express, PCI-Express Gen2
- Advances in Interconnect techniques
  a. Shared and switched networks
  b. Interconnect fabrics

c. Approaches for improving interconnect performance
d. Case studies – Ethernet, Infiniband, SCI

- Cache

a. Associative, Direct mapped
b. Write through, Write back
c. MESI
d. Shared caches

- Advances in storage systems

a. Direct attached storage, Network attached storage, Storage Area Networks
b. File level and block level accesses
c. Storage protocols
d. Case studies - ATA, SATA, SCSI, SAS, Fiber channel
e. Case studies - FC, iSCSI, iSER, SRP

Parallel Computing

- Introduction to High Performance Computing

a. Need for HPC
b. Applications of HPC
c. HPC Overview – Conventional Supercomputers, Parallel Computers, Classification (SISD, SIMD, MIMD)

- Pipelining, Vector processing, SIMD

a. Pipeline, Speedup and Efficiency of pipeline
b. Pipeline stalls, out of order execution
c. Techniques to improve pipeline efficiency
d. Superscalar, Superpipelined, VLIW, EPIC architecture
e. Vector processors, vector instruction sets, registers

- MIMD Architecture

a. Classification of MIMD machines
b. UMA, NUMA, CC-NUMA, COMA, NORMA

- Interconnection networks and topologies

a. Interconnection Concepts – Bandwidth, Latency, Network Diameter, Bisection Width, Node degree, Static and Dynamic Networks
b. Various topologies – Ring, Hypercube, Torus, Mesh, CLOS, Fat tree etc.

- Current Parallel Architectures

a. Parallel Vector processor
b. Symmetric Multiprocessors
c. CC-NUMA
d. Massively Parallel Computers
e. Clusters of workstations

- Clusters

a. Classification of clusters
b. Cluster software
c. File systems for clusters

- Software concepts of High Performance Computing

a. Parallelism – Algorithmic, Geometric, Event, Data
b. Granularity – Coarse and Fine grains
c. Speedup, Efficiency, Amdahl's and Gustaffson's Laws

- Parallel Programming Models

a. Shared Variable Model
b. Message Passing Model
c. Threads Model
d. Data parallel Model

- Design of parallel algorithms

a. Data dependencies
b. Data partitioning
c. Communication patterns
d. Synchronization
e. Load balancing

- Parallel Programming Environments

a. Parallel Languages
b. Parallel Extensions to Sequential Languages
c. Parallel APIs – MPI, OpenMP

- Parallelization of example programs – Dot product, Matrix Multiply, etc. at the pseudo code level
- Message Passing Interface (MPI)

a. Introduction to MPI
b. MPI constructs
c. Example programs in MPI

- Benchmarking
- Case studies – ANUPAM series of parallel computers

Grid Computing

- Introduction to Grid Computing
  a. Evolution of Grid Technology comparison with contemporary technologies,
  b. Issues of virtualization, events that have lead to grid computing, client-server, peer-peer, operating system perspective,
  c. Overview of Grids: Formal definition of Grids - how do they work?
  d. How are they different from clusters? Computational Grids, Data Grids, Production Grids worldwide - Applications of Grid.
- Components of Grid
  a. Grid Security- concepts of single sign on, How the security requirements are met?
  b. Concept of Digital certificate- How RSA works? - Working of Kerberos
  c. Concepts of Myproxy services
- Grid Resource management
  a. Issues in Grid Resource management
  b. Abstract model for Grid Resource Management
- Grid Scheduling
  a. Issues in Grid Scheduling
  b. Taxonomy Of Grid Schedulers
  c. Resource Discovery issues
- Visualization and interactivity in Grids, High Performance Computing in Grids- Grid enabled MPI – MPI-G2
- Grids Services
  a. How are they different from Web services?
  b. Concepts and their implementation
- Data Management in Grids
- Information services- Building information services in Grids
- Grid Portals, Their Purpose, Issues in Portal design, discussion on portlets
- Grid Workflow
  a. Concepts
  b. Taxonomy of Grid Workflow
- Semantic Grids
- Virtualization
  a. Concept
  b. Its utility in Grid Computing
- Grid Enabling Applications
  a. Issues
  b. Implementations
- Discussion about GRID standards
  a. OGSA
  b. OGSA-DAI
- Comparative study of different Grid Middlewares
  a. Lacuna in current Grid Architectures
  b. Grid as operating system of operating systems
- Case study of Middlewares:
  a. GT4,
  b. Glite
  c. DAE Grid
- Future of Grids - Concepts of Cloud Computing

References

1. Advanced Computer Architecture, Kai Hwang
2. Scalable Parallel Computing, Kai Hwang, Zhiwei Xu
3. Introduction to Parallel Computing, Ananth Grama, George Karypis, Vipin Kumar and Anshul Gupta
4. High Performance Computing – Paradigm and Infrastructure, Laurence T.Yang, Minyi Guo
5. Storage Networks Explained, Ulf Troppens, Rainer Erkens, Wolfgang Muller
6. Computer Organization and Architecture: Designing for Performance, William Stallings
7. Grid Computing – Making the Global Infrastructure a Reality, Fran Berman, Geoffery Fox, Anthony J. Hey
8. The Grid2 Blueprint for a new Computing Infrastructure, Ian Foster, Carl Kesselman
9. Grid Computing for developers, Silva
10. Current Journal Articles in the area of Parallel Computing, Computer Architecture and Grid Computing

~~EN 617~~

EN 618: Electrical Systems for Nuclear Power Plants (30)

- Interaction of Nuclear Power Station With The Grid Number of evacuation lines; Optimum size of NPP in grid; Brief introduction to Power System Analysis - Short circuit, load-flow and stability studies, Tariff and Capacity factor.
- Ehv Switchyard Design Switching schemes; Clearances; Com parison between types of svvitchyards; Brief introduction to equipments in switchyard and their functions; Lightning arresters and insulation co-ordination; Lightning protection.

- Protection Line protection; Generator protection; Transformer protection; Motor protection.
- Selection of Transformers Accessories; Types; Specifications and testing; Voltage regulation calculations.
- Selection of MV & LV Switchgear Types; specifications and testing, MCCS; Distribution boards; Generator circuit breaker; ELCB.
- Motors In NPP Types of motors; Radiation withstand requirements; Performance requirements.
- Station Auxiliary Systems of NPP Class 1, 11, Ill and IV systems classifications; Nature of electrical loads and supply voltages; Effect of voltage variation on Electrical equipments and remedial measures; Emergency transfer system; Load shedding scheme; Auto transfer schemes; synchronizing schemes.
- Class 1 e requirements Cabling, lighting & grounding Specific requirements for safety related electrical equipments & systems in NPR Cabling, Lighting, Grounding systems in NPP; Bus ducts. Introduction to seismic qualification of electrical equipments., Electrical system control from Control Room. Introduction to []G sets, UPS & Batteries.
- Billing and metering scheme for a typical NPP. Introduction to brushiess and static excitation systems for Generators. Introduction to SCADA systems.

References:

1. Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity :.CBProblems and Remedial Measures. IAEA Report - Technical Reports Series No. 271.
2. Elements of Power System Analysis - W.D. Stevenson
3. Electrical Transmission & Distribution Hand Book - Westinghouse Electrical Co., USA
4. Protective Relays - Application Guide, GEC Measurements.
5. Manual on Layout of Substations - CBIP, New Delhi
6. The J & P - Transformer Book
7. The J & P - Switchgear Book
8. Utilization of Electrical Energy - E. Openshaw Taylor
9. Cabling - Siemens Hand Book
10. Illumination Engineering Society - IES Lighting Hand Book
11. Modern Power Station Practice - Volume D - Electrical System & Equipment, British Electrical International.
12. Standard Hand Book for Electrical Engineers - Donald G. Fink and H. Wayne Beaty
13. IEEE-80 - IEEE Guide for Safety in AC Substation Grounding
14. IEEE-308 - Criteria for class 1E Equipments for Nuclear Power Generating Stations
15. IEEE-323 - Qualifying class 1E Equipments for Nuclear Power Generating Stations
16. Indian Nuclear Power Programme with PHWR - Published by Directorate of E & P A, NPCIL, Bombay
17. IS-3716 - Application Guide for Insulation Coordination
18. IS-2309 - Code of Practice for the Protection of Buildings and Allied Structures Against Lightning
19. Handbook of Batteries and Fuel Cells - McGraw Hill Book Company

EN 619: Embedded & Computer Based System Design (45)

Module I [22]

Part A - Microprocessor based Design [10]

- 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
- Introduction to Microcontrollers and comparison with Microprocessors
- Introduction to DSP Processors

Part B [12]

- ARM processor: architecture details and introduction to programming
- Board level buses: I2C and SPI
- Introduction to USB

Module II [23]

Part A – Computer based hardware design [8]

- Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
- Industry standard bus systems: ISA, PCI, VME: Mechanical, electrical, functional and procedural specifications
- Multi processing, bus arbitration and Plug and Play
- System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
- Design Case Study:
- I/O Board design, bus interface (ISA, PCI) FIFO and shared memory interfaces.

Part B - Computer Communication and Networks [7]

- Overview of asynchronous and synchronous communication standards
- Encoding (NRZ, Manchester),
- Ethernet, Industrial networks, Field Bus, CAN bus
- Networking hardware: Cables, Hubs, switch and routers.

Part C - Software development for embedded and PC based systems (8)

- Basic RTOS concepts
- C programming for ARM based applications
- Programming for PC based systems:
  - Interface between applications & device drivers
  - Windows: Programming of I/O, ISR, DMA

References:

1. Computer Networks. By: A.Tanenbaum

2. Principles of Communication. By: Taub and Schilling.
3. Microprocessors and Interfacing. By: D.V.Hall
4. CAN Application Note: Robert Bosch GmBH
5. Microcomputer System 8086/8088 family- Architecture, Programming and Design.

Yi -Cheng Liu & Glenn.A.Gibson.

6. The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486 and Pentium series: Architecture, Programming and Interfacing. By: Barry.B.Brey.
7. The Scientist and Engineer's guide to DSP. By: Steven.W.Smith
8. High speed digital design: A handbook of black magic. By: Howard Johnson & Martin Graham
9. Interference control in computer and microprocessor based equipment. By: Michel Mardiguian
10. Interfacing to the IBM Personal Computer. By: Lewis C. Eggebrecht
11. PCI bus system architecture – Mindshare publication
12. VME bus standard document
13. USB complete. By: Jan Axelson
14. ARM System Developer's Guide. By: Andrew Sloss, Dominic Symes, Chris Wright
15. Designing Embedded Hardware. By: John Catsoulis

EN 620: Extractive Metallurgy (40)

Principles of Metallurgical Thermodynamics (15)

- Thermodynamic Functions: Enthalpy, Entropy, Free Energy, Chemical Equilibria
- Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Phase Diagrams
- Solution Thermodynamics, Integral and Partial Molar Thermodynamic Properties
- Experimental Methods- Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.
- Computation of predominance area diagram and Phase diagrams

Kinetics(5)

- Principles of Chemical Kinetics, Homogeneous Reactions, Effect of Concentration, Effect of Temperature
- Theory of Reaction Rates, Heterogeneous Reactions, Reaction Models, Mass Transport Phenomena, Heat Transport Phenomena.

Process Metallurgy (25)

- Methods of attaining High Temperatures,Measurement of Temperature,
- Vacuum Metallurgy Principles and Equipments,
- Process Metallurgy of Rare and Refractory Metals,
- Resources of Special Metals, Beneficiation Methods, Physical, Chemical, Separation Methods, Halide Metallurgy, Vacuum Metallurgy, Electro Metallurgy, Reduction Processes, Refining Processes, Ultrapurification Processes,
- Preparative aspects of Special Materials and Alloys,
- Advanced Materials Processing Techniques,
- Reprocessing of irradiated nuclear fuels, Process Metallurgy of - Uranium, Thorium, Plutonium, Beryllium, Zirconium, Hafnium, Niobium, Tantalum, Rare Earths.

EN 621: Finite Element Techniques (35)

- **Introduction to FEM:** Weighted residual method, Galerkin's methods, Weak form formulation, Piecewise approximations. Basis of Finite Element Method, Variational principles, energy principles in structural mechanics, Element libraries 5
- **Element shape functions**: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements. 15
- **Bar element:** Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss
- **Beam element:** Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- **2D plane elements** – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- **2D isoparametric formulation** – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature.
- **Incompatible displacement model**: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements.
- **Introduction and Application to 3D elements:** Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Plate bending elements: Thin and Thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration

- **Shell element**: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking.
- **Introduction to Nonlinear problems:** Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method
- **Finite element applications for design**:Finite element modelling and discretization criterion, h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

References:

1. **Bathe K.J., Finite elemen**t procedures in engineering Analysis, Prentice Hall of India, 1990
2. Cook R.D., D.S. Malkus and M.E. Plesha, Concepts and Applications of finite element analysis, John Wiley, 2000.
3. Reddy J.N., An Introductions to Finite Element Method, 4th Edition, McGraw Hill, 1993.
4. Seshu P., Finite Element Method, Prentice Hall of India, New Delhi, Fourth printing, 2006.
5. Zeinkiewicz, O.C., and K. Morgan, Finite elements and approximation, John Wiley, 1983.
6. Zeinkiewicz, O.C., and R.L. Taylor, The Finite Element Method, Vol. 1 & 2, Tata McGraw Hill.
7. M. Asghar Bhatti, Advanced Topics in Finite Element analysis of Structures, John Wiley, 2006.

EN 622: Fracture Mechanics (40)

Linear Elastic Fracture Mechanics (5)

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks and concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture
- Superposition of K
- Plastic zone correction - Irwin's approach
- Basic design principles in LEFM
- **Plane stress vs. plane strain - Variation of toughness (KIc and Kc)**

Elastic-plastic Fracture Mechanics (5)

- J-integral as energy release rate
- J-integral as amplitude of HRR singularity
- J-integral as contour integral
- Laboratory measurement of J-integral - η factor approach
- Fracture resistance of materials – J-R curve and JIc and possible explanation for shape of J-R curve
- Stable and unstable crack growth – Tearing Modulus approach
- J-controlled fracture
- Basic design principles in EPFM
- **J-estimation schemes**

Laboratory measurements of material fracture properties (2)

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- KIc testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of JIc from J-R curve – blunting line equation and SZW

Limit load (2)

- Definitions of limit load
- Global and local limit load
- Basic expressions of limit load of some common geometries

R6 method (2)

- Basic principles of R6 method
- Sensitivity analysis

Fatigue (7)

- Conventional high and low cycle fatigue – S-N diagram, Coffin-mansion relation
- Fatigue crack growth under constant and variable amplitude loading
- Rainflow algorithm
- Environmental effects on fatigue crack growth
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- **Experimental determination of Paris law constants as per ASTM procedure Fracture assessments of welds (2)**
- Basic aspects of fracture assessment of welds – residual stress effect
- Special considerations in fracture toughness determination of welds

PTS and ASME reference/Master curve (6)

- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Warm pre-stress effect

- Reference ASME curve in assessment of PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Computational Fracture Mechanics(4)

- Barsoum's crack tip element and showing the singularity from shape function
- Evaluation of SIF by displacement correlation technique from FEM
- Evaluation of 2-D J-integral by contour integral technique
- Evaluation of 3-D J-integral by domain integral technique

Fracture Mechanism (4)

- Basic mechanism of ductile fracture – Void nucleation, void growth and coalescence
- Cleavage fracture- Mechanism of cleavage initiation
- Mathematical model of cleavage fracture toughness, explanation for scatter in cleavage fracture toughness, RKR model

Application of Fracture Mechanics Principles to Leak-Before-Break (1)

- History of LBB
- Basic concepts of LBB – three levels
- Application to Indian reactors

EN 623: Mechanical Metallurgy (30)

Elasticity and Plasticity

- Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
- Equations of equilibrium.
- Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria

Dislocations:

- Elastic stress field of edge and screw dislocation.
- Self energy of dislocations.
- Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP

Deformation Behaviour

- Single crystal deformation, critical resolved shear stress, Schmidt's factor, Thermally activated deformation, Strengthening mechanisms.

Creep of Metals and alloys

- Various stages of creep and creep laws
- Types of creep tests, evaluation of parameters of a creep test and its use
- Factors influencing creep resistance
- Deformation mechanism map and identification of creep mechanisms, Irradiation creep

Fracture Mechanics

- Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
- Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
- Concepts of R-curves, Evaluation of various fracture parameters, fracture control

Fatigue of Metals:

- High cycle and low cycle fatigue
- Factors contributing to fatigue failure and its mitigation
- Various stages of fatigue damage and Fatigue life improvement
- Fracture mechanics approach to characterize crack growth behavior

References:

1. Engineering Fracture Mechanics - S. A. Meguid.
2. Mechanical Metallurgy - G. E. Dieter
3. Mechanical Behaviour of Materials - T. H. Courtney
4. Elementary Dislocation Theory - J. Weertman & J. R. Weertman
5. Introduction to Dislocations - D. Hull
6. Mechanical Metallurgy : Principles and Applications - M. A. Meyers & K. K. Chawla
7. Deformation and Fracture Mechanics of Engineering Materials - R. W. Hertzberg

EN 624: Mechanics of Solids (40)

Introduction to Theory of Elasticity Mathematical Frame Work (2)

- Illustration of concepts of elasticity, Stress-strain curve, Isotropy, Homogeneity
- Illustration of equilibrium equation, Cauchy equation and stress strain relation in 1-D
- Solution of 1-D boundary value problems using theory of elasticity equations: (a) Natural frequency determination. (b) Solution under external excitation force to show resonance condition, stress wave etc.
- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Kronecker Delta, Permutation symbol ; Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of Stress (3)

- Description / Notations of Forces
- Description / Notations of Stress
- Component of stress
- Reciprocity of shear stress in 3D

- Stresses Transformation using direction cosines
- Stress Traction Vectors or Traction Vectors
- Stress component on an arbitrary plane
- Principal stresses
- Stress Invariants
- Mohr's Diagram for 3D state of stress
- Hydrostatic and Deviator components of stress
- Principle planes and their orthogonally
- Octahedral plane, Octahedral stresses
- State of pure shear

Analysis of Strain (2)

- Description / Notation of Strain in 3D
- Components of strain
- Strain Transformation using direction cosines
- Principle Strains, Strain Invariants
- Cubical Dilation
- Strain Deviator Tensor
- Maximum and Octahedral Shear Strains

Principles and Fundamental Equations of Elasticity (8)

- Strain and displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Stress and strain relationship
- Equations of equilibrium (Navier's Equations , Lame's equations)
- Strain Energy
- Uniqueness theorem
- Bounds on elastic constants
- Superposition Principles
- Saint-Venant's Principle
- General Solution Procedures for a elasticity problem

Two and Three Dimensional Formulation (8)

- Elasticity equation for Plane strain
- Elasticity equation for Plane stress
- Biharmonic equations
- Airy's Stress Functions
- Solution for beam bending problems
  a) Special cases by use of polynomials
  b) General solutions using fourier series method
- Solution in polar co-ordinates
  a) Tube subjected to internal and external pressure (Lame's problem) ; shrink fit
  b) Stress Concentration due to a circular hole in stressed plate (Kirsch's problem)
- Stress in spherical shell under internal and external pressure

Thermal Stresses (4)

- Thermal stress definition and their significance
- Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
- 2D thermal stress analysis
  a) The problem of circular disk
  b) The problem of circular cylinder
- 3D thermal stress analysis : The problem of sphere
- Transient thermal stress

Introduction to Plasticity (4)

- Stress-strain curve, Examples of Multiracial stress
- Different Yielding Criteria and their significance
- Yield Surface , Tresca and von-Mises
- Path dependence of Plastic Strains
- Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
- Prandtl-Reuss Equations
- Incremental or flow theory
- Deformation theory of plasticity, Hencky equations
- Plasticity Relations (plastic strain and total strain)

Theory of Plates

- Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
- Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.

- Introduction to analysis of Thick Plates

Theory of Shells

- Introduction to shell theory.
- Classification of shells, Membrane theory of shells of revolution and translation.
- Application to spherical, conical and cylindrical shells.
- Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
- Application to cylindrical shells, spherical and conical shells.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Piblications, Inc.
6. Plasticity Theory and Application, Alexander Mendalson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K .Chandrasekhara, University Press
9. Stresses in shell- W.Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN 625: Modern Control Systems Design and Simulation (35)

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analyti- cal methods of modeling.
- State Space Characterization State 5PaCe representation, solution of state equation, state Transition matrix, properties of STM, computation methods, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kaiman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Control- lability and observability of Discrete data systems.
- Stability liapunov,s stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design Guillemin-Truxal design Procedure, pole placement by state feedback. H,' meth- od, Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kaiman filter as OPtimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency re- sponse methods, Recurise Least square Identification technique.
- Introduction to Adaptive and Robust control.

References:

(Reference materials will be provided during the course)

EN 626 Design Basis Hazards and Geotechnical Engineering (40)

Design Basis Hazards (Natural)

Role of civil engineering in achieving overall nuclear safety: Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.

Introduction to hazard evaluation:

Hazard due to internal and external events, case studies.

Seismic Hazard

Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum

Flood hazard

- Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
- Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
- Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding

Wind hazard

Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India,Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.),

Solar radiation

Temperature map(Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)

Snow hazard

Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides

Design Basis Hazards (Human-Induced)

Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)

Geotechnical Engineering

Soil Mechanics

- Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
- Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
- Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability; Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.
- Bearing capacity – Determination of bearing capacity for soils and Rock.

Geotechnical and Geophysical investigations:

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

Soil Dynamics and Liquefaction

Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

References:

1. Kramer . S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. **I**S 875(Part 3) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. **I**S 875(Part 4) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance”
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – “Basic and applied soil mechanics”.
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities’
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN 627: Networking and Information Security (40)

Networking

General Issues in the transport of data traffic over networks of digital transmission media.

- V.24, V.35, Modems, xDSL, Multiplexing

Circuit switching & Packet switching

- ISDN (BRI), PRI.

Datalink Layer

- Data link layer protocols, Medium access method, Flow control, Error Control
- Ethernet technologies, Bridge, Switching, Analysis of collision domain, Layer 2-based network attacks

Introduction to Satellite communication

- Satellite orbits, VSATs, VSAT network Topologies

Network Layer

- IP, IP Fragmentation, ARP, DHCP, Classes of IP address, CIDR, Layer 3 based network attacks, ICMP
- IP Routing algorithms, RIP, OSPF, BGP.

Transport Layer

- TCP & UDP, TCP Call establishment & Call termination, Sockets, TCP state machine, TCP timers
- RTP, Layer 4 based network attacks

Firewall
- Layer 3 firewall, Layer 4 firewall, Application based firewall

Network Applications
- FTP, DNS, Mail, application based attacks

Network Security
- Data security, type of possible attacks on data etc?
- Ecurity services for secure data communication?
- Like Identification, Authentication, Authorization, Data Integrity, Confidentiality, Non-repudiation, Replay, Availability etc.
- Cryptography and its services Cryptology, cryptanalysis.
- Components of cryptology like algorithms, Keys, Message Digest, Digital signature, Digital Certificates etc. with block diagram.

Types of Algorithms
- Symmetric and Asymmetric.

Symmetric Algorithm
- stream cipher algorithms
- Type of stream ciphers, Unconditional security with stream ciphers, one time pad, LFSRs, Linear complexity in LFSRs, Shanon's concept of perfect secrecy
- Type of possible attacks, Conversion of block ciphers onto stream ciphers etc.

Asymmetric Algorithms
- Diffie-Hellman, RSA with detail mathematics and applications.
- Key management methods for symmetric and asymmetric keys.
- PKI infrastructure, Digital certificates, digital signatures for asymmetric key managements. CRL (certification revocation list)
- Symmetric key certificates. Difference between symmetric and asymmetric key certificates etc.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN 628: Nuclear Chemical Engineering (35)

Intoduction

Role of chemical engineering in the nuclear industry

Recovery & processing of nuclear materials from ores / intermediates (5)
- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources , New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths : Occurrence, importance and separation.

Uranium Conversion / reconversion (6)
- Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF6: choice and problems, Fluorination of UF4, Purification and collection process for UF6, Conversion to UO2.

Isotope Separation (9)
- Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical- exchange: H2S-H20, NH3-H2, monothermal and bithermal process, salient features of equipment like contacting towers, tower internals. Heavy water plants in India. Final enrichment and upgradation plants. Distillation and electrolysis, Tritium removal.
- Laser based separation and new processes (2)
- A brief description of laser based isotopic separation processes.
- Fuel Reprocessing (6)
- Fuel Reprocessing: Introduction to Radiochemistry; Differences between a conventional chemical plant and radio chemical plant- Process and equipment limitations, criticality, safety and other hazards, numerical examples, ventilation, shielding, Typical compositions and burn-up of irradiated nuclear fuels.
- Thermal Reactor Fuel Reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements. Evolution of solvent extraction process fore reprocessing, 'PUREX' and 'THOREX' processes in detail; Head-end process, flow sheet, co-decontamination and partitioning cycles.
- Fast Reactor Fuel Reprocessing and Introduction to reprocessing of Thorium based fuels.

Nuclear Waste Management (7)

- Sources, characteristics and classification of radioactive wastes; general philosophies of management.
- Method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Discussion of the various chemical engineering operations involved. Use of desalination and membrane separation techniques in waste management.
- Conditioning of radioactive waste- cementation, bituminisation, use of polymers and vitrification methods.
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical Engineering in Decommissioning of nuclear facilities.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series,IAEA,Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)

EN 629: Nuclear Materials (50)

Melting & Casting (10)

- Introduction to vacuum measurement units and types of vacuum pumpsincluding diffusion pump & turbo- molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and methods to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits

Mechanical working of Metals (10)

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Methods of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Powder Metallurgy & Advanced Ceramics (30)

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production methods, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.
- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. "Introduction to Ceramics" by Kingery et al.
11. "Ceramics Through Chemistry" by Brinker et al.
12. "Electroceramics" by Buchanan
13. "Ceramics Fabrication Processes" by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman

16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
19. 'Ceramics Fabrication Processes" by Wang.

EN 630: Nuclear Metallurgy (30)

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post- Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradition effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels,definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister fomation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Bengamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brain R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN 631: Physical Metallurgy (40)

- Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor Stereographic projection, X-ray, Electron and Neutron diffraction Common Crystal structures and quasi crystals, Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics
- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation. Ordered omega and Hydride formation.
- Recovery, Recrystalization and Grain Growth

References:

1. Physical Metallurgy Principles - R. E. Reed-Hill
2. Modern Physical Metallurgy - R. E. Smallman
3. Introduction to Metallurgy - A. H. Cottrell
4. Physical Metallurgy - P. Haasen
5. Introduction to Physical Metallurgy - S. H. Avner
6. Structure of Metals - C. S. Barrett & T. B. Massalski
7. Crystallography and Crystal Defects - A. Kelley and G. W. Groves
8. Principles of Phase Diagrams in Materials Systems - P. Gordon
9. Thermodynamics of Alloys - C. Wagner
10. Introduction to Metallurgical Thermodynamics D. R. Gaskel
11. Physical Chemistry of Metals - L. W. Darken and R. W. Gurry
12. Metallurgical Thermochemistry- O.Kubuschewski

13. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering - K. Denbigh
14. Modern Chemical Kinetics - H. Eyring
15. Kinetics of Phase Transformations in Metals - J. Burke
16. Transformation in Metals - P. G. Shewmon
17. Phase Transformations in Metals and Alloys - D. A. Porter and K. E. Easterling
18. Diffusion in Solids - P. G. Shewmon
19. Modern Metallography - R.E. Smallman and K.H.G. Ashbee
20. Electron Optical Applications in Materials Science - L. E. Murr
21. Electron Microscopy and Analysis - P. J. Goodhew and F. J. Humphreys
22. Defect Analysis in Electron Microscopy - M. H. Loretto and R. E. Smallman
23. Thermoanalytical Method of Investigation - P. D. Garn
24. Thermal Analysis - T. Daniels
25. Methods of Surface Analysis - A. W. Czanderna (Ed.)

EN 632: Process Control and Instrumentation (MT)(25)

Principles of Measurement (2)

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.

Sensors, Transducers and Transmission methods for parameters (10)

- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical& Radiation Pyrometers.
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli's Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

Principles of Automatic Control Systems (8)

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doeblin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN 633: Process Control & Instrumentation (EE)(30)

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysterisis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of following process variables
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter, Different types of standard pressure taps for orifices. Variable Area Flowmeters- Glass tube rotameters, armoured rotameters, bypass rotameters,
- Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs- Wire wound and thin film RTDs, self heating error, differential temperature measurement by using RTDs. Thermistors - Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer, two colour pyrometer.
- Pressure and Differential Pressure: Manometers-U tube, well and inclined manometers, mechanical pressure gauges- Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressureTransducers and transmitters, Smart pressure transmitters, Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauges, Mcleod gauge.
- Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass,

Purge system, capacitance probes, displacer type, ultrasonic type, nucleonic type and conductivity type level gauge.

- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- Distributed Control System: Programmable Logic Controllers, Smart Transmitters Control room concepts.
- P & I Diagrams: P &ID symbols, Typical P &ID.
- Class 1E Instruments in nuclear power plant: Definition of Class 1E equipment, various tests for Class 1E equipment qualification.

References:

1. ‘Fundamentals of Temperature, Pressure and Flow Measurements” – Bendict
2. “Instrument Technology”, Vols. 1 to 5, - E.B. Jones, Butterworth and London
3. “Mechanical and Industrial Measurements” - R.K.Jain, Khanna Publishers, New Delhi
4. “Measurement System, Application and Design”, Ernest D. Deophhlin.
5. “Fluid Meters” - ASME Publication
6. “Principles and Practice of Flow meter Engineering” - L.K. Spink, Published by the Foxboro Company
7. “Process Instruments and Control Handbook” - Edited by D.M. Considine, McGraw Hill
8. “Handbook on Applied Instrumentation”: Edited by D.M. Considine and S.D. Ross, McGraw Hill
9. “Instrument Engineer’s Handbook”, Part I & II: Edited by Bela G. Liptak, Chilton Book Company
10. “Instrumentation for Process Measurement and Control”, Norman A. Anderson, Hilton Co.
11. “Manual on the use of Thermocouples in Temperature Measurements” (ASME Publication by subcommittee 4).
12. “Process Control Systems: Application Design and Tuning”. F.G. Shinskey, Mcgraw Hill.
13. “Fluid Meters - Their theory and Application” Edited by H.S. Bean. ASME Publication

EN 634: Process Dynamics & Control (45)

Instrumentation , Controls & Computers(20)

- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real- time control applications.

Advanced Process Control (25) Background theory

- Introduction to state-space controls, state & measurement equations, general solution **o**f the state equation, state- transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.

Introduction to Advanced Process Controls

- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

EN 635: Process Modelling, Simulation & Optimization (45)

Simulation

- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Methods of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent methods.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution methods for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization:

- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies.Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals,evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.

- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

References:

1. Bisio, A and R.L.Kabel, 'Scale-up of Chemical processes', Wiley-Interscience,NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W.Hoffman, A.I.Johnson, D.R.Woods and P.T.Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Methods and Modelling for Chemical Engineers, Winley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain,A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)
6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs,E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Rekliatis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Methods & applications, John Wiley,N.Y (1983)

EN 636: Reactor Control and Instrumentation and Human Machine Interface (40)

Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
- Practical

EN 637: Reactor Control Engineering & Instrumentation -1(15)

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic methods (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant Tav program, constant pressure program, Boiler level and

pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., " Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN 638: Reactor Control Engineering & Instrumentation-2 (20)

- Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.
- Reactor Instrumentation
  - Measurement ranges of reactor neutron flux and considerations
  - Principles of detection and types of neutron detectors: in-core and out – of –core
  - Modes of signal processing: Pulse, Campbell, DC
  - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- Health Physics Instrumentation
  - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
  - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
  - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Contamination Monitors

References:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerl

EN 639: Reliability Engineering (EE)(20)

Introduction: Reliability Engg Applied to C&I Systems

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

Reliability Maths/Statistics

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

Fault Tolerance and Systems Reliability:

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

QA/QC Concepts in Brief:

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.

Environmental Qualification and Reliability Testing:

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

PSA/PRA Concepts in NPPs:

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

Additional safety concepts:

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
- Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc.

References:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
6. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
7. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
8. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
9. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
10. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
11. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
12. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
13. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN 640: Software Engineering and Formal Methods (40)

Software Engineering (20)

- Importance of Software Engineering (1)
- Life cycle, Phases and Work-Products of different Phases, traditional models, agile models, Extreme programming (1)
- Project Management: Relationship to lifecycle, planning, control, Risk Management, Cost Models.(1)
- Requirements: Gathering, Categorization, Analysis, and Specification.(1)
- Software Architecture and Design: Architectural Styles, Design Notation, Design principles. (5)
- Object oriented Design: OOAD, Design Patterns (7)
- Testing: Principles of program Testing, Test Coverage, Static Analysis, and Tools for testing. (2)
- Support Activities: Configuration Management, Verification and Validation, Software Engineering Standards, Documentation formats, Tools and environments for Software Engineering (2)

Formal Methods (20)

- Introduction to Formal Methods, Role of Formal Methods in Software Life Cycle – development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, Statecharts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing - Assertions and their verification (dynamic and Static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)

- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic,, Case study from hardware and software, model cheking tools (SPIN, NuSMV etc.) (4)

References:

1. Software Engineering: Roger S. Pressman McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Adison-Wesley
3. Unified Modeling Language *User Guide*: G. Booch, J. Rumbugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I & II , Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K. McMilan, Kluwer, 1993

ELECTIVE COURSES

EN 701: Advanced Computational Techniques (30)

Programming Language C++

- C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.
- C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initialisers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogona Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions,parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

EN 702: Advanced Electrical Engineering Design-I I (25)

Special Electrical Machines

- Special Electrical Machines and their applications :Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

Pulse Power Technology

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

EN 703: Artificial Intelligence Methods & Applications (30)

- **AI Basics**Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert

Systems.

- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence **theorem,** Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification methods, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig
2. Genetic Algorithms in Search, Optimization, and Machine Learning, by David E. Goldberg
3. Neural Networks: A Comprehensive Foundation, by Simon Haykin
4. Reinforcement Learning: An Introduction, by Richard S. Sutton and Andrew G. Barto

EN 704: Computer Based System Design- II (25)

Communication, Networking, Realtime systems, RTOS and Software

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- USB
- Encoding schemes
- Local Area Networks
- OSI 7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Networking hardware – cables, hub, switch, router, etc
- Role of fibre optics in communication
- Fieldbus standards
- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking
- Realtime Systems, their characteristics and applications
- Realtime Operating Systems:
- Concepts of
- Process and threads
- Concurrency
- Latency, context switching
- Scheduling policies
- Inter process communication
- Semaphores
- Priority inversion
- Shared memory
- Common systems calls, Communication features in RTOS
- Comparative study of various RTOSs
- Integrated S/W development environment

EN 705: Data Base Management System and Web Technology(30)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

EN 706: Digital Signal Processing and Image Processing (30)

Digital Signal Processing

- **Introduction**

Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**

  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
- Fast Fourier Transform

Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- Digital filters

FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- DSP Applications

  Applications of digital signal processing in nuclear and other fields.

Image Processing

- **Introduction**

  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- **Image Enhancement**

  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- **Image Segmentation andAnalysis**

  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation; Boundary extraction and representation;
- **Morphological operations**

  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy- based methods;

  Image Compression Models, Error free compression, Lossy compression, Standards;

References:

1 Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
1. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles,
2. Algorithms and Applications, Prentice- Hall of India,1995.
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.
4. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine
6. Vision,Vikas Publishing House,2003.
7. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004

EN 707: Embedded Electronics Software(25)

Programmable Digital System Design, Representation & Synthesis [8]

- Introduction to HDLs, Introduction to PLD, FPGA, ASIC. Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Handel-C, VHDL. Introduction to Design Flows and EDA Design Tools.

Real-time Software [11]

- Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion,

Priority Inheritance
- Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development

Introduction to Microprocessors / Microcontroller and Interfaces [6]
- Introduction to Microprocessor and microcontroller, Synchronous and Asynchronous Standards, RS232C, RS485, FieldBus (Profibus, Foundation FieldBus, CAN, Ethernet , MIL-STD-1553B), TTP

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P.Singh & Renu Singh
3. Fieldbus Technology: by N.P.Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN 708: Feedback Control Systems (25)
- Introduction: The control systems, Basic elements of FIB control systems, Types of FIB control systems.
- Transfer Function: Transfer function of linear systems, Impulse response, Block diagrams, Signal flow graphs, Mason's gain formula, Polar plots, Bode plot.
- State Variable Characterization: State concept, State equation, Standard representation, State transition matrix and solution of state equations, relationship between state equations and transfer functions, Characteristic equation, Illus- trative examples of some electrical, mechanical, electromechanical systems.
- Time Domain Analysis: Test input signals, Time domain perform- ance characteristics, Transient response of a typical second order system, PID controllers
- Stability: Definition, Routh-Hurwitz criterion, Nyquist criterion. Relative stability, Gain and Phase margins.

EN 709:Fluid Power Technology (25)
Basic Fluid Power & Components

Basic principles of Hydraulics and pneumatics
- Fluid power introduction and fundamentals of fluid mechanics
- principle of pneumatics, basic definitions
- pressure – gauge, vacuum, absolute; flow
- Pressure loss, Power, torque, energy – mechanical, hydraulic etc. , power, force, speed, viscosity, hydraulic terms in fluid power, resistances, bulk modulus, Pascal's Law, law of conservation of energy
- Transmission and multiplication of force, Momentum theorem, Angular momentum theorem, continuity equation, Euler's equation of motion, Bernoulli's theorem, laws of compression, forces developed by jets on plates (curved plate, moving plate, etc.) orifice flow formula, flow measurement, pressure measurement, comparison of Pneumatics with Hydraulic power transmissions.

Hydraulic Fluids and pneumatic air
- Basic properties of hydraulic fluids and pneumatic air, compressibility, pour point, flash point, fire point,
- Desirable properties of fluid, undesirable properties of fluids,
- Types of fluid, composition of fluids, effects of additives to hydraulic fluids,
- Advantages of various types of oil.
- Advantages of oil vs. air as working fluid.

Fluid power pumps and compressors
- Function and purposes of pumps and compressors
- Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump. (ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps (iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
- Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
- Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.

Hydraulic and Pneumatic pressure control

Pressure Control Valves, construction and working principles of relief valves- direct acting and pilot operated relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Hydraulic fuse, pressure switch, Pneumatic Pressure regulating valves.

Flow control valves

Basic two way valves, non-compensated flow control valves, throttle valves, restrictor valve, needle valve, ball tip valve, check valves, control valve circuits, pressure compensated flow control valve, demand-compensated flow control, pressure, temperature-compensated, flow control valve, methods of speed regulation in pneumatics.

Directional control valves

Application of directional control valve (DCVs),, designs, construction and operation of check valves, pilot operated check valves, rotary and spool type valves, two way valves, shuttle valves, three way valves, diversion valves, four way valves, solenoid operated, control valves, operation of directional control valves, mounting interfaces, designation, type of actuation of DCVs, pneumatic direction control valves – two way, three way, four way valves, etc., solenoid operated, push button operated, lever operated pneumatic DCVs.

Actuators

Definitions, linear actuators – Hydraulic cylinders, Plunger type, , piston type, Single acting, double acting cylinders, spring return type, tandem and telescopic cylinder, construction of hydraulic cylinders, cylinder seals – piston seal, rod seal, wipes, wear pads, etc. mounting style of cylinders, Pneumatic reciprocating actuators.

Rotary actuators –motors and limited rotation rotary actuators, their types, construction, advantages, vane type single and double vane rotary actuators, rack and pinion type rotary actuators, gear motors – external and internal, gerotor motors, vane motors, Radial piston motors, non-rotating barrel type axial piston motors, advantages of hydraulic motors. Pneumatic rotary actuator, radial piston, vane, and axial piston type air motors etc.

Seals

Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

Pipes, Tubes and Hoses, fittings

Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.

Accessories

Hydraulic and pneumatic filters, their applications, working principles and designs, beta ratio, absolute filtration, nominal filtration, selection of filters, heat exchangers – types, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, types of pneumatic filters, regulators, lubricators, mufflers, dryers, reservoirs etc.

Hydraulic Circuit Design

- Introduction to fluid Power Symbols, Overview of IS 7513,
- Classification of hydraulic circuits, Criteria for designing open loop hydraulic circuits, Analyzing resistive loads, overrunning loads and inertial loads, Heat generation and control.
- Flow control circuits, Pressure control circuits, Direction control & check valve circuits, Cylinder circuits, Pump circuits, Hydraulic motor circuits, Accumulator circuits, Intensifier circuits, Regeneration circuits.
- Sizing of Hydraulic circuit components :
- Reservoir.
- Heat Exchanger: Oil to air heat exchanger, Oil to water heat exchanger.
- Filters: Sizing of suction filter, return line filter, pressure line filter, Beta ratio, Necessary sizing information for filters.
- Fluid Conductors: Flow v/s Pressure drop, Pressure losses, tube/ hose sizing, Pressure rating, Hose/ Tube designation, Calculation of pressure drop in straight lines, bends, fittings etc.
- Pumps: Fixed displacement, variable displacement pumps, Design of suction side and pressure side of pump
- Hydraulic cylinders and motors.
- Accumulator: Isothermal &Adiabatic charging / discharging of accumulator. Sizing of accumulator for various applications i.e. energy storage, shock absorber etc.
- Valves sizing: Direction, pressure & flow control valves.
- Hydraulic Circuit Dynamics considerations: Bulk modulus, Spring rates, natural frequencies, Transmission line dynamics, Pulses in transmissions, Energy controls, Load energy output interaction, system stability, damping, time constant, system response, hydraulic system parameters i.e. resistance, capacitance, impedance.

Advanced Hydraulic Control Circuits

- Various pilot operated valves, construction features, operation, and advantages.
- Modular valves, Stacked type direction control valves, flow control valves, pressure control valves and

combinations.
- Electrically modulated pressure control valves, flow control valves. Pulse width modulation,
- Proportional controls, Servo controls, construction, Uses, differences, operation, advantages and disadvantages.
- Cartridge Valves: Design and construction features of cartridge valves, Types and Operation of cartridge valves, Advantages of cartridge design.
- Advanced pump controls, load sensing, pressure compensation.
- Integrated Hydraulic Circuit:Construction , Advantages of integrated hydraulic circuit, Case study of PVG32 valve, Various modules of PVG 32 valve block, Features of integrated hydraulic circuit of PVG 32, Electronic control capabilities.
- Pneumatic control circuits, proportional and servo valve, proportional and servo actuators

Water Hydraulics and Component Design
- Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals.
- Case Study-1: Differential Pressure Reducing Valve: Conceptual design and sizing
- Case Study-2: Auto Differential Pressure Control Valve - Conceptual design and sizing.
- Case Study-3: Pressure Compensated Flow Control Valve - Conceptual design and sizing.
- Case Study-4: Pilot Operated Pressure Control Valve - Conceptual design and sizing

Electronics and Instrumentation for Hydraulics:
- Current/ Voltage Sources and its measurements, Electronic components –resistance, capacitor, transistors, Opamps etc. Basic circuits for Addition multiplication, division using Opamps. Digital electronics, Logic gates.
- Analog to Digital converters (ADC) and Digital to analog controllers (DAC), Signal conditioning circuits, filters.
- Sensors-Pressure measurement, pressure switches, Position measurement, limit switches-proximity switches, Velocity measurements, Temperature measurement, temperature switches, Viscosity, density measurement, Force, torque, strain measurements.
- Controllers, Closed loop and open loop controllers, Proportional, Integral, derivative controllers and its uses and characteristics. Analog and digital controllers, comparison between digital and analog controllers. Programmable logic controllers, different I/O modules, wiring sensors to PLC. Introduction to microcontrollers, Applications, programming.
- Data Acquisition, Communication buses RS232,RS485, CAN bus, MODBUS, CANOpen bus uses and applications.

Fluid Logic & Control:
- Need for Fluid Control.
- Building Basic Elements for Control Logic (AND, OR, NOT, NAND, NOR).
- Function Implementations using Control Logic.

Experiments :
1. Tuning of PID controller in rotary actuator test facility.
2. Speed control of hydraulic motor using PLC.
3. Measurement of cleanliness level of hydraulic oil samples using particle counter.
4. Qualitative analysis of oil samples using Ferrograph.
5. Establishing position control using frictionless hydraulic linear actuator.
6. Finding characteristics of Differential Pressure Reducing Valve.
7. Finding characteristics of Auto Differential pressure control valve.
8. Finding characteristics of Pressure Compensated Flow Control Valve.
9. Finding characteristics of Pilot Operated Pressure Control Valve.
10. Study of Rexroth/Bemco oil hydraulic power pack and carrying out pressure setting, flow setting etc. in the same.
11. Experiments on ROHYTAM
12. Testing of oil hydraulic filter using filter test set-up.
13. Dismantling & assembling of various valves and actuators.

EN 710: Image Processing & Machine Vision (30)

Image Processing
- Introduction: Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;
- Boundary extraction and representation;
- Morphological operations;
- Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy-based

methods;
- Image Compression: Models, Error free compression, Lossy compression, Standards;

Machine Vision
- Imaging model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflectance, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, Boundary representation,Mathematical Morphology;
- Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, The Generalized Hough Transform;
- High Level Vision: Scene interpretation;
- Texture – Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, Classification and recognition, Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

References:
1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine , Vision,Vikas Publishing House,2003.
6. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004.
7. Davies E.R., Machine Vision Theory Algorithms Practicalities, Academic Press.
8. D.A. Forsyth & J. Ponce, Computer Vision A Modern Approach, Prentice Hall,2003.
9. Horn B.K.P., Robot Vision, The MIT press, 1987.
10. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
11. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

EN 711: Machine Design (25)

Principles of Machine Design:
- Objectives of machine design, general design rules, design methods
- Lightening of' parts and rational design schemes,
- Rigidity of structures, Cyclical/ Contact/ Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs.
- Introduction to inventive problem solving.

Design and Drawing Practices
- Drawing standards, selection of tolerances, fits, and positional tolerances.
- Introduction to Drawing Practices: (matter from various drafting standards),
- Introduction to CAD (including introduction to various drafting and solid modeling softwares)

Sealing Methods
- Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric 'O' rings, mechanical seals, labyrinth, valve packings.
- Methods of sealing for high and ultra high vacuum.

Special Dimensional Inspection Techniques
- Description of special dimensional inspection techniques, gaging techniques including composite and paper gauging, Advanced inspection tools including co-ordinate measuring machines and form measuring machines.

Advanced Manufacturing Techniques:
- Precision machining, super finishing, advanced manufacturing
- Micro machining.

References:
1. "Mechanical Engineering Design" by Joseph E. Shigley.
2. "Machinery's Hand Book" (24th edition)
3. "ISO Standards Hand Book" 18.
4. "SKF Bearing Catalogue."
5. "Relevant IS standards."
6. "Friction, Wear, Lubrication, Tribology Hand Book" edited by Prof. I.V.Kragelsky & V.V Alisim.

7. "Gear Hand Book by" Dudley.
8. "AGMA Standards 218.01" Dec. 1982.
9. "Industrial Sealing Technology" by H.HUGO BUCHTER

EN 712: Material Science in Nuclear Engineering (ME) (20)

- Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.
- Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X- ray Radiography, etc. for welds.

Corrosion

- Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards

Metallurgy of steels

- Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
- Selection and application of advanced alloys.

Nuclear Materials

- Fabrication, properties and application of Zircaloy, Zr-Nb alloys
- Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications.

Advanced Polymeric materials and Composites

- Physical and Chemical Properties, corrosion, mechanicalproperties
- Equipment design with polymeric materials
- Fabrication principles; standards for design, fabrication and testing.

References:

1. "Introduction to Materials Science for Engineers" - James Shackelford
2. "Physical Metallurgy Principles & Practice" - V.Raghavan
3. "Introduction to Solids" - L.V.Azaroff
4. "Structure and Properties of Materials" - Wulff Series, Wiley Eastern, New Delhi
5. "Materials in Nuclear Application" - C.K.Gupta
6. "Nuclear Chemical Engineering" - Benedict and Pigford

EN 713: Materials Characterisation (20)

Microscopy Techniques

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
    - Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
    - Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High reolution electron microscopy
    - Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, Other modes of operation, Applications in failure analysis, fracture surfaces etc.
    - Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

X-Ray Diffraction and Applications

- Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production and detection of x-rays.
- Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
- Experimental methods in x-ray analysis; Laue methods, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates,

crystal size crystal perfection, crystal orientations:

Chemical Analysis (with applications in materials science).

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

Basics of Analytical Transmission Electron Microscopy,

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, llllcorrections
- Cliff Lorimer factor, thin film correction

Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
- Fundamentals of energy filtering and its uses in life sciences
- Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
- Case studies for metallic bulk samples, life science samples, nano-materials

Physical and Thermal Characterization Techniques

- **Thermal expansion**: Methods and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
- **Thermal Conductivity**: Methods and their principle, advantages and limitations of each method, data of nuclear Fuels
- **TGA/DTA/DSC**: Methods and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
- **Elastic Properties**: Methods and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
- **Hardness**: Different methods and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

EN 714: Membrane Technology (35)

Fundamentals and Overview of Membrane Processes: (5)

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Growth Potential, Classification and description of membrane processes
- Pressure driven membrane processes (MF, UF, NF and RO)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

Novel Membranes

- Features, transport mechanism and application areas
- Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Membrane Bio-reactor, Fuel cell membranes, Membrane sensors, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

Membrane Materials, Preparation and Characterization: (10)

- Material selection
- Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity Molecular weight and molecular architecture
- Membrane preparation techniques- Phase-Inversion, In-situ polymerization, Track-etching, Slip-casting, Sintering
- Membrane Casting Aspects for continuous casting
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of charged membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
- Surface characterization -pore size, roughness, in-homogeneities, and hydrophilicity
- Bulk characterization -porosity, permeation study through flux and solute rejection.

Engineering and Design Aspects of Membrane Technology (10)

- Transport through membranes-Preferential sorption-capillary model,Solution Diffusion model, Irreversible thermodynamics model
- Derivation of basic transport equation for RO membranes

- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants
- Pretreatment considerations, Water chemistry- turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control,Scaling assessment parameters (SDI, MFI)
- Materials of construction
- Process design and system design for water desalination-Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices -pelton wheel, turbo-charger and pressure exchanger
- Effect of operating parameters on membrane performance
- Membrane cleaning and protocols
- Trouble-shooting analysis of operating plants
- Post-treatment techniques
- Membrane autopsy, Reject disposal techniques and brine management.

Membrane Technology Applications (10)

- Techno-economics of membranedesalination plant - seawater / brackish water
- Design aspects of water recovery & recycle from spent streams including sewage Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle
- Hybrid membrane systems, Combo systems -membrane + conventional- for separation application
- Nuclear Desalination
- Membrane based water purification systems-RO/UF application in food processing, pharmaceuticals and Bio-technology
- Fractionation & Value Recovery.
- Zero Liquid Discharge (ZLD)

References

1. Membrane Technology & Applications by Richard W Baker (2008)
2. Membrane Handbook by Ho and Sircar (1992)
3. Transport Phenomena in Membrane by K. Lakshminarayanaiah (1970)

EN 715: Multi-Scale Material Modeling (20)

Introduction

- Spatial and temporal hierarchy of microstructure and dynamics in materials
- Types of models: quantum mechanical, atomistic, mesoscopic, continuum
- Multiscale approaches

Short review and elements of differential equations (numerical solution)

- Differential equations in discrete and continuum simulation methods
- Ordinary differential equations for particle dynamics
- Partial differential equations, conduction/diffusion equation

Atomistic models: Molecular dynamics

- The basics of classical molecular dynamics
- Initial conditions, creating lattice structures, introducing defects
- Defining and maintaining temperature and pressure
- Boundary conditions (periodic, stochastic, conducting, non-reflecting)
- Methods for constant temperature or/and pressure simulations
- Tricks of the trade (neighbor lists, force/energy tables, potential cutoffs, etc.)

Monte Carlo methods

- The basics of Monte Carlo
- Monte Carlo integration, thermodynamic averages
- Importance sampling, Metropolis scheme
- Lattice Monte Carlo, Ising model
- Multi-state Potts models (grain coarsening, recrystallization)
- Kinetic Monte Carlo (surface processes, thin film growth)

Interatomic potentials

- Introduction, Born-Oppenheimer approximation
- Pair potentials and their limitations
- Calculation of elastic constants from potential function

- Potentials for ionic systems, ceramics
- Many-body potentials for metals
- Many-body potentials for covalently bounded systems
- Forces from "first principles"

Analysis of the simulation results

- Equilibrium properties (energy, temperature, pressure, velocity distributions)
- Structural properties (geometrical tessellation, pair correlation functions, atomic level stresses)
- Dynamic properties (diffusion, time correlation functions)

Mesoscopic methods

- Discrete dislocation dynamics
- Strain and stress fields for edge and screw dislocations in an isotropic medium
- The equation of motion in Newtonian Dislocation Dynamics
- Examples from 2D and 3D simulations
- Current problems
- Coarse-grained models

Bridging the scale gaps between different simulation levels

- Simultaneous integration of the models
- Sequential integration of the models (hierarchical approach)
- Examples of combined methods (MD-FEM, MD-MC, etc.)

Modeling at microscale

- Mechanism of ductile fracture and cleavage fracture
- Gurson constitutive law for modeling ductile damage
- Roussiler constitutive law for modeling ductile damage
- Beremin's model for cleavage fracture
- Modeling of material under transition temperature
- Case studies

EN 716: Preparedness & Response to Nuclear Emergencies (35)

- Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
- Radiation Shielding & Study of Criticality parameters and control
- Nuclear Waste Management
- Nuclear Accidents/emergencies
- Transport of Radioactive material
- Radiological accidents/emergencies
- Effects of Hiroshima & Nagasaki bombing
- Detection of Nuclear detonation
- Nuclear weapons: effect (Blast, heat, Radiation and EMP)
- Medical decontamination with demonstration
- Nuclear weapon tests (atmospheric)
- Nuclear & Radiological terrorism (Method to contain and control)
- Chemical warfare & Biological warfare (Method to contain and control it)
- Emergency Response methodology/ Philosophy
- Systems and methodology for Radiological impact assessment
- Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities
- Emergency Monitoring & Shelters
- Civil defence WEB plan for Nuclear attack on major cities
- Monitoring of High radiation field area
- Lab Visits

EN 717: Project Management (25)

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
  - Resources of project.
  - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an

activity, earliest start time EST, latest completion time LCT.
- Scheduling in a project by critical path method, CPM
- Scheduling in a project by Precedence Diagram Method.
- Use of Project Management Software for project planning, scheduling & monitoring.
- Preparation of master control management milestone network, Level-1,2, 3 & 4 network.

- Preparation of Target Plan, updating of progress, monitoring variance & reporting
  - Constraints of project and its effective management
  - Development of Six Monthly Plan and its review process
  - Resource based planning
  - Physical & Financial Monitoring of project, Use of S-curve
  - Capital Budgeting & expenditure control in a project
  - Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis methods, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN 718: Reliability Engineering (ME) (25)

- Reliability Mathematics – Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
- Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
- Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
- Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
- System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
- Application of Reliability - PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

References:

1. Mishra, K.B., “ Reliability Analysis and Prediction”, Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M.,Reliability& Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., “Reliability in Engineering Design”, John Wiley & Sons, 1977.
5. Balaguruswamy, E., “Reliability Engineering” Tata Mcgraw-Hill, 1984.

14. Provan, J.W., “Probabilistic Fracture Mechanics & Reliability”, Martinus Nijhoff, 1987.
15. Nowak, A. S. and Collins, K. R., “Reliability of Structures” McGraw Hill, 2000.
16. Ayyub, B. M. and McCuen, R. H., “Probability, Statistics and Reliability for Engineers”, CRC Press, 1997.
17. Haldar, A. and Mahadevan, S., “Probability, Reliability and Statistical Methods in Engineering Design”,
18. John Wiley and Sons, Inc. 2000.

EN 719: Signal Conditioning, Recovery & EMI Aspects (25)

Review of Analog Signal Conditioning & Recovery Techniques

- Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types ofA/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

Theory of Quantization

- Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti- aliasing filters, fast algorithms for implementation.

Theory of Signal Analysis and Reconstruction

- Function space, orthogonal basis functions, Limitation of Shanon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

Review of EMI Aspects

- Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

EMI Modeling

- Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EN 720: Software Engineering (25)

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools.(3)
- Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods Testing principles, unit testing, integration testing, acceptance testing Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

EN 721: Vibrations (25)

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.
  - Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
  - Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor;

Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinary.

- Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, aperiodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN 722: Safety and Reliability of Civil Engineering Structures (25)

Introduction to Probability Theory

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, ProbabilityDistributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

Structural Reliability

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment Method, Hasofer Lind Reliability Index, Rackwitz Fiesseler Method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

Probabilistic Safety Assessment

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

Industrial Safety

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

Safety assessment of existing structures:

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

Introduction to decommissioning of structures

References:

1. Hahn, G. J.and Shapiro, S. S. (1994), “Statistical Model in Engineering” Wiley-Interscience.
2. Ranganathan, R. (2000), “Reliability analysis and design of structures”,Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), “A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”, The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety Standard No. AERB/SS/CSE.
6. AERB (1996),“Atomic Energy (Factories) Rules”.

7. AERB (1991), “Safety Guide for Works contract”, Safety Guide No. AERB/SG/IS-1
8. AERB (1996), “The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex”, Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”.
10. Regulatory Guide 1.165 (1997), “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion”, U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (25)

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- BeamWelding Processes
- Arc-Beam Hybrid WeldingProcesses
- Study of welding arc characteristics
- Metal transferduringarcwelding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on themacro-andmicro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high coolingrates
- Phenomena of hot-crackingand coldcracking
- Residualstresses anddistortion duringand afterwelding
- Residual stressmeasurements
- Application ofaboveprinciplesto welding ofcarbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

EN724: Advanced Structural Dynamics and Earthquake Engineering(CE) (30)

I. Introduction to Structural Dynamics and Earthquake Engineering

II. Performance Based Design of structures, systems and components subjected to earthquake loading

Concepts of performance bases, Seismic demand, Capacity of structures, systems and components, performance levels, energy dissipation and damping.

II. Seismic and Vibration Control

Concepts of seismic and vibration control, Passive control using Yielding dampers, friction dampers, tuned mass dampers, Tuned liquid damper, etc., Semi active and active control strategies.

III. Base Isolation Techniques

Concepts of vibration and seismic isolation, laminated rubber bearings, Lead plug bearings, Friction Isolation System etc.

V. Testing and Modal analysis

Need of testing, Methods of testing, qualification of systems by testing, data processing using FFT and Wavelets, modal analysis for frequency, mode shapes and damping. Causes and types of experimental error, statistical analysis of data.

VI. Seismic and Vibration Instrumentation

Measurement Methods and Applications: Measurement of displacement, velocity, acceleration, pressure, forces, strain and optical methods of measurements; Data Acquisition and Processing.

Types of inputs: analog and digital signals, calibration and uncertainty, Measurement System: Performance characteristics, linearity, dynamic range, sensitivity, stability, accuracy, bandwidth, noise, repeatability, hysteresis- threshold- resolution, readability and span.

VII. Fluid-structure interaction techniques

Coupling of fluid with structure, Dimensionless numbers in fluid-structure interactions, Added mass and added stiffness, Fluid sloshing, Flow induced vibration, Flow over bluffed bodies, Vortex shedding.

VIII. Multibody Dynamics

Rigid-Body Kinematics, Kinematics for General Multibody Systems, Modelling of forces in multibody systems, contact forces, friction effect, Equations of Motion of Multibody Systems.
Numerical integration methods for free standing objects, spring-mass system with friction, Runge Kutta methods, error estimation, Computer programs.

Text / Reference Books

1. A. K. Chopra, "Dynamics of structures", Prentice Hall, 4th edition, 2007.
2. S. S. Rao, "Mechanical vibration", Prentice Hall, 5th edition, 2014.
3. Holman, "Experimental Methods for Engineers", 6e, McGraw-Hill, 1994.
4. Doeblin, Engineering Experimentation, McGraw-Hill, 1995.
5. Hans-Joachim Bungartz Michael Schäfer, "Fluid-Structure Interaction Modelling, Simulation, Optimization", Springer-Verlag Berlin Heidelberg 2006.
6. Soong, T.T. and G.F. Dargush, "Passive Energy Dissipation Systems in Structural Engineering", Wiley & Sons, New York, 1997
7. Farid Amirouche, "Fundamentals of Multi Body Dynamics, Theory and Applications", Springer Science, 2006

NON-SUBJECT ASSIGNMENTS

EN 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

EN 592.1: Process Control Trainer (15)

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

Expt 1

Introduction to typical process under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.

Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

Expt 2

Optimisation of process control - using ultimate sensitivity method.

Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.

Optimum gain and integral / differential time constants are calculated using empirical formulae.

Expt 3

Feed forward control configuration - study of process response in comparison with normal feedback control.

Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

Expt 4

Smart Differential Pressure transmitter.

Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.

Re range transmitter using HART communicator.

Re configure transmitter for linear and square root characteristics.

Expt 5
Final control element - Linear pneumatic control valve.
Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.
Virtual instrumentation and wireless data communication between controller and PC.

EN 592.2: Nuclear Detectors (15)

A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.

NaI(Tl) γ- Ray Scintillation Detector

This experiments imparts training on the use of NaI(Tl) detector using known γ- Ray sources (Co^{60} & Cs^{137}) , plotting of calibration curves and identification of unknown sources.

α-Particle spectroscopy using a Solid State Detector

This experiment imparts training on the use of the Solid State Detector using known α-Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup. **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter , testing counting statistics of the counter and studying absorption behaviour of β-rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN 593: Mini-Project Work (300)

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.). Project runs on a part time basis for 11 weeks from mid May to Mid July.

BACK TO MAIN

BARC TRAINING SCHOOL - AMD CAMPUS

ORIENTATION COURSE FOR ENGINEERING GRADUATES & SCIENCE POST-GRADUATES (OCES)

SYLLABUS

GEOSCIENCES

Course No.: 102
Subject: Nuclear Physics and Radiation Detection

S. No.	Topics	Chapters
1	Nuclear Physics	Structure of nucleus - Atom, Electron, Proton and Neutron, the Proton-Electron hypothesis of the constitution of the nucleus, Proton-Neutron hypothesis
		Magnetic and Electric property of the Nucleus
		Additional Properties of Atomic Nucleus
		Natural Radioactivity - Basic theory of Radioactive disintegration, disintegration constant, Half-life, Mean-life
		Radioactive equilibrium, Units of Radioactivity
		Alpha decay - Velocity and Energy of Alpha Particle, Absorption of Alpha Particle, Range, Ionization and Stopping Power, Range-Energy curve, Nuclear Energy Levels and the Theory of Alpha Decay;
		Beta decay - Velocity and Energy of Beta Particle, Absorption of Beta Particle, Range, Ionization and Stopping Power, Range-Energy curve, Nuclear Energy Levels and the Theory of Beta Decay, Symmetry law and Non-conservation of parity in Beta Decay
		Gamma decay - Gamma decay, Internal Conversion, Nuclear energy levels theory, Absorption of gamma ray with matter; Interaction of radiation with matter - Interaction of charged particles, Interaction of gamma rays: Photoelectric effect, Compton scattering, Electron-Positron pair-production;
		Natural decay series - Uranium Series, Thorium Series, and Actinium Series
		Radioactive growth and decay: Mathematical explanation of growth and decay curve
		Disequilibrium: Secular Equilibrium, Transient Equilibrium, Ideal Equilibrium
		Nuclear fission: Discovery of Nuclear fission, Fission cross-section and threshold, Neutron emission in fission and theory of fission process, Energy distribution in fission process
		Nuclear fusion: Discovery of Nuclear fusion, theory of fusion process, Energy distribution in fusion process; Counting statistics: Explanation of Binomial
		Distribution, Poisson Distribution and Gaussian Distribution
		Propagation of errors; Artificial radioactivity: Explanation of Induced Radioactivity, Radioactivity cross-section.
2	Radiation detection and measurement	General properties of detectors - Efficiency, Resolution, Dead time of the detectors; Gaseous detectors - Ionization Chamber, Proportional Counter
		Geiger-Muller Detector etc; Scintillation detectors

S. No.	Topics	Chapters
		The basic function of a scintillation detectors, photo multiplier tube and its function
		Various types of Scintillation detectors, Detection mechanism of NaI(Tl); Semiconductor detectors
		The Basic principle of Semiconductor Detector, Energy Gap, Various types of semiconductor detectors and its principles, Resolution, Fano factor; Neutron detectors
		Slow and Fast Neutron detection methods
		Nuclear Reaction of Interest in Neutron Detection
		Counters based on Neutron Moderation
		Other detectors - Explanation of Cherenkov Detectors, Photographic Emulsions, Thermoluminescent Dosimeters, Track Etch Detectors etc. Pulse processing and measurements - Pre amplifier, Amplifier and MCA etc.
3	Lab	
3.1	Gamma ray spectrometry	Measurement of gamma ray energy for the estimation of Ra(eq), ThO2 & %K
		Beta-Gamma technique
		Explanation and practice of technique used for the estimation of U3O8 in the sample
		Gamma ray logging & core analysis
		Explanation and practice of technique used for Gamma ray logging
		Shielded Probe Logging, and analysis of core samples
3.2	Instrumental Neutron Activation Analysis (INAA)	Principle and operation of INAA
3.3	Radon Emanometry	Methods for the measurement of Radon: CCT-Method, SSNTD Method, and ROAC Method
4	References	1. Radiation Detection and measurement – By G.F.Knoll. 2. Nuclear Physics- By D.C.Tayal. 3. The Atomic Nucleus- By R.D.Evans. 4. Measurement and Detection of Radiation- By N. Tsoulfanidis. 5. Nuclear Physics -by Irving Keplan 6. Basic Electronics, - Bernard Grob

S. No.	Topics	Chapters

Course No : 103
Subject: Basic Geophysics for Geologists

S. No.	Topics	Chapters
1	Introduction	Geophysical methods and the associated physical properties
		Classification of geophysical methods
		Role of geophysical methods in mineral exploration
		Effectiveness and limitations of various geophysical techniques with special reference to uranium exploration
		Geophysical signatures of uranium deposits
2	Magnetic and gravity methods of prospecting	Magnetic Method - Earth's magnetic field and its variations
		Magnetic properties of materials, Remnant magnetization
		Instruments for measuring magnetic field
		Field surveys, Corrections Reduction of magnetic data
		Magnetic anomalies due to bodies of simple geometry
		Gravity Method -Earth's gravity field and its variations, Figure of Earth, Isostacy, Absolute and relative measurements of gravity field
		Instruments for measuring gravity field, Field surveys, Reduction of gravity data Interpretation of gravity and magnetic data
		Anomaly patterns, Characterization of anomalies. Anomalies due to bodies of simples geometry (1D, 2D and 3D).
		Variation of magnetic anomaly in relation to magnetic latitude, azimuth and dip of the body, Ambiguity in interpretation of data, Forward and inverse modeling
		Applications and field examples
3	Electrical methods	Classification of electrical geophysical method
		electrical properties of rocks
		Self Potential method: Origin of self potentials field equipment and survey, anomalies due to bodies of simple shape

S. No.	Topics	Chapters
		Interpretation, field examples and applications
		Resistivity method: Ohm’s law,
		True and apparent resistivity
		Geoelectrical sections, Different electrode arrays, resistivity profiling and sounding
		Field equipment
		Interpretation of field data
		typical resistivity profiles over simple geological structures, use of Master curves for interpretation of data over multilayered medium
		Applications and Field examples
		Induced Polarization method: Origin, Membrane polarization, Electrode polarization, Time domain and frequency domain measurements, Parameters measured, Field equipment
		Typical profiles, Interpretation, Applications, Field examples
		Electromagnetic methods: Classification of methods
		Elementary theory of propagation of electromagnetic waves.
		Primary, Secondary and Resultant fields, Skin depth
		Frequency domain methods: Fixed source method, Moving source-moving receiver method, Very low frequency (VLF) method
		Ground penetrating radar technique, Parameters measured
		Field equipment
		Presentation of data
		Applications and field examples
		Time Domain method: Principle, Merits and demerits
		Survey configuration, Field procedure and equipment, typical profiles
		Applications and field examples Natural source EM methods.
		Telluric and magnetotelluric methods: Sources and the frequencies studied, Typical profiles, Applications and field examples.
4	Seismic methods	Elastic constants, Longitudinal, Transverse and Surface waves

S. No.	Topics	Chapters
		Hooke's law, reflection, refraction and diffraction from multilayered media
		Seismic energy sources and detectors
		Refraction seismic: Principle, Critical angle, critical distance, Velocity inversion, Refractions at parallel and non-parallel interfaces. Source-detector arrays, Fan shooting, applications and case histories
		Reflection seismic: Principle, Acoustic impedance. Time-distance graph, Reflections at parallel and non-parallel interfaces, Field procedures, Common Depth Point technique
		Applications and field examples.
5	Borehole logging methods	Objectives, different logging techniques, Principles
		Instrumentation and operational procedures of Self Potential, Electrical resistivity, Induction, Magnetic susceptibility, Sonic, Caliper, density, I.P. and radiometric logging techniques
		Applications and field examples
6	Tutorials	Computation of magnetic and gravity anomalies over regular shaped bodies;
		Smoothing of data by filtering techniques
		Estimation of mass from gravity data
		Interpretation of vertical electrical sounding curves
		Preparation of pseudo-sections of resistivity and IP data
		Interpretation of HLEM data using standard curves
		Interpretation of seismic refraction data by graphical and analytical methods
		Identification of formational boundaries from well logs.
7	References	1. Ramachandra Rao, M.B., 1975 Outlines Of Geophysical Prospecting - A Manual For Geologists, Prasaranga, University Of Mysore, Mysore,. 2. Bhirnasankaram V.L.S. 1990. Exploration Geophysics An Outline , Association Of Exploration Geophysicists, Osmania University, Hyderabad,. 3. Telford W.M., Geldart L.P., Sheriff, R.E. and Keys D.A. 1976, Applied Geophysics By Oxford And Ibh Publishing Co. Pvt., Ltd., New Delhi,. 4. Rama Rao, B.S. and Murthy, I.V.R. 1978, Gravity And Magnetic Methods Of Prospecting Arnold Heinemann Publishing, New Delhi,

S. No.	Topics	Chapters
		5. L.L. Nettlton, 1976, Gravity And Magnetic In Oil Prospecting , Mcgraw Hill 6. Dobrin, M.B An Introduction To Geophysical Prospecting 1984, Mcgraw Hill. 7. Telford W.M., Geldart L.P., Sheriff, R.E. And Keys D.A. 1976, Applied Geophysics By Oxford And Ibh Publishing Co. Pvt., Ltd., New Delhi. 8. Parasnis, D.S. 1997 Principles of Applied Geophysics. Chapman & Hall 9. Sumner, J.S.1976, Principles of Induced Polarisation for Geophysical Exploration. Elsevier. 10. Philip Kearey 2007, An Introduction To Geophysical Exploration, Michael Brooks, Ian Hill Blackwell. 11. Electromagnetic Methods In Applied Geophysics.Applications Ed. Misac N Nabighian, Society Of Exploration Geophysicists 1997 12. Dobrin, M.B., 1984.An Introduction To Geophysical Prospecting By Mcgraw Hill, New Delhi, 13. W.M., Geldart L.P., Sheriff, R.E. And Keys D.A. 1976. Applied Geophysics By Telford Oxford And Ibh Publishing Co. Pvt., Ltd., New Delhi, 14. C.L. Liner, 2004, Elements of 3d Seismology, Pennwell Corporation, U.S. 15. R.E. Sheriff and L.P. Geldart, 1995 Exploration Seismology, Cambridge University Press. 16. E.S. Robinson and C. Coruh, 1988. Basic Exploration Geophysics, John Wiley And Sons, New York 17. O.Serra, 2003. Well Logging And Geology, Technip, Paris 18. O. Serra, 1984. Fundamentals of Well Log Interpretation, Elsevier. 19. R.M. Bateman, 1985, Open hole Log Analysis And Formation Evaluation, Reidel, Dordrect. 20. G. Asquith and C. Gibson, 1982. Basic Well Log Analysis for Geologists, Academic Press, London

Course No.: 104
Subject: Basic Geology for Geophysicists

S. No.	Topics	Chapters
1	Introduction to geology	The origin and internal structure of the Earth
		Composition of crust mantle and core
		Surface and internal processes: geomorphic processes and sedimentation; orogenic processes, mountain building, volcanism, metamorphism and rock deformation

S. No.	Topics	Chapters
		Rock structure: folds, faults and joints, brittle and ductile deformation, lineation and foliation
		Principles of stratigraphy
		Geological Time Scale, correlation and geochronology
		Elements of Indian stratigraphy
		Precambrian shield areas
		Important Phanerozoic successions, elements of Himalayan geology.
2	Introduction to minerals and their identification	Major rock forming silicates and common ore minerals
		Brief introduction to the formation and classification of common igneous, sedimentary and metamorphic rocks
		primary igneous and sedimentary structures, unconformity, dip and strike.
3	The dynamic earth	Continental drift, theory of plate tectonics
		different types of plate margins, association of metallic deposits in different tectonic settings
4	Introduction to ore forming processes and mode of occurrence of common ore deposits	Epigenetic and syngenetic deposits. Classification of ore deposits
		Orthomagmatic processes and examples of orthomagmatic deposits
		Pegmatitic and pneumatolitic deposits
		Classification of pegmatites, skarn and metasomatic deposits
		Hydrothermal processes Examples of modern ore solutions, aqueous transport of metals and deposition of metals from ore solutions, meteoric and juvenile solutions and their discrimination
		Hydrothermal deposits forms and classifications
		Weathering, supergene enrichment and residual deposits.
		Sedimentary deposits, deposits formed by mechanical transport and by chemical precipitation, Eh-pH diagrams
		Metamorphic and metamorphosed ore deposits.
5	Lab	Identification and interpretation of geological features in topographic maps
		Identification and interpretation of structural elements in geological maps: Faults, folds, unconformities

S. No.	Topics	Chapters
		Construction of geological cross-sections, stratum contours, isopach maps
		Stereographic plotting of planes and lines
		Study of stratigraphic maps of India
		Analysis of folds, Analysis of faults, Strain measurements
		Identification and description of hand specimens of common silicate minerals, common igneous, sedimentary and metamorphic rocks, common sulphides and oxide ore minerals and economic rocks
		Introduction to optical identification of minerals
6	References	1. Evans, A.M. Ore Geology and Industrial Minerals - An Introduction, Oxford Blackwell Scientific Publ, London, 1993. 2. Guilbert, J.M.andPark, C.F.Geologyof Ore Deposits, Freeman, W.H, 1986. 3. Jensen M.L. and Bateman, A.L. Economic Mineral Deposits, Wiley, 1979. B.J.Skinner, and S.C.Porter, The Dynamic Earth – An introduction to Physical Geology, Wiley, 1989 4. G.W. Tyrrel, The Principles of Petrology: an introduction to science of rocks, BI Publications, India. 1985. 5. D.R.Prothero and F.Schwab, Sedimentary Geology: An introduction to sedimentary rocks and stratigraphy, Freeman and Co., New York 6. B.J. Skinner and S.C.Porter, the Blue Planet, Wiley, 1995. 7. P.D. Duff, (Ed). Holmes, Principles of Physical Geology, 4th Edition. ELBS, 1992. 8. H.H.Read, and J.Watson, Introduction to Geology I and II. Macmillan, 1978. 9. G.H.Davies, Structural geology of rocks and regions, Wiley, New York, 1996

Course No.: 105

Subject: Uranium Geology, Survey , Prospecting

S. No.	Topics	Chapters
1	Introduction	Objectives and challenges
		Geological considerations, time and project value estimation, terrain, legal, political and local issues
2	Uranium in the crust	Distribution of uranium - crustal abundance
		Time bound character
		Uranium in different rocks and minerals with some examples;.
		Classification of uranium deposits; uranium deposits in the world
3	Exploration guides	Controls of mineralization – stratigraphic, structural, lighological and other controls;
		Stratigraphic guides: earl
		Lithological guides
		Structural guides - fault, fracture, foliation and their intersections, fault-breccia systems;
		Geochemical guides - Indicator/pathfinder elements,
		Mineralogical guides - Poly metallic mineralisation- Pb, Cu, Ni, Co, Se, As, Au, Ag, Te and Zn and sulphide mineralization
		Weathering and alteration, diffusion aureole, leakage anomaly, dispersion and mobility patterns, K2O/ MgO, U, Ni, As, V, Mn and B abundances,
		Geochemical association of uranium with other trace elements
		Proterozoic basal Quartz- Pebble Conglomerate (QPC) type
		Proterozoic unconformity type
		Porous, permeable carbonaceous matter rich Mesozoic sandstone type
		Intrusive and reactivated granites
		Carbonaceous/ graphitic metapelites
		Graphitic schists, black shales
		Calcrete
4	Exploration methodology	
		Literature survey and conceptual modeling - study of available maps, identification of favourable parameters and

S. No.	Topics	Chapters
		geological environments;
		Reconnaissance and detailed survey – geological mapping from exploration point of view by remote sensing and ground surveys, narrowing down the target area;
		Uranium mineralogy – primary and secondary uranium minerals, their field identification.
5	Geochemical techniques	Stages of geochemical survey (Planning, deciding parameters for exploration, Orientation survey, Reconnoitory survey, detailed surveys)
		Hydrogeochemical techniques (Uranium and radium in surface and ground water, sampling);
		Lithogeochemical and pedogeochemical techniques (choosing grid pattern, sampling techniques),
		interpretation of analytical data
6	Radiometric techniques	Ground radiometric survey, gross gamma and spectometric measurements, demonstration of field equipments,
		Traverse planning, background radiation and anomaly detection, evaluation of anomaly
		Isorad mapping, channel sampling, shielded probe logging and radiometric assay of grab samples
		radon emanometry - isotopes of radon, migration, sampling techniques (CCT, SSNTD, ROC) and limitations
		Helium survey - principle, diurnal variation, sampling system, uses
7	Prospecting for uranium	Sampling: point, grab, grid samples; channel sampling; sample volumes; Sampling by drilling,
		stratigraphic, reconnoitary, exploratory and evaluation drilling;
		Planning of boreholes, choosing location and grid pattern,
		Borehole plan, selection of type of drilling(non-core/core),
		Lithological and geophysical logging
		Drift/deviation
		Borehole correlation sections,
		Preservation core, core skeletonization, sampling of boreholes sludge/core, comparative study of physical and chemical assay results of boreholes
		Estimation of disequilibrium.
		Assaying, rock density;
		Averaging of assay values from one location – samples of equal length/unequal lengths
		Averaging of assay values from different locations – evenly spaced samples, unevenly spaced samples;

S. No.	Topics	Chapters
		Compensation for varying rock density; erratic assays;
		Recent trends in uranium exploration
		Present status of uranium supply and demand, new discovery of uranium deposit in the world and in India; Case studies using different exploration techniques with examples from India and World.
8	References:	1. Economic Mineral Deposit-Alan M. Bateman 2. Uranium Supply and Demand-Michael J.Spriggs, Uranium Inst London 3. Uranium resources, production and demand summary-OECD-NEA and IAEA 4. World uranium deposits: uranium exploration geology; Proceedings of a panel, IAEA, Vienna-S. H. U. Bowie 5. Uranium Geology and Exploration -Richard H. De Voto 6. Classification of Uranium deposits-F. J. Dahlkamp 7. Radioactivity in geology: principles and applications- E.M.Durrance

Course No.: 106
Subject: Surveying, Drilling and Mining

S. No.	Topics	Chapters
1	Surveying	Types of surveys and applicability
		Principles and methods of surveying & mapping
		Surveying Equipment – Compass, The Transit, Optical Distance Measuring
		Modern surveying electronic equipments - Digital levels, Digital theodolites, EDMs and Total stations
		Principles, working and applications
		Survey Methods - Co-ordinate methods, Bearings, Traversing and Trilateration (Topo)
		Detail Survey, Orientation and position, Determination of True bearing, Horizontal and vertical control, Accuracy standards;
		Positioning – Introduction, Differential positioning,
		GPS instruments, Global Positioning Augmentation Systems; Errors in measurements – Blunders, Systematic errors, Random errors, Most probable value, Average error, Standard deviation
		Analysis and adjustment of measurements
		Distribution, Adjustment of errors by Approximate method and Least squire method

S. No.	Topics	Chapters
		Coordinate System in Geodesy - Geocentric Cartesian Coordinates, Topocentric Cartesian or local geodetic Cartesian Coordinates, Geodetic Coordinates, Planimetric Cartesian coordinate
		Datums - Horizontal datums - Everest spheroid, WGS – 84, datum transformation; Vertical datums - Mean Sea Level, Geoid, EGM 96
		Projection – Polyconic projection, Traverse Mercator projection (TM Projection), Universal Transverse Mercator Projection
2	Tutorials	Adjustment of instrument errors by approximate method and Least square method. Datum transformation exercises.
3	Drilling	History of Drilling; Methods of soil sampling - Auger, Drive sampling;
		Rock Drilling – Percussive, Attritive, Rotary Cutting, Shearing etc.,
		Rotary reverse circulating, Rotary with down hole motors, Cable tool method;
		Diamond Drilling - Diamond quality, types of diamond bits, natural and synthetic diamonds, Rotary core drilling equipment, Drilling standards, circulating media, Drilling fluid properties
		Controlled Directional Drilling - Deviation in drilling, Measurement of deviation and control, Tools for directional drilling, Downhole motors
		Various types of drills in use in AMD
	References:	1. Drilling Technology by C.P. Chugh 2. Drilling Technology Part 1 & 2 by British Drilling Association 3. Thomas, L.J. An Introduction to Mining, Methuen, Brisbane, 1978. 4. Sinha, R.K. and Sharma, N.L. An Introduction to Mineral Economics, Wiley Eastern, 1993. 5. Chatterjee, K.K. An Introduction to Mineral Economics, Wiley Eastern, 1993.

Course No.: 107
Subject: Theory of Fields

S. No.	Topics	Chapters
1		Mathematical and physical fields, Continuity, Scalar and Vector fields.
		Static fields in free space, Coloumb's law, Newton's law, Field intensity, lines of force, charge density, Curl of vector, Stoke's theorem, Gauss's law, Gauss's divergence theorem, Poisson's and Laplace's equations, Electrical dipole, Double layer. Dielectrics and conductors, Polar and non-polar dielectrics.

S. No.	Topics	Chapters
		Harmonic functions, orthogonal curvilinear, spherical and cylindrical co-ordinates, Method of images, Green's theorem, Green's function, Green's equivalent stratum, Dirichletand Neumann problems
		Electric fields in conductors, Ohm's law in integral and differential forms. Magnetic fields, Magnetic flux, Magnetic vector potential, Induction in magnetic media, Relation between gravity and magnetic potentials. Electromagnetic induction.
		Laws of induction, Electric and magnetic energy densities, displacement currents, Poynting's theorem
		Electromagnetic radiation from an oscillating dipole.
	References:	1. V.L.S. Bhimasankaram And S.V. Seshagiri Rao, 1973, Theory Of Fields, Osmania University, Hyderabad, 2. Alexander A. Kaufman, 1992, Geophysical Field Theory And Method: Gravitational, Electric And Magnetic Fields. Academic Press.

Course No.108
Subject: Geochemistry and Geochemical Exploration

S. No.	Topics	Chapters
1	Geochemistry	Geochemistry as a branch of Chemistry, Brief understanding of the periodic table and inter-relationships between various elements, Hunds rule, Aufbau principle, Pauling's exclusion principle, Ionisation energy, electron affinity, electronegativity etc
		Primary geochemical differentiation, Geochemical classification of elements, geochemical associations
		Distribution of Major and trace elements in primary and secondary environment,Partition coefficient/ distribution coefficient and separation constants, Stable isotopes, Geochemical cycle of Uranium, Geochemistry of uranium, REE Geochemistry
		Eu and Ce anomaly interpretations
2	Geochemical thermodynamics	Equilibrium thermodynamics, state functions, ideal and real gases, equations of state, properties of vapours and solutions
		Laws of thermodynamics, reversible and irreversible processes, internal energy, enthalpy, heat capacity and entropy, calorimetric measurements
		Gibb's free energy in relation to temperature and pressure. Chemical potential, Gibb's-Duhem equation, heterogeneous equilibria and phase rule
		Standard states, activity and fugacity. Ideal solutions, Henry's law, Roults law

S. No.	Topics	Chapters
		Non-ideal solutions
		Phase diagrams.
3	Water chemistry	Solutions and solubilities, solute-solvent, solubility product and ion activity product
		Ionic strength of the solution, Debye-Huckel theory, Davies equations, units of concentration- molarity, molality, mole fraction, equivalents and normality
		pH and Eh concepts, Nernst equation (derivation), Geochemical fences, Limits of water stability
		Ore Genesis-Physico-chemical environment of ore genesis, Major theories- Origin due to Internal processes, Magmatic segregation, Magmatic deposits, Sublimation
		Hydrothermal deposits, metamorphic deposits, Contact metasomatism and wall rock alterations. Origin due to surface processes-Evaporation, residual and mechanical concentration/accumulation
		Origin due to secondary processes-Oxidation and Supergene enrichment.
4	Geochemical Exploration	Geochemical surveys–litho geochemical, hydro geochemical, pedo geochemical, Geobotanical /biogeochemical and Atmo geochemical techniques, Pathfinder and indicator elements
		Dispersion - Primary dispersions-Zonality, Wall rock alterations
		Secondary dispersions-mechanical, Gaseous, Residual, outcropping concealed and superimposed
		Hydro geochemistry- Significance of Eh, pH, T°C, Ec. solubility index and its significance in the secondary environment
		Eh-pH Diagrams constructions and their Significance
		Soil geochemistry, ionic potential and geochemical separation. Geochemical maps
	Tutorials	Evaluation Analysis & Interpretation of Geochemical Data (litho- pedo- hydro- biogeo & atmo- geochemical data) using conventional techniques and through use of various geo-software
		Derivation and interpretation of Partition coefficient/ distribution coefficient and separation constants.REE data normalisation using different rock standards, Eu and Ce anomaly interpretations
		Gibbs free energy in relation to temperature and pressure
		Gibbs- Duhem equation, construction of phase diagrams, solubility product and ion activity product, derivation of solubility index, Nernst equation (derivation), Calculation of limits of water stability using thermodynamic data, Geochemical fences, construction of Eh-pH Diagrams, Preparation of various geochemical maps
	References	1. Mason, B. Principles of Geochemistry, Wiley Eastern, 1982.

S. No.	Topics	Chapters
		2. Krauskopf, K.B. and Bird, D.K. Introduction to Geochemistry, McGraw-Hill International Edn., 1995. 3. Anderson, G.M. and Crerar, D.A. Thermodynamics in Geochemistry- the Equilibrium Model, Oxford Univ. Press, NY, 1993. 4. Wood, B.J. and Fraser, D.G. Elementary thermodynamics for geologists. Oxford, 1977. Nordstrom, D.K. and Munoz, J.L. Geochemical Thermodynamics, The Benjamin/ Cummings Publishing Co., Inc. 1985.

Course No. : 109
Subject: Seismic methods

S. No.	Topics	Chapters
1		Basic concepts, Hooke's law, Elastic wave propagation Wave equation, Elastic constants, Elasticc waves, Huygene's and Fermat's principles, Snell's law, Reflection, refraction and diffraction from multilayered media; Factors affecting seismic wave velocities, Partition of energy at an interface, acoustic impedance, Reflection and transmission coefficients, Zoeppritz's equation, Structure of Earth; Seismic refraction method - Head wave refraction, critical angle, Time distance curves, Critical distance, Geometry of refraction paths – two layer and multilayer media; Velocity inversion/hidden layer problem, Field lay outs, Fan shooting, Interpretation of refraction data – graphical and analytical approaches; Seismic reflection method- Principle, Time-distance graph, Geometry of reflection paths – horizontal reflector, dipping reflector; Common depth point technique, Stacking chart and CDP diagram for normal and crooked profiles, Static corrections, NMO, Velocity analysis, Migration, Wavelet propagation, attribute analysis. Wide angle reflections; Deep seismic soundings; Field procedure; Vertical seismic profiling; 3D and 4D seismic exploration, Seismic tomography, Basic concepts; Data acquisition; Energy sources – dynamite, vibroseis, hammer, airgun, Detectors – geophone, hydrophone; Grouping of geophones, Noise profile analysis, Source-detector arrays, Directional shooting, Instrumentation, Digital seismic recording- general lay out, pre-amplifier, filters, multiplexers, A-D converter, AGC, SEG formats; Telemetry systems;
2	Tutorials	Construction of wavefronts for two and three layer cases, Interpretation of refraction data –graphical approach (Mean minus T and Hale's methods) and analytical approach (Generalised reciprocal method).; Construction of CDP diagram and stacking chart for normal and crooked profiles; NMO correction; Determination of velocity and interface from reflection data; Plotting of reflection points on dipping reflecting layers; Noise profile analysis and optimum group spacing; Seismic data processing from demultiplexing to migration using standard software package; Simulation of seismic responses by finite element and finite difference methods.
3	References:	1. C.L. Liner, 2004, Elements Of 3d Seismology, Pennwell Corporation, U.S. 2. R.E. Sheriff And L.P. Geldart, 1995 Exploration Seismology, Cambridge University Press. 3. E.S. Robinson And C. Coruh, 1988. Basic Exploration Geophysics, John Wiley And Sons, New York

S. No.	Topics	Chapters
		4. Dobrin, M.B., 1984. An Introduction To Geophysical Prospecting Mcgraw Hill, New Delhi, 5. Encyclopedic Dictionary Of Exploration Geophysics. Sheriff, R.E. Society Of Exploration Geophysicists, 1984

Course No. 110

Subject: Remote Sensing and GIS

S. No.	Topics	Chapters
1	Introduction	Fundamental concepts of Remote Sensing – Electromagnetic Spectrum, Energies available for sensing, Interaction of EMR with the atmosphere and terrain features
		. Mineral and Rock spectra. Application of energy bands for Geological studies
2	Imaging systems and sensors	Sensors in space today- Radiometric, Spectral and Spatial resolutions
		Selection of spectral and spatial resolutions for different geological themes
		Identification of the satellite data product, product codes, browsing of quality, product availability and procurement procedure
3	Elements of remote sensing and data interpretation	Fundamentals of image interpretation and geological applications-Tone, Texture, Drainage patterns and anomalies, colour, size and Object to background relationship
		Applications of geomorphology. Lithological and structural interpretation from satellite data
4	Digital image processing	Objective of Digital Image Processing, Georectification, Image mosaicing
		Image enhancement: Single band enhancement - Contrast stretching – Linear contrast stretching, Multiple linear stretching, Logarithmic or functional stretching, Gaussian stretching, Histogram equalization stretching and Density slicing
		Application of stretching techniques for geological interpretation and for anomaly zone extraction from airborne radiometric images; Edge enhancement – Anisotropic Kerenels (Linear edge), Gradiant image (1st Derivative), Laplacian image (2nd Derivative), Image smoothening
		Application of different edge enhancements to radiometric images; multiple Image Enhancement - Addition and substration of Images, Principle component Transformation, Image ratioing.
		Application of these transformations for Geological and radiometric interpretation; Spectral and spatial resolution merging – different methods, and its application to geological studies

S. No.	Topics	Chapters
5	Digital Image classification	Supervised classification, unsupervised classification, Application of classification for geological studies
6	Geographical Information Systems (GIS)	Introduction to GIS, Basic map concepts and Data layer generation, Topology building and Attribute Table generation
		Getting spatial data into GIS and making spatial data usable
		Getting attribute table in GIS and making it Linked and usable
		Defining real world coordinate system and Map projections to multi-coverage database
		Performing GIS analysis – Spatial operation, generating buffers, manipulating spatial features, polygon overlay and Tabular analysis
7	Geo-modelling	Introduction, principles of various modelling techniques in mineral exploration; concepts of mathematical modelling
		Vector and Raster geographical information system
		Geological, geophysical and geochemical data used in modelling
		Presentation of case study- nature of data, grid file generation, interpolation algorithms, validation of surface fitting, mathematical equations of trend surface, estimation of parameters of surface equations, goodness of fit, preparation of residual maps for variables and uranium accumulation trend analysis
8	Lab	Handling data products: different sensors and scale; procedure of browsing and selecting data; Interpretation of satellite data based on elements of Remote sensing - sedimentary, Igneous and Metamorphic terrain; Interpretation of structural features.
		Digital Image Processing: Georectification and Mosaicing; contrast stretching, edge enhancement, multiple image enhancements, Merging images, and image classification, using both satellite and radiometric data.
		GIS: working on ERDAS DIPS and ArcGIS for spatial data creation; defining real world coordinate system and Map projections; working on ArcGIS for some GIS analysis; Map Presentation
9	Reference	1. Remote Sensing and Image Interpretation - Thomas M, Lillesand and Ralph, W. 2. Remote Sensing Application for Mineral Exploration - Ed.William L. Smith 3. Remote Sensing data Book – 1999 - Gareth Rees 4. Remote Sensing for Geologists – a Guide to image interpretation - Gary L. Prost (2001) 5. Remote Sensing for Earth Sciences. Ed - Andrew 6. Remote Sensing Geology - Ravi P. Gupta

Course No.: 202

Subject: Exploration for Beach sands

S. No.	Topics	Chapters
1	Placers and the placer environments	Classifying the environments,
		Environmental change, the placer geological time-scale,
		Types of placer minerals
2	Placer sediments and sedimentation	Energy balance, Process-response elements, Sedimentary processes - Mechanical agents of weathering, Chemical agents of weathering, Biological agents of weathering, susceptibility of minerals to change, resistance of minerals to change, Erosion;
		Properties of sediments- Particle size, Particle shape, Particle density;
		Characteristic properties of placer minerals
		Sedimentation - flow of solids through fluids-sediment transportation and settling, Transitional marine sedimentation.
3	Placers and their formation:	Provenances and related minerals, Time related provenances, Tectonically related provenances, Regional aspects of provenance and placer mineral distribution ,Connecting provenance with minerals characteristics;
		Placer formation- Continental placers, Transitional placers, marine placers
		Transitional (Beach) Placers
		Beach terminology, beach morphology, common HMs on the beaches
4	Exploration and prospecting	The placer exploration model- Programme logistics, Exploration tools, Remote sensing and satellite imagery, aerial photography, geophysical and geo-chemical methods
		Prospecting – Reconnaissance, close testing, drilling methods,sampling,analytical methods
5	Placer valuation:	Classification of ore reserves and resources - geometrical and geo-statistical methods - cut-off grade, blending, dilution, feasibility studies
6	Placer mining and placer mineral processing:	Mining methods- Mechanical mining - wet and dry methods – dredging, ecological consideration; Mineral processing: Gravity concentration, magnetic and electro static separation
7	Economic value of placer	

S. No.	Topics	Chapters
	resources – world scenario	

Course No.: 202

Subject: Rare metals and Rare Earths

S. No.	Topics	Chapters
1		Introduction to Rare Metal & Rare Earth minerals and their significance in Modern Technology
		Geochemistry and mineralogy of RM RE minerals
		Geological characteristics of Rare Metal bearing granites, pegmatites ,carbontites and alkaline rocks
		Potential Rare Metal bearing of pegmatite belts of India and world scenario
		Rare metal bearing carbonatite-alkaline rock complexes of India and World scenario
		Geologic characteristics and genetic problems associated with development of granite hosted deposits of Tantalum and niobium
		Exploration Techniques for rare metals minerals
		Geochemical methods in exploration of Rare Metals and their ore reserve estimation
		Gravity Technique for Recovery of Rare Metals
	References	1. Alluvial Mining by Eoin H. Macdonald (1983), Chapman and Hall, London and New York. pp. 508 2. Macdonald, E.H. (1973) Manual of Beach Mining Practice, Exploration and Evaluation, 2nd Edition, Canberra 3. Techniques in Mineral Exploration by J.H.Reedman(1979) pp515 4. Cerny Peter 1992 Rare element granitic pegmatites part-I, Anatomy and internal evolution of pegmatite deposits, Geoscience Canada, vol 18, no.2 5. Heinrich, E.W. 1958 Economic geology of the rare earth elements. Canadian mining journal, 1979 6. Henderson, P. 1984 Rare earth element geochemistry 7. Moller, P. 1986 Rare earth mineral deposits – Lanthanides, tantalum and niobium. Proceedings of a workshop, Berlin. Springer-Verlag 8. Cermy, P. 1989. Characteristics of pegmatite deposits of Tantalum. In Lanthanides, Tantalum-Niobium spl. Publication

S. No.	Topics	Chapters
		vol.7, pp271-299 9. Ginsburg, A.I., Trimofeyer, I.N., and others 1979. Principles of geology of granitic pegmatites, Nedra, Moscow. 10. Ginsburg, A.I. 1984. The geological condition of the location and the formation of granitic pegmatites, proceedings of 27th international geological congress, vol. 15. 11. Teertstra, K.K., Cermy, P. and Howthrone, F.C. 1998. Rubidium feldspars in granitic pegmatites, vol. 36, part-Canadian Mineralogist

Course No.:203

Subject: Inversion methods in Geophysics and signal processing

S. No.	Topics	Chapters
1	Inversion techniques	Fundamental concepts, Inverses with discrete and continuous models
		Inverse methods based length, generalized matrix,
		inverses and maximum likelihood methods
		Non-uniqueness, applications of vector space, resolving kernels
		singular value decomposition, non-linear inverse problems
		Optimization techniques and algorithms, Marquardt algorithm, Parametric, generalized and constrained inversion procedures
		Backus-Gilbert Inverse problem, Applications of inverse theory to geophysics
2	Signal Processing	Signal processing in geophysics, Periodic function, Even and odd functions; Delta function Step function, Analog to Digital conversion; Integral transforms, Fourier transform, Discrete Fourier transform, Fast Fourier transform; Hilbert transform, Hankel transform, Walsh transform, Laplace transform, Z transform; Impulse response, Transfer function, Digital filtering; Convolution, Deconvolution; Auto correlation , Cross correlation; Sampling and reconstruction, Statistical Signal processing; Auto regression, Moving average. Auto recursive moving average filters; Weiner least square method for designing shaping and spiking filters, Butter worth filter, Applications in geophysics
3	References:	1. W. Menke, 1989, Geophysical Data Analysis: Discrete Inverse Theory, Academic Press. 2. J.A. Scales, M.L. Smith and S. Trietel, 2001, Introductory Geophysical Inverse Theory, Samizdat Press. 3. D. Gubbibns, 2004, Tgime Series Analysis and Inverse Theory for Geophysicists, Cambridge University Press. 4. E.A. Robinsonand S. Trietel, 1980. Geophysical Signal Analysis. Prentice Hall, New Jersey

S. No.	Topics	Chapters
		5. Ronald N. Bracewell, 1999, the Fourier Transform and Its Applications, Mcgraw-Hill. 6. John F. Clearbout, 1985, Fundamentals of Geophysical Data Processing With Applications To Petroleum Prospecting. Blackwell Scientific Publications 7. P.S.Naidu & M.P.Mathew, Advances in Exploration Geophysics 5: Analysis of Geophysical Fields. A Digital Signal Processing Approach..Elsevier. Amsterdam 8. M.Bath, Spectral Analysis in Geophysics. Elsevier. Amsterdam

Course No.: 204

Subject: Ore Reserve Estimation

. No.	Topics	Chapters
1	Ore Reserve Estimations	An overview and outline, Exploration and Data Collection (Resource database) - Survey information, Geological data,
		Geological model, Density factor, Sampling issues
		Analytical procedures, Digital databases and validation, Audits of the resource database
		Geological interpretation and Geological modeling
		Role of geological interpretation
		Interpretative techniques, Geological interpretation and modeling for mineral resource estimation
		Ore reserve estimation- Area of Influence methods, Estimation for flat lying deposits
		Uniform area of influence method
		Variable area of influence method
		Polygonal method
		Triangular method
		Cross-section method
		Isopach method and General outline method;
		Estimation method for steeply dipping deposits;
		Inverse distance method
		Geostatistical methods

. No.	Topics	Chapters
		Variography, Variography and data validation, Optimization of sampling grid and Domaining, Semivariogram, Kriging techniques (linear and nonlinear); Conditional simulation
		Mineral sands – Evaluation, resource estimation and reporting
		Reserve categories: Measured/indicated/Inferred, RAR/EAI/EAII/Speculative
		Feasibility studies: Environmental issues and Ore reserve estimation
	Tutorials	Calculation of ore reserves by different methods
	References:	1. Edwards, A.C., (Ed) (2001). Mineral Rersource and Ore reserve estimation – The AusIMM Guide to Good Practice (Monograph 23). Published by The Australiasian Institute of Mining and Mettallurgy, Carlton Victoria Australia. 2. International Atomic Energy Agency (1985). Methods for the estimation of Uranium ore reserve, An instruction Manual. Technical Reports series no.255.

Course No.: 205
Subject: Gravity and magnetic methods

S. No.	Topics	Chapters
1	Gravity method	Earth's gravitational field , Gravitational potential, Potential field equations, Derivatives of potential
		Poisson's equation Geoid
		Figure of Earth, Isostacy, ,Geodetic measurements Density estimations from field data
		Absolute and relative measurement s of gravity
		Theory and principle of gravimeter, zero length spring, Super conducting gravimeter, Calibration of gravimeter, Field procedure, Reduction of gravity data, Free Air, Bouguer and Isostatic anomalies,
		Gravity anomalies due to regular bodies- Sphere, vertical and horizontal cylinders, sheet, step/fault and bodies of arbitrary shape, Simple interpretation methods using thumb rules, characteristic curves, curve matching , excess mass estimation, location of mass centre, over burden effects, maximum-depth rules.
2	Magnetic method	Geomagnetic field, Magnetic field of external and internal origin,
		Van Allen radiation belts, diurnal variation, magnetic storms, Dipole-nondipole fields and their origin, Secular variation
		Magnetic petro physics
		Factors affecting magnetization of rocks and magnetic minerals, magnetism of igneous , metamorphic and sedimentary

S. No.	Topics	Chapters
		rocks
		magnetic signatures in different ore environments
		Remnant magnetization
		Magnetic character of continental and oceanic crusts, reversals of magnetic field, sea floor spreading and plate tectonics
		Theory and principles of magnetometers -Flux gate, Proton precision, Optical pumping and SQUID. Gradiometers
		Measurement of remanence and magnetic susceptibility
3	Processing of gravity and magnetic data	Regional-residual separation, graphical method, Polynomial fitting, Spectral analysis, Average depth estimates
		Smoothing and enhancement techniques, wavelength filtering, matched filtering,
		Werner Deconvolution, Euler depth estimates, Upward and downward continuation, derivatives, reduction to pole for magnetic data, analytical signal, susceptibility mapping, direct and inverse methods of interpretation.
4	Lab	Computation of gravity and magnetic anomalies due to two dimensional and three dimensional regular shaped bodies
		Study of variation of magnetic anomaly with magnetic latitude, azimuth and dip of the body
		Application of spectral analysis for interpretation of field data
		Computation of radially averaged spectrum
		Average depth estimates, upward, downward continuation of data
		Regional-residual separation
		Computation of vertical derivatives,
		Reduction to pole for magnetic data
		Computation of analytical signal
		Euler depth estimates
		Inversion of gravity and magnetic anomalies,
		Estimation of anomalous mass from gravity data,
		Modelling of gravity anomaly over a outcropping sedimentary basin
	References	1. M.B. Dobrin and C.H. Savit, 1988. Introduction to Geophysical Prospecting, Mcgraw Hill. 2. L.L. Nettlton, 1976, Gravity And Magnetic In Oil Prospecting , Mcgraw Hill 3. W.M. Telford, L.P. Geldart and R.E. Sheriff, 1990, Applied Geophysics, Cambridge University Press. 4. I.V. Radhakrishna Murthy, 1998, Gravity and Magnetic Interpretation in Exploration Geophysics, Geological Society of

S. No.	Topics	Chapters
		India, Bangalore. 5. B.S.R. Rao And I.V. Radhakrishna Murthy, 1978, Gravity And Magnetic Methods Of Prospecting, Arnold-Henniman Pub. Co. 6. D.S. Parasnis, 1979, Principles of Applied Geophysics, Chapman and Hall. 7. B.Bhattacharya, 1965, Two Dimensional Harmonic Analysis as a Tool for Magnetic Interpretation. Geophysics Vol. 30, Pp 829-857. 8. Paterson, N.R. And Reeves, C.V. Geophysics 1985 Applications of Gravity and Magnetic Surveys: The State Of The Art in 1985. Geophysics, Vol 50 Pp 2558-94,

Course No.: 206
Subject: Petro-graphic techniques in uranium exploration

S. No.	Topics	Chapters
1	Optics and Mineralogy	Electromagnetic spectrum, light, double refraction; Polarised light microscopy,
2	Transmitted light microscopy	Minerals in plane polarized light – shape and cleavage, relief, colour, pleochroism/diachroism, opacity, vibration direction, birefringence
		Minerals in cross polarized light – anisotropism, interference colors, extinction angle, twinning, mineral identification; Interference figures – significance; sign of elongation
		Unitarian optics – determining optic sign with gypsum plate, quartz wedge
		Biaxial optics – determining optic sign with optic axis figure and acute bisectrix figure, determining 2V/Mallards method
		Becke's lines, oblique illumination method for determining relief, determination of plagioclase compositions using the Michel Levy method;
		Modal analysis, norm calculation
3	Reflected light microscopy:Properties to be studied under	Colour, bireflectance and reflection pleochroism, anisotropism, internal reflections
		Structural and morphological characters – crystal form and habit, cleavage and parting, twinning. Mineral identification
		Qualitative methods –; Colour – quantitative measurement of colour, reflectance, microindentation hardness, standard measure of Vicker's hardness, Knoop's hardness, standards, factors affecting microindentation hardness values for minerals;

S. No.	Topics	Chapters
	reflected light	polishing hardness, scratch hardness; paragenesis
4	Petrography	Petrography, petrology, petrogenesis
		Igneous petrology – rock classification-plutonic and volcanic rocks, textures, alkaline rocks and carbonatites
		Sedimentary petrology – clastic rocks, classification and origin, provenance of accessory minerals in sandstones, significance of glauconite, tectonics and sandstone compositions, climate and sandstones, diagenesis of sandstones, cementation, sandstone interpretation guide
		Chemical and biochemical sedimentary rocks – carbonate mineralogy, classification
		Tectonic setting
		Texture as an indicator of energy levels
		Metamorphic petrology – definition, grade, types, classification, nomenclature, textures and metamorphic settings.
5	Radioactive, Rare earth element and rare metal bearing minerals	. Uranium mineralogy, different stages of formation of uranium minerals, occurrence of radioactive minerals in different rock types
		Thorium: Mineralogical expression of radioactivity
		Types of radioactive minerals/phases, location and identification of radioactive minerals, optical properties of radioactive minerals – colour, reflectance, bireflectance, reflection pleochroiism, anisotropism and isotropism, internal reflection, micro indentation hardness
		primary uranium minerals, complex oxides of uranium and thorium
6	Presentation and preservation of data and assessment	Entry in registers, database, slide cataloging, photomicrography and report writing
7	Lab Petromineralogical techniques	
		Preparation of polished slab, polished thin section -advantages, araldite mount (cold setting), Bakelite mount, preparation of wafers for fluid inclusion studies
		Determination of specific gravity
		staining techniques – feldspars and carbonates

S. No.	Topics	Chapters
		Density separation of mineral grains – coarser than 200 mesh sieves and finer than 200 mess sieves; unconsolidated sediments,
		Identification of minerals, special techniques for radioactive minerals – chromogram test
		CN-85 film autoradiography/SSNTD study, fission tract studies, separation of secondary uranium minerals
8	Parts of the microscope	Objective lenses, ocular lenses, illuminating systems, accessory plates and their uses, monochromators, photometers, stage micrometers, sample holders
		Resolution, numerical aperture calibration of the micrometer, field of view, centering of the objectives
9	Transmitted light microscopy	Minerals in plane polarized light – shape and cleavage, relief, colour, pleochroism/diachroism, opacity, vibration direction, birefringence
		Minerals in cross polarized light – anisotropism, interference colors, extinction angle, twinning, mineral identification
		Interference figures – significance; sign of elongation; Unitarian optics – determining optic sign with gypsum plate, quartz wedge
		Biaxial optics – determining optic sign with optic axis figure and acute bisectrix figure, determining 2V/Mallards method
		Becke's lines, oblique illumination method for determining relief, determination of plagioclase compositions using the Michel Levy method; Modal analysis,
10	Reflected light microscopy	Mineral identification, Kalb's line. Qualitative methods Colour – quantitative measurement of colour, reflectance
		Microindentation hardness, standard measure of Vicker's hardness, Knoop's hardness, standards, factors affecting microindentation hardness values for minerals; polishing hardness, scratch hardness
11	Petrology	Study of thin sections of common igneous, sedimentary and metamorphic rocks
12	Radioactive, Rare earth element and rare metal bearing minerals	Mineralogical expression of radioactivity; types of radioactive minerals/phases, location and identification of radioactive minerals
		Optical properties of radioactive minerals – colour, reflectance, bireflectance, reflection pleochroiism, anisotropism and isotropism, internal reflection, micro indentation hardness
		Primary uranium minerals, complex oxides of uranium and thorium, common accessory radioactive minerals, labile uranium along grain boundaries, secondary uranium minerals
		uranium minerals in igneous, sedimentary and metamorphic environments.
	References	1. Berry, L.G., Mason, Brian 1959. Mineralogy – concepts, descriptions and determinations, W.H.Freeman and

S. No.	Topics	Chapters
		Co.,California 612p. 2. Deer, Howie, Zussman – Rcok forming minerals, vol. 1 to 5. 3. Kerr, F.P. 1959. Optical mineralogy, McGraw-Hill Book company Inc., 441p. 4. Nesse, W.D. 1991. Introduction to optical mineralogy, Oxford University press Inc., New York, 335p. 5. Winchell, A.N. and Winchell, H. 1951. Elements of optical mineralogy – an introduction microscopic petrography, John Wiley & sons Inc., New York, Vol. 1 & 2, 551p. 6. Lecture notes: Internet. Prof. Stephen A. Nelson, Petrology, Tulane University – updated on 12th August, 2008. 7. Cameron, E.N. 1961. Ore microscopy, John Wiley & sons Inc., New York 8. Craig and Vaughan, Ore Microscopy 9. Ramdohr, P 1980. The ore minerals and their intergrowths, 2nd edition, vol. 1 & 2, Pergamon Press, Oxford. 10. Uytenbogaart, W. and Burke, E.A.J.1971. Tables for microscopic identification of ore minerals, Elsevier, Amsterdam, 430p. 11. Frondel, C. 1958. Systematic mineralogy of uranium and thorium, Geol. Sur. Bull. 1064, U.S.Government Printing Office, Washington, D.C., 400p. 12. Heinrich, E.W., 1958. Mineralogy and geology of radioactive raw materials, McGraw Hill Book Company, New York, 654p. 13. Hutchison, C.S. 1973. Laboratory handbook of Petrographic techniques, John Wiley and sons, New York, 527p. 14. Verma, H.M. 1994. Petrographic study of radioactive minerals and the relevance of petrological data to exploration and extraction of uranium, Geotutorials, vol.1, pp1-23, Atomic Minerals Division, Govt. of India, Hyderabad.

Course No. 207

Subject: Electrical and electromagnetic Methods

. S. No.	Topics	Chapters
1	Electrical Methods	Classification of electrical methods, Natural and artificial source methods,
		Conduction in rocks, Electrical properties of rocks and minerals and their measurement
2	Self Potential method-	Origin of self potentials, Electro-filtration, Diffusion, Adsorption, Mineral potential occurrence and stability ,
		Field procedure, equipment, non-polarizable electrodes, Interpretation of anomalies due to simple shaped bodies.

. S. No.	Topics	Chapters
3	Resistivity method-	True and apparent resistivity, Current flow and potential in homogenous and non homogenous media, Potential at a plane interface, Surface potential due to horizontal beds, Effect of anisotropy and topography.
		Geo-electrical parameters- Longitudinal conductance, Transverse resistivity, longitudinal resistivity
		Various configurations and their geometric factors, Comparison of electrode arrays, Principle of reciprocity, Electrode effect, Depth of investigation, Field about a point, Dipole field region, Concept of image in potential theory, analytical continuation of potential fields, numerical methods in potential theory, Resistivity profiling and sounding.
		Typical profiles across contacts, dykes
		Expressions for apparent resistivity over layered earth, Principle of equivalence and suppression, Resistivity transform and linear filter theory, Interpretation of vertical electrical sounding curves. Applications and case histories
4	Induced Polarization method	IP phenomenon, electrochemical theory, over voltage, fixed layer, double layer, Faradaic and non-Faradaic paths, Warburg impedance, equivalent circuits, IP phase angle, mathematical formulation of IP response, Factors affecting IP phenomenon, Time domain, frequency domain and Spectral IP measurements and their equivalence
		Complex resistivity, Cole-Cole model, Discrimination of minerals, Negative IP, Field procedure and equipment, EM and capacity coupling, Computation of theoretical IP curves, IP soundings and interpretation, Magnetic Induced Polarization method, Field procedure and equipment, advantages, Applications and case histories
5	Electromagneti c methods	Classification of electromagnetic methods, Sources for EM waves, EM wave propagation
		Maxwell' s equations, Boundary conditions, wave equation, self and mutual inductance
		Electromagnetic energy and power, Poynting vector
		Diffusion equation and its solution, skin effect and skin depth, Reflection and transmission of electrical and magnetic fields, elliptic polarization
		radiation from dipole, retarded potential, near and far fields, radiation resistance, Field due to a rectangular loop, horizontal wire, horizontal circular coil, vertical straight wire, Phasor diagram, Electric circuit analogy for an EM system
		Negative screening, overburden effect, current channeling and current gathering.
		EM response over bodies with high magnetic permeability.
		EM scale modeling. Cagniard's resistivity
6	Frequency domain EM	Dip angle, Compensator method, Turam method, Horizontal and vertical loop EM methods, Controlled source audio magneto telluric method

. S. No.	Topics	Chapters
	methods-	Frequency and geometric soundings, Very low frequency (VLF) method- VLF station, parameters measured Ground Penetrating Radar method
		Field procedures and equipment
		Processing of Turam data Interpretation of HLEM data and Turam data using standard curves
		Fraser and Hjelt filters, Derivation of Current density cross section from VLF data
7	Time Domain EM methods	Comparison of FDEM and TDEM methods
		Survey configuration, Impulse and Step response measurements, Diffusion time, Transient EM response over confined targets, homogenous half-space, layered earth, thin sheets
		Field procedure and equipment. Interpretation using plate model
		Interpretation of sounding data over layered earth.
8	Natural source EM methods	Magneto-telluric, telluric and AFMAG methods. Source and the frequencies investigated
		Field procedure and equipment. Interpretation of the MT soundings. Applications and case histories
	Lab	Construction of two, three and multilayered VES curves, Interpretation of two ,three and multilayered VES curves using auxiliary point charts and master curves, Interpretation of VES curves by direct and inverse methods, Preparation of pseudo-sections, Current density cross sections from VLF data, Interpretation of HLEM data using master curves, Processing of Turam data and interpretation by using characteristic curves Interpretation of TEM profiles using plate mode, interpretation of TEM sounding data using inversion

Course No.: 208
Subject: Mineral process Engineering

S. No.	Topics	Chapters
1	Ore preparation	Significance of mineralogy in ore/mineral beneficiation
		Mineral liberation, locking factor, image analysis, Particle size analysis
		graphical representation of the results, number, mass, surface area, volume distributions as function of particle size
		statistical distributions, Laser particle analyzer
		Crushing and grinding of ores, operating principles, work index of ores, grinding efficiency and various grinding mills, mathematical treatment of grinding operation, design of grinding circuits

S. No.	Topics	Chapters
		Classification of ground ores, various types of classifiers, classifier performance, classifier efficiency
2	Ore processing by physical beneficiation	Principles of physical beneficiation of ores, qualitative and quantitative separation efficiencies, metallurgical accounting methods applicable to ore processing
		Gravity separation using the differences in specific gravities of mineral constituents, flow of particles in fluid medium, free and hindered settling, terminal velocity
		Introduction to various gravity separators, such as jigs, shaking tables, spiral concentrators, FLOATEX separators
		Electrostatic and high tension separation, the operating principle and applications in processing of atomic and strategic minerals, Froth flotation, basic principles, significance of surface properties in determining the floatability of heavier-than-water minerals, flotation equipment
		Magnetic separation, Principles of operation, magnetic separators Case studies with respect to processing of ores of atomic and strategic minerals such as those of uranium, beach sand minerals (thorium and zirconium), niobium-tantalum, tin, tungsten, molybdenum, cobalt etc
		Fine particles processing, challenges and techniques of separation, introduction to commercially available fine particle processing machines/techniques such as multi-gravity separator (MGS), Knelson concentrators, column flotation and other novel methods
3	Ore processing by chemical and bio-processing methods, hydro-metallurgical operations	Principles of leaching, acid and alkaline leaching, atmospheric and pressure leaching, factors affecting leaching behaviour
		Solid-liquid separation, various types of filters, filtration efficiency
		Hydrometallurgical unit operations, ion exchange, solvent extraction, principles of ion exchange and solvent extraction, process equipment to carry out these operations,
		Recovery of metals from the concentrated/purified solutions including precipitation
		Bio-processing of minerals, bacterial leaching, Case studies of flow sheets for processing uranium ores including those of Jaduguda, Narwapahar, Turamdih, Tummalapalle and Gogi
		Uranium recovery from secondary sources like phosphate ores, copper plant tailings and monazite
		Pilot Plant studies, scale-up and design of industrial size uranium recovery plants and project planning, management and execution
		Material and energy balancing. Process engineering, synthesis and flow sheet design.
4	Tailing processing, effluent treatment and disposal	Dewatering operations, thickening and drying and material handling.
		Significance of tailings and effluent processing in uranium ore processing Tailings neutralization, mine backfilling, tailings pond, fixing of deleterious heavy metal ions and radioactive ions, Bioremediation and impact analysis.

S. No.	Topics	Chapters
5	Lab	Size reduction of ores in laboratory ball and rod grinding mills. Screen analysis of ground ore, data presentation, by graphical methods using standard models and interpretation of data
		Settling characteristic for mineral particles in ground ore slurries and determination of parameters for dewatering of slurries
		Determination of Bonds Work Index in Ball mill, estimation of power requirement and sizing a mill for specific design specification
		Gravity separation of heavy minerals using spirals, jigs, shaking table, estimation of valuable mineral content, calculation of recovery and grade
		Magnetic separation of heavy mineral concentrates from beach sands on low and high intensity magnetic separators
		Froth Flotation of sulfide minerals, generation of kinetic curve of flotation determination of optimum grade and recovery from the graphical plots. Agitation chemical leaching of uranium ores by acid / alkaline leaching methods and computation of leachability.
6	References	1. Mineral Processing Technology, B.A.Wills, Pergamon Press, New York. 2. Introduction to Mineral Processing, Kelly and Spottiswood. 3. Chemical Engineering, Coulson and Richardson, Pergamon Press. 4. Mineral Comminution Circuits, T.Napier Munn, Univ. Of Queensland Press. 5. Hydrometallurgy, S.Venkatachallam. 6. Laboratory Experiments in Mineral Engineering, S.Venkatachallam and S.N.Degaleesan, Oxford & IBH. 7. Mineral Bio-processing, Smith and Misra, TMS. 8. Extractive Metallurgy of Uranium, R.C.Merrit. 9. Uranium Ore Processing, John W.Clegg and Dennis D.Foley, Addison-Wesley. 10. Significance of mineralogy in the development of flowsheet for processing uranium ores. Technical Reports Series. 196, IAEA, 1980. 11. Current practices for management and confinement of uranium mill tailings, Technical Report Series 335, IAEA, 1992.

Course No.: 209

Subject: Airborne geophysical methods

S. No.	Topics	Chapters
1	Introduction	Procedures for obtaining needed licenses for flying in an area
2	Survey	Survey design, and fixation of survey parameters- flight height, flight line spacing and direction, and selection of suitable

S. No.	Topics	Chapters
	designing and implementation	geophysical methods.
3	Airborne survey instruments	Magnetometer, Gravimeter, Electromagnetic system, Gamma Ray Spectrometer and their working principles.
4	Navigation aids-	DGPS, Radio-altimeter and Barometer. Types of platforms. Precautionary measures in flying – weak link mechanism, airworthiness of equipment.
5	Data acquisition	Selection of base frequency, pulse duration in case of EM methods, Sampling interval, format of output data. Types of noise in different sets of data. Quality control, data validation. Calibration procedures.
6	Processing of data	Application of attenuation coefficients, stripping coefficients, gridding, interpolation procedures, contouring
7	Presentation of data	Profiles, contour maps, images, ratio maps, conductivity –depth sections, DTM. Qualitative interpretation- Characterization of gravity and magnetic anomalies and delineation of lineaments, identification of structures
		Delineation of zones of anomalous distribution of radio-elements and identification of alteration zones. Marking positions of conductors and their extent.
8	Quantitative interpretation	Depth estimates using radially averaged spectrum of gravity and magnetic anomalies, Euler depth estimates. Forward and inverse modeling of different sets of data using available software. Modeling of conductors using plate model. Integration of various geophysical data sets and surface geological data in order to refine geological maps.
9	Tutorials	Quality control and validation of various data sets, Processing of radiometric, gravity and magnetic data, after applying the needed corrections, Presentation of data in the form of profiles, contour maps, images using available software. Qualitative interpretation to identify various litho-units and structural features. Computation of derivatives, analytical signal, Quantitative estimates using radially averaged spectrum, Euler depth estimates. Delineation of alteration zones, younger intrusive from processed radiometric data. Forward and inverse modeling of gravity, magnetic and electromagnetic data using available software. Preparation of a refined geological map after integrating various data sets.
	References	1. M.B. Dobrin and C.H. Savit, 1988. Introduction To Geophysical Prospecting, Mcgraw Hill. 2. L.L. Nettlton, 1976, Gravity And Magnetic In Oil Prospecting , Mcgraw Hill 3. W.M. Telford, L.P. Geldart and R.E. Sheriff, 1990, Applied Geophysics, Cambridge University Press. 4. I.V. Radhakrishna Murthy, 1998, Gravity and Magnetic Interpretation In Exploration Geophysics, Geological Society Of

S. No.	Topics	Chapters
		India, Bangalore. 5. B.S.R. Rao And I.V. Radhakrishnal Murthy, 1978, Gravity And Magnetic Methods Of Prospecting, Arnold-Henniman Pub. Co. 6. Parasnis, D.S. 1997, Principles Of Applied Geophysics. Chapman & Hall 7. Proceedings of Exploration 97: Fourth Decennial Conferrence on Mineral Exploration. Toronto 1997 Ed. A.G. Gubin 8. Proceedings of Exploration 07: Fifth Decennial Conferrence on Mineral Exploration. Toronto 2007 Ed. B. Milkcreit 9. Proceedings of International Conference on Airborne Electromagnetics, Sydney. Exploration Geophysics Vol 29 No. 1 & 2 1998 10. Electromagnetic Methods In Applied Geophysics. Applications Ed. Misac N Nabighian, Society Of Exploration Geophysicists 1992 11. Guidelines for Radioelement Mapping Using Gamma Ray Spectrometry Data. International Atomic Energy Agency, Technical Report July 2003.

Course No.: 210

Subject: Analytical techniques in geosciences

S. No.	Topics	Chapters
1	DC Arc spectroscopy	Dispersion of light - Basic operating principle, Dispersion devices used for spectral analysis, Prism and grating, Linear dispersion, Fundamental principles of prism dispersion, Deviation angle, Snellins – Descartes law, Prism dispersion , instrument main components, Littrow and Cornu prisms
		Optical spectra - classification of spectra, structure of line spectra, Instrumentation, Overall arrangement, Arc and spark discharge, Electrodes
		Sample preparation - General aspects, Sampling and preparation of non conducting solid substances, Spectroscopic buffer
		Behavior of elements in an arc discharge
		Simultaneous multi element analysis, Method development, Major and minor element analysis, Trace element analysis, Photo plate detection
		Measurement of the intensity of spectral lines, Straightening of the characteristic curve, Determination of the density of spectral lines, Semi quantitative/ quantitative reconnaissance analysis
	Lab	Sample preparation-weighing-filling of standards and samples in electrodes; arcing; photo plate

S. No.	Topics	Chapters
		development-computation-reporting
2	X-Ray Diffraction	Principles and methods of X-ray diffraction, Preparation of different types of geological samples for XRD studies
		Use of search-match methods for identification of primary and secondary uranium and associated minerals
		Use of search-match methods for identification of rare metal and rare earth and related minerals
		Use of search-match methods for identification of iso-structural, metamict and clay minerals
		XRD techniques for determination of unit cell parameters of atomic minerals
	Lab	Sample preparation-sample diffraction-data output-search and match method-study of diffractogram-identification of minerals-reporting
3	Electron Microprobe (EMP)	X-ray generation by electron bombardment of a sample, the detection of x-rays by WD Spectrometers, qualitative microanalysis
		Standards-based quantitative WDS microanalysis, detection limits, precision and Accuracy, methods for assessment of data quality
		technique of electro microprobe Analysis, imaging, qualitative and quantitative data acquisition, Processing & documentation
	Lab	Sample preparation and operation of EPMA Instrument for both qualitative and quantitative microanalysis.
4	X-ray fluorescence Analysis (XRF)	Qualitative and quantitative rock analyses; Standards-based quantitative WDS XRF analysis; detection limits, precision and Accuracy
		methods for assessment of data quality
		technique of XRF [WDS & EDS] Analysis, qualitative and quantitative data acquisition, data Processing and documentation.
	Lab	Sample preparation and operation of WDS XRF Instrument for both qualitative and quantitative analyses of major and minor elements, in major rock types
5	Chemical Analysis	Introduction to chemical analysis/characterization of geological materials
		Whole rock analysis - Major, minor, trace and ultra trace analysis; Sample types
		Conventional and Modern instrumental analytical techniques
		Sample preparation - Solid sampling, Solution methods for rocks, soils, water, minerals and concentrates, HF & other mineral acid dissolutions(open & closed), Fusions & fluxes
		Field measurements - pH, conductivity, TDS, Eh and Titrimetry for anions, ferrous etc
		Optical emission techniques - Flame Emission - theory, instrumentation, merits, limitations & applications

S. No.	Topics	Chapters
		Fluorimetry - Laser & Pellet methods, theory, instrumentation, merits, limitations & applications
		Atomic Absorption Spectrometry - Flame Hydride Generation and Electro thermal - theory, instrumentation, merits, limitations & applications
		UV-Visible Spectrophotometry - theory, instrumentation, merits, limitations & applications
		ICP-AES - theory, instrumentation, merits, limitations & applications
		ICP-MS - theory, instrumentation, merits, limitations & applications
		Data Quality Assurance - Errors - types, minimization
		figures of merit like accuracy, precision; standard reference materials, statistical criteria for accuracy, precision.
	Lab	Sample solution preparation for Whole rock analysis, beach minerals, niobate-tantalate
		Determination of uranium in water samples by laser fluorimetry using Scintrex analyzer and solid samples by pellet fluorimetry
		Determination of Na, K by flame photometry and Si, Ti, P by Spectrophotometer
		Determination of Fe, Mn, Al, Cu, Co etc. by FAAS
		Determination of rare earths etc. by ICP-AES; Analysis of hydro-geochemical samples for major cations & anions
6	Geochronology and Isotope Geochemistry	K-Ar system, Rb-Sr system, Sm-Nd System, U-Th-Pb System, Zircon Dating, U-Decay Series Dating, Other Decay Systems
		Analytical Methodology Radiogenic Isotope Geochemistry
		Radiogenic Isotope Geochemistry of the Mantle, Isotopic Evolution of the Mantle and models, Isotope Geochemistry of the Continental Crust
		Isotope Geochemistry of Subduction Zone
		Magmas Stable Isotope Geochemistry
		Stable Isotope Theory - Equilibrium Fractionations, Kinetic Fractionation and the Hydrologic Cycle Isotope Fractionation in the Biosphere
		Stable Isotope Applications - at High Temperatures, Oxygen Isotopes as An Indicator of Assimilation
		High Temperature Applications in Subduction zones, Hydrothermal Activity, Metamorphism, and Ore Deposits
	Lab	Sampling and sample preparation; Sample dissolution techniques and ion exchange separation for Rb/Sr, Sm/Nd, U and Pb
		Isotopic analysis using TIMS; Stable Isotope (C,S and O) analysis using IRMS

S. No.	Topics	Chapters
	References	1. The Powder Method in X-Ray Crystallography by Leonid V. Azaroff and Martin J. Buerger, McGraw-Hill Book Company, Inc., New York, U.S.A. 2. X-Ray Diffraction Methods by E.W. Nuffield, John Wiley & Sons, Inc., New York, U.S.A. 3. Elements of X-Ray Diffraction by B.D. Cullity, Addison-Wesley Publishing Company, Inc., Massachusetts, U.S.A. 4. X-Rays in Theory and Experiments by H. Compton & S.K. Allison, D. Van Nostrand Company, Inc., New Jersey, U.S.A. 5. X-Ray Diffraction Procedures by H.P. Klug & L.F. Alexander, John Wiley & Sons, New York, U.S.A.. 6. Mika, J., and Torok, T (1974): Analytical emission spectroscopy. London Butter worths. pp 529 7. Torok, T., Mika J., and Gegus, E., (1978): Emission spetrochemical analysis., Adam Hilger, London pp. 692. 8. Willard, H.H., Merritt, L.L., Dean, J.A. (1965): Instrumental methods of analysis, affiliated East West press pvt. ltd. 4th edition pp 784 9. Brode,. W.R. (1958) Chemical spectroscopy. Johnwiley & Sons pp. 677 10. ASTM committee E-2 (1982) Methods for emission spectro chemical analysis pp.1098 11. Winefordner, J.D., (1972) Trace analysis, spectroscopic methods for elements. Johnwiley & Sons pp 484.Pott, P.J.- A handbook of silicate rock analysis, “arc and spark source optical emission spectrometry”, chapter-6 . Blackie – pp.198-212. 12. Goldstein, J., Newbury, D., Joy, D., Lyman, C., Echlin, P., Lifshin, E., Sawyer, L. and Michael, J., 2003. Scanning Electron Microscopy and X-Ray Microanalysis 3rd Ed. Kluwer Academic/Plenum Publishers. 13. Reed, S.J.B., 2005. Electron Microprobe Analysis and Scanning Electron Microscopy in Geology 2nd Edition. Cambridge University Press. 14. Faure, Gunter and Mensing, Teresa. Isotopes: Principles and applications, 3rd edition. John Wiley. 15. Dickin, Alan P. Radiogenic Isotope Geology, Cambridge university press, 1997 16. Faure, G and Powell, J.L. Strontium Isotope Geology, Springer Verlag, 1972. 17. DePaolo, Donald, J. Neodynium Isotope Geochemistry, Springer Verlag, 1988 18. Aggarwal, S.K. and Jain, H.C. (Eds.) Introduction to mass spectrometry, 1997 19. Hoefs, J. Stable Isotope Geochemistry, 4th edition, Springer Verlag

Course No.:

Subject: Borehole Logging methods

S. No.	Topics	Chapters
1.		Objective, Basic concepts- Archie's equation, Humble's equation, borehole conditions, Principles, operational procedures, equipment, applications of various well logging techniques
		Self-Potential Logging.- Sources for S.P. Use of Self Potential Logs for Oil exploration Shale base line, Sand base line Interpretation of SP logs Use of Self Potential Logs for mineral exploration
		Single point resistance log
		Resistivity Logging - Normal resistivity logging Lateral resistivity logging Microlog resistivity logging Focussed –current logging Induction logging
		Interpretation of logs
		Sonic Logging -Elastic waves in boreholes Estimation of porosity. I.P. Logging
		Nuclear Logging Nuclear Processes Gamma Ray Logging Neutron Logging, Pulsed neutron logging. Magnetic Susceptibility Log
		Nuclear Magnetic-Resonance Log. Borehole gravity log. CalliperLog
		Qualitative and quantitative interpretation of well logs. Determination of reservoir parameters. Delineation of lithology and fractures from logs
		Saline water-fresh water interface from log data. Applications. Field examples.
2.	Lab	Computation of normal and lateral log responses. Identification and delineation of sub-surface formations from well log data. Calculation of formation factor, porosity, permeability, resistivity, fluid saturation, correlation of rock units. Saline water-fresh water interface rom log data.
3.	References	1. O.Serra, 2003. Well Logging And Geology, Technip, Paris 2. O. Serra, 1984. Fundamentals of Well Log Interpretation, Elsevier. 3. R.M. Bateman, 1985, Open Hole Log Analysis And Formation Evaluation, Reidel, Dordrect. 4. G. Asquith and C. Gibson, 1982. Basic Well Log Analysis for Geologists, Academic Press, London.

Course No.: 212
Subject: Nuclear Reactor: Theory, Types and Nuclear Fuel Cycle

S. No.	Topics	Chapters
1	Introduction	The need for nuclear energy, power scenario in India, Atomic Energy establishments in India and programmes of DAE.
2	Nuclear reactor theory and types of reactors	Scientific fundamentals of fission and fusion processes and resultant release of energy
		Interaction of sub-atomic particles and ionization radiations with matter
		Nuclear structure and functions of the reactor systems
		Various types of reactors
		Moderator and coolant
		Typical reactor control system
		Steady and dynamic behavior of reactors
		Requirements of safety systems in nuclear power plants
2	Nuclear Fuel Cycle	Nuclear fuel cycle options for PHWR, BWR, PWR and FBR: Nuclear materials, Nuclear fuel cycle in India, specifications of fuel
		Mining, processing, enrichment, manufacturing, usage and burning of fuel
		Quality control aspects
		Storage and safe transportation of spent fuel bundles
		Nuclear fuel enrichment; fuel reprocessing ; generation and management of radioactive wastes
3	Environmental issues	Need for environmental protection
		Indian legislation and controls related to environment, environmental impact assessment clearances related to setting up of a nuclear power plant and its operation
		Environment survey requirements
	References	1. P.D. Wilson (Editor) 1996, The Nuclear Fuel Cycle from Ore to Wastes, Oxford University Press. 2. C.K. Gupta (1989) Materials in Nuclear Energy Applications, volume 1 & 2, CRC Press, Inc. USA. 3. D. Bhaskar Rao (Editor) 2001, Nuclear Materials Issues and Concerns, Volume 1 & 2, Discovery Publishing House, New Delhi. 4. Lawrence Berkeley National Laboratory, university of California, Geological Problems in Radioactive Waste isolation; A World Wide Review (Proc. 28th Int. Geological Congr. Washington, DC, 1989), Lawrence Berkeley Natl Lab. Berkeley, CA (1991). 5. International Atomic Energy Agency, Radioactive Waste Management: An IAEA Source Book, IAEA, Vienna (1992).

S. No.	Topics	Chapters
		6. International Atomic Energy Agency, Report on Radioactive Waste Disposal, Technical Reports Series procedures, Preparation of MT master curves , Detectability and resolution studies in electrical and EM methods. References: 1. Dobrin, M.B 1984, An Introduction To Geophysical Prospecting. Mcgraw Hill, New Delhi. 2. Telford W.M., Geldart L.P., Sheriff, R.E. And Keys D.A. 1976, Applied Geophysics By Oxford And LBH Publishing Co. Pvt., Ltd., New Delhi,. 3. Parasnis, D.S. 1997, Principles of Applied Geophysics. Chapman & Hall. 4. Sumner, 1976, J.S Principles Of Induced Polarisation For Geophysical Exploration.. Elsevier. 5. Philip Kearey, 2007, An Introduction To Geophysical Exploration. 6. Michael Brooks, Ian Hill Blackwell. 7. Electromagnetic Methods in Applied Geophysics. Applications Ed. Misac N Nabighian, Society Of Exploration Geophysicists 1997 8. Proceedings of International Conference On Airborne Electromagnetics, Sydney. Exploration Geophysics Vol 29 No. 1 & 2 1998 9. Proceedings of Exploration 97: Fourth Decennial Conferrence On Mineral Exploration. Toronto 1997 Ed. A.G. Gubin 10. Proceedings Of Exploration 07: Fifth Decennial Conferrence On Mineral Exploration. Toronto 2007 Ed. B. Milkcreit 11. Appliciations Of Transient Electromagnetic Techniques Technical Note Tn 7 Geonics Limited, Canada 1980 12. Overvoltage Research and Geophysical Applications. Ed J.R. Wait. Pergamon 1959

Course No.: 101 & 201
Subject: Basic Mathematics for Geoscientists I and II

S. No.	Topics	Chapters
1	Basic mathematical concepts	Concepts of a Set, Functions and Relation
		Graphs of Functions,
		Trigonometric Functions, Basic Trigonometry
		Hyperbolic Functions and summation of Trigonometric series

S. No.	Topics	Chapters
		De Movire's Theorem
		Mathematical Induction
		Quadratic Equations
		Permutations and Combinations,
		Binomial Theorem
		Concept of a Sequence, Series
		Exponential, Logarithmic and Power series
		Convergence, Divergence tests
		Equations of Lines and Circles in 2-Dimensional Geometry and Basics of 3-D Geometry Spheres, Cones, Cylinders
2	Calculus	General, Limits and Continuity
		Differentiation- Basic concepts
		Curve stretching, Maxima and Minima
		Exponential functions and Exponential models
		Differentiation of Trigonometric
		Logarithmic and Exponential Functions
		Integration- Basic Concepts
		Indefinite and Definite Integrals ,Area and integration, Numerical Integration
		Ordinary differential equations- First Order Equations,
		Homogeneous and Non homogeneous equations
		Multiple Integrals
		Functions of several variables
		Double integral, Limits at infinity and Improper Integrals
3	Matrices	Concept of Matrix, matrix operations, determinant,
		Inverse of a Matrix
		Orthogonal Hermition, skew-Hermition and unitary matrices,
		rank Solution of simultaneous equations, quadratic forms
		Linear dependence and independence of vectors

S. No.	Topics	Chapters
		Linear and orthogonal transformations
		Eigen values and Eigen vectors
		properties of Eigen values, Caley-Hamilton theorem
4	Numerical methods	Solution of non-linear algebraic and transcendental equations
		Newton-Raphson, iterative, false position and bisection method
		Generalized Newton's method for multiple roots
		Numerical intergration by Taylor series
		Finite difference operators and their relations
		Factorial notation of a polynomial, data smoothing
		Newton-Gregory and Lagrange's interpolation formulae
		Inverse interpolation by Lagranges and interactive methods
		Numerical differentiation and integration – trapezoidal
		Simpson and Weddle rules, Gaussian quadrature formula
		Matrix and system of linear equation- Pivoting, Triangular factorisation, eigen value problem solving
5	Statistical concepts	Concept of frequency distribution, moments, skewness and kurtosis
		Probability- various approaches of probability- classical, frequency, statistical, subjective and axiomatic, theorems on probability, conditional probability, Independence
		Bayes theorem random variable – discrete and continuous
		Distribution functions and their properties
		Central tendency, probability mean and density function
		Mathematical expectation / moment generating function and its properties
		Probability distribution,Bernoulli's, Binomial
		Poisson and Gaussian distribution Theory of least squares and curve fitting
		Regression Analysis Variance, SD,Covariance
		Correlation – regression lines, regression coefficients Test of significance, normal test, t-test, Chi-square test and f-test
		Filters and smoothening functions
		Moving Averages, Kriging

S. No.	Topics	Chapters
		Trend surfaces Distribution of points, Contouring, Splines, Semi variograms Discriminant functions, Cluster analysis, Eigen values and Eigen vector methods
		Methods of Factor analysis – Prinicpal component analysis

Course No.: 106
Subject: Surveying, Drilling and Mining

S. No.	Topics	Chapters
1	Surveying	Types of surveys and applicability
		Principles and methods of surveying & mapping
		Surveying Equipment – Compass, The Transit, Optical Distance Measuring
		Modern surveying electronic equipments - Digital levels, Digital theodolites, EDMs and Total stations
		Principles, working and applications
		Survey Methods - Co-ordinate methods, Bearings, Traversing and Trilateration (Topo)
		Detail Survey, Orientation and position, Determination of True bearing, Horizontal and vertical control, Accuracy standards;
		Positioning – Introduction, Differential positioning,
		GPS instruments, Global Positioning Augmentation Systems; Errors in measurements – Blunders, Systematic errors, Random errors, Most probable value, Average error, Standard deviation
		Analysis and adjustment of measurements
		Distribution, Adjustment of errors by Approximate method and Least squire method
		Coordinate System in Geodesy - Geocentric Cartesian Coordinates, Topocentric Cartesian or local geodetic Cartesian Coordinates, Geodetic Coordinates, Planimetric Cartesian coordinate
		Datums - Horizontal datums - Everest spheroid, WGS – 84, datum transformation; Vertical datums - Mean Sea Level, Geoid, EGM 96
		Projection – Polyconic projection, Traverse Mercator projection (TM Projection), Universal Transverse Mercator Projection
	Tutorials	Adjustment of instrument errors by approximate method and Least square method. Datum transformation exercises.
2.	Drilling	History of Drilling; Methods of soil sampling - Auger, Drive sampling;
		Rock Drilling – Percussive, Attritive, Rotary Cutting, Shearing etc.,

S. No.	Topics	Chapters
		Rotary reverse circulating, Rotary with down hole motors, Cable tool method;
		Diamond Drilling - Diamond quality, types of diamond bits, natural and synthetic diamonds, Rotary core drilling equipment, Drilling standards, circulating media, Drilling fluid properties
		Controlled Directional Drilling - Deviation in drilling, Measurement of deviation and control, Tools for directional drilling, Downhole motors
		Various types of drills in use in AMD
	References:	1.Drilling Technology by C.P. Chugh 2.Drilling Technology Part 1 & 2 by British Drilling Association 3.Thomas, L.J. An Introduction to Mining, Methuen, Brisbane, 1978. 4.Sinha, R.K. and Sharma, N.L. An Introduction to Mineral Economics, Wiley Eastern, 1993. 5.Chatterjee, K.K. An Introduction to Mineral Economics, Wiley Eastern, 1993.
3.	Mining	Introduction to Mining
		Mining Terminologies
		Types of mining
		Techniques in Open Cast mining
		Techniques in Underground Mining
		Stages of mine development
		Blasting technique
		Economic feasibility studies andMining, milling and waste disposal etc.

BARC TRAINING SCHOOL

NFC

HYDERABAD-500062

SYLLABUS OC: 2019-20

CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (CHEMICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Computational fluid Dynamics and Heat Transfer	CEM:E 21:CM-40	40	5	150
2	Basic Process Instrumentation and Control	CEM:CC03-M - 20	20	3	75
3	Process Dynamics and Control	CEM:E31 E29:50	40	5	150
4	Advanced Mass Transfer, Solvent Extraction and Equipment Design	CEM-04:E32 AC03:C 45	45	6	200
5	Process Modeling, Simulation and Optimization	CEM-5:E 33:C20	20	3	75
6	Advanced Chemical Reaction Engineering	CEM:E 30:C-25	25	3	100
Core Total			**190**	**25**	**750**

ELECTIVES (CHEMICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Electrical Engineering Practices in Process Industries	CElect:FC09:E -20	20	2	75
3	Energy Conservation and Demand side Management	CElect:AC07-CMI-20	20	2	75
4	#Vacuum Technology/ Statistics for Engineers/ Corrosion Engineering/ Design of Experiments for Chemical Engineers	CElect :M-13 :New-C-20 CElect 10:New M C:20 CElect : C	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total		**520**	**62**	**2100**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (1/150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2725**

ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (ELECTRICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Applied process Instrumentation	CEM :E 50:CEEI-45	45	6	200
2	Programmable Logic Controllers and Applications	CEM:EEI-40	30	4	125
3	Electrical Engineering Practices-I	AC13:E-30	35	5	125
4	Electrical Engineering Practices-II	EEP-II: E:20	30	4	100
5	Networking Communications	CEM-9:E61: Etrn-I-20	20	3	75
6	Modern Electronic Control of AC and DC Drives	CEM:JNTU:30	25	3	125
Core Total			**185**	**25**	**750**

ELECTIVES (CHEMICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Electrical Engineering Practices in Process Industries	CElect:FC09:E -20	20	2	75
3	Energy Conservation and Demand side Management	CElect:AC07-CMI-20	20	2	75
4	Industrial Instrumentation and Human Machine Interface	CElect 17:E581 E:50:I-30	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total		**515**	**62**	**2100**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce **(2/150);** Practical **(1/150);** Project **(12/200);** Internal Assessment (125)	**15**	**625**

Grand Total	**77**	**2725**

ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (ELECTRONICS)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Applied process Instrumentation	CEM :E 50:CEEI-45	45	6	200
2	Programmable Logic Controllers and Applications	CEM:EEI-40	30	4	125
3	Embedded and Computer based System Design	CEM:E 54:Electrn-40	40	5	150
4	Digital Signal, Image Processing & Machine Vision	CEM :NEW	30	4	100
5	Networking Communications	CEM-9:E61: Etrn-I-20	20	3	75
6	Modern Electronic Control of AC and DC Drives	CEM:JNTU:30	25	3	125
Core Total			**190**	**25**	**775**

ELECTIVES (ELECTRONICS)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Mechatronics / Robotics	CElect AC14:EEMI :20 CElect:MI-14:New-EC:20	20	2	75
3	Modern Control Systems	CElect:E52A-EC - 20	20	2	75
4	Industrial Instrumentation and Human Machine Interface	CElect 17:E581 E:50:I-30	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**520**	**62**	**2125**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (1/150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2750**

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (MECHANICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Computational fluid Dynamics and Heat Transfer	CEM:E 2l:CM-40	40	5	200
2	Basic Process Instrumentation and Control	CEM:CC03-M - 20	20	3	125
3	Pressure Vessel and Piping Design	CEM-13:E 20 CC08:M-30	30	4	150
4	Engineering Design and Finite Element Methods	CEM:AC09	45	6	100
5	Computer Aided Design and Manufacturing	CEM-14: M-35	35	3	75
6	Vibrations	C EM :E26: M:20	20	3	125
Core Total			**190**	**25**	**775**

ELECTIVES (MECHANICAL)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Mechatronics	CElect AC:14:EEMI :20	20	2	75
3	Welding and Quality Assurance of Welds	C-Elect :CC06-M-20	20	2	75
4	#Vacuum Technology / Manufacturing and Industrial Engineering/ Design of High Temperature Components / Statistics for Engineers	CElect :M-13 :New-C-20 C-Elect-JNTU,M -20 CElect 11:New Mech-20 CElect 10:New M C:20	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**520**	**62**	**2125**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (11150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2750**

QUALITY ASSURANCE ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Engineering Mathematics	E01 E02-CMEI-30	30	4	125
2	Nuclear and Reactor Physics	NE 2-E07-CMEI-45	35	4	150
3	Reactor Engineering and Radiation Shielding	NE 03-E 13-CMEI-30	30	4	125
4	Health Physics, Chemical Plant safety and Environmental Engineering	NEM – FC02, E06, CC09-CMEEI-25	30	3	125
5	Nuclear Power Plants Engineering	NE 05- CMEI-30	30	3	125
6	Material Science in Nuclear Engineering	NE 06 –CMEI-25	25	3	100
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE 7FC07 FC08-CMEI-50	45	5	175
Foundation Total			**225**	**26**	**925**

CORE ENGINEERING (QUALITY ASSURANCE)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	Statistical Quality Control for QA	CEM:QA-01	30	4	100
2	NDT and QC of Nuclear Fuel and Structural components	CEM:QA-02	40	5	150
3	Design of PHWR Fuel and Structurals	CEM:QA-03	30	4	100
4	Engineering Design and Finite Element Methods	CEM:AC09	45	6	200
5	Materials Characterization and Applications	CEM:EN713	35	3	100
6	Basic process instrumentation and control	CEM:CC03-M - 20	20	3	100
Core Total			**190**	**25**	**750**

ELECTIVES (QUALITY ASSURANCE)

Sr.No	Subject Title	Course No	Hours	Credits	Marks
1	**System Management**	C Elect :AC06,AC08, CC10: CEEIM:50	45	5	200
	A)Project Management: 10	AC06			
	B)Maintenance Management :10	CC10			
	C)Operations Management :10	AC08			
	D)Quality Management: 5				
	E)Reliability Engineering: 10				
2	Corrosion Engineering	CElect : C	20	2	75
3	Image Processing and Machine vision	CElect:EN-710	20	2	75
4	# Data Base Management System and Web Technology / Advanced Computational Techniques	CElect:EN-705 CElect:EN-701	20	2	75
Electives Total			**105**	**11**	**425**

#Optional Subjects (One out of three Subjects to be selected)

Theory Total	**520**	**62**	**2125**

NON-SUBJECT ASSIGNMENTS

Subject Title	Credits	Marks
All Viva Voce (2/150); Practical (11150); Project (12/200); Internal Assessment (125)	15	625

Grand Total	**77**	**2750**

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Project Work	**Code:** P-NFC-BARC-01
Discipline: Chemical, Electrical, Mechanical and Quality Assurance	**No. of Lectures: 175**

Following Placement in various DAE Units, the Trainee Scientific Officers will carry out project work at their respective places of posting under the guidance of their Reporting officers, on a well-defined project/problem for a period of 7-8 weeks. The Project work will commence immediately after the Placement Committee meeting leading to the placement of TSOs in various DAE Units. The TSOs shall submit a project report at the end of the project duly certified by the project guide.

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General Lectures

1) Series of Invited Lectures by Eminent Speakers on various programmes of DAE (about 4-6 talks to be arranged during the year)

2) Lectures on

   a) Public Speaking & Presentation Techniques (2 Hrs)
   b) Administrative Procedures (2 Hrs)
   c) Vigilance & Service Conduct Rules (2Hrs)
   d) Financial & Accounts Procedures (2 Hrs)
   e) Purchase Procedures (2 Hrs)
   f) Contract/Works Procedures (2 Hrs)
   g) Role of Official Language In Central Government Offices (2Hrs)
   h) Fire Safety (2 Hrs)
   i) Security (2 Hrs)

Nuclear Engg. Module

BARC Training School

NFC, Hyderabad

Syllabus

Subject: Engineering Mathematics	**Code: E01 E02-CMEI-30**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 30**

Part – A

Overview of arithmetic errors in computations
Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
Linear systems solutions by direct methods, iterative methods and acceleration techniques.
Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
Linear systems: Eigen values.
Non -Linear systems: Newton-Rapson & Successive Approximation methods
Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

Part - B

Finite Difference Approximation in 1-D and 2-D
Solution of steady and unsteady heat conduction equations
Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
Response Surface Method 2K+1, factorial design, 3k factorial design
Monte Carlo Method
Artificial Intelligence and Genetic Algorithm
Artificial Neural Network
Gram-Schmidtt Orthogonalization
Transformation of matrix
Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.

Reference Books

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.

Contd….

9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.

10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.

11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.

12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.

13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.

14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.

15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.

16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.

17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.

18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

19. Ramana,B.V., "Engineering Mathematics", McGraw Hill, 2006

20. Desai& Abel, " Introduction to the finite Element Method: QA numerical Method for Engineering Analysis", CBS, 2002

21. Grewal, B.S. and Grewal, J.S., "Higher Engineering Mathematics" , 39th Edition, Khanna Publications, 2005

22. George F Simmon & John S Robertson, "Differential Equations with Applications and Historical Notes", 2nd Edition, Tata McGraw Hill, 2003

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Nuclear and Reactor Physics	**Code: NE 2-E07 -CMEI-45**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 35**

NUCLEAR AND REACTOR PHYSICS (35)

1. **Properties of Nuclei:**
   - Binding energy-formula and interpretation, nuclear forces, nuclear structure.
2. **Fission process:**
   - Fission rate and reactor power
   - Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
   - Fissile, fertile and fissionable materials
   - Fission product activity after shut down –decay heat.
3. **Interaction of Neutrons with Matter**
   - Production of neutrons
4. **Concept of microscopic cross section:**
   - Inelastic and elastic scattering
5. **Variation of cross-section with energy**
   - Fast, resonance and thermal ranges
   - 1/v law of neuron cross-section
   - Resonance absorption, Doppler effect.
   - Eta vs E curve conversion & breeding concept
   - Thorium utilization
6. **Diffusion of Neutrons**
   - Fick's law and its validity
   - Steady state neutron diffusion equation
   - Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.
7. **Chain Reaction**
   - Four Factor formula
   - Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
   - Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,
8. **Slowing Down Process**
   - Neutron slowing down
   - Slowing down power/ moderating ratio of moderators
   - Slowing down with spatial migration
   - Fermi age concepts, migration length
   - Multi zone reactors
   - Ideas of reflectors/blankets, reflector savings, form factor.

Contd…

9. Heterogeneous Reactors

- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

10. Reactor Kinetics

- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

11. Core Burn Up

- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

12. Neutron Poisons

- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

13. Reactivity Coefficients

- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Reference Books:

1. S Glasstone and M C Edlund, "Elements of Nuclear Reactor Theory", Van Nostrand, 1952.
2. K S Ram, "Basic Nuclear Engineering", Wiley Eastern, 1977.
3. J R Lamarsh, "Introduction to Nuclear Reactor Theory", Addison Wesley, 1960.
4. S Glasstone and S Sesonske, "Nuclear Reactor Engineering", Van Nostrand, 1963.
5. A M Weinberg and E P Wigner, "Physical Theory of Neutron Chain Reactors", Chicago University Press, 1958.
6. H S Isbin, "Introductory Nuclear Reactor Theory", Reinhold Publishing Corp., NY, 1963.
7. P P Zweifel, "Reactor Physics", McGraw Hill, NY, 1973.
8. R V Meghreblian and D K Holmes, "Reactor Analysis", McGraw Hill, 1960
9. Suresh Garg, Feroz Ahmed & L. S. Kothari, "Physics of Nuclear Reactors", Tata McGraw-Hill,1986.
10. Weston M. Stacy, "Nuclear Reactor Physics", John Wiley & Sons, Inc.
11. Ronald Allen Knife, "Nuclear Energy Technology – Theory and Practice of commercial Nuclear Power", Hemisphere Publishing Corporation.
12.Cohen Bernald, "Concepts of Nuclear Physics", McGraw Hill, 2002
13. Kaplan Irving, "Nuclear Physics", 2nd Edition, Narosa Publications, 2002

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Reactor Engineering & Radiation Shielding	**Code: NE 03-E 13-CMEI -30**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 30**

Introduction to reactor system & Indian Nuclear power programme; station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems, classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR, AGR, HTGR, AHWR etc,.), Fast reactors; Research reactors (CIRUS, DHRUVA etc.) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.

Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems. Heat flow & temperature distribution in plate & solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example. **(10Hours)**

Brief description of various types of fuel; metallic (DHRUVA, CIRUS) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; heat and mass balance in a BWR; boiling height in a BWR core; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pr, temp) in various reactors.

Nuclear Fuel Cycle:
Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
Global options of fuel cycles; Issues related to Resources, Long-lived radioactive waste, Proliferation, and Advanced Technologies.
Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle, Thorium utilization; Indian capabilities in: managing nuclear waste, long lived radio active waste and fuel cycle technologies.
Advanced fuel cycles; Role of ADS. **(10 Hours)**

Contd……

Radiation Shielding

Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors. **(10 hours)**

Reference Books:

1. Introduction to Nuclear Reactor Theory - J.R. Lamarsh, Wasley Reading Mass.
2. The Technology of Reactor Safety, Vol. 1 & 2 - T.J. Thompson & J.G Backerley, Eds., M.I.T. Press.-Cambridge, Mass.
3. Nuclear Reactor Engineering - S. Glasstone & A. Sesonske, D. Van Nostrand Co. Princeton, New Jersey.
4. Engineering Compendium on Shielding - Vol.1, II & III- R.G. Jaeger, Editor-in-chief, Sponsored by International Atomic Energy, Vienna.
5. Reactor Shielding Design Manual - Theodore Rockwell III.
6. Indian Nuclear Society(INS), "Nuclear Technology Challenges in 21st Century:12th Annual Conference of INSAC-2001", INS Publications, 2001
7. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor Design Basics", 4th Edition, Vol.1, CBS, 1998
8. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor System Engineering", 4th Edition, Vol.2, CBS, 1998

BARC Training School
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Syllabus

Subject: Health Physics, Chemical Plant Safety And Environmental Engineering	Code: NEM - FC02, E06, CC09-CMEEI-25
Discipline: Mechanical, Chemical, Electrical Electronics and Instrumentation Engineering	**No. of Lectures: 30**

Health Physics (8 Lectures)
Radiation Sources, Quantities & Units: Natural & Technologically enhanced radiation sources, Radiometric quantities, Interaction coefficients, Dosimetry, Radioactivity, Exposure-dose relationship. Calculation of dose from alpha, beta, gamma & neutron sources.

Fundamentals of Radiation Protection: Objectives of radiation protection, ICRP system of dose limitation, radiation protection standards, annual limit of intake, derived air concentration. Exposure and absorbed dose, equivalent dose, effective dose and their units (old & new), Limits of intake for radio nuclides including radon, accidental & emergency exposure, Atomic Energy Act, Radiation Protection Rules, Safety organization, Regulatory aspects of radiation protection.

Non- stochastic or immediate effects: Acute radiation sickness - LD 50 / 60, radiation effect on gonads, blood & blood, storming organs, lung, thyroid & skin.
Stochastic or Delayed effects: Cancer, life shortening linearity of dose effect:
Effects on embryo & foetus, genetic effects, doubling dose. Human data for calculating risk coefficients.

Operational Radiation Protection: Modes of exposure, Exposure control.
1.External: time, distance & shielding
2.Internal: containment, ventilation, plastic suits, respirators. Design of hot laboratories, zoning of areas, personal control, medical control, concept of controlled area, supervised area, radiation protection procedures, special work permit, barrier rubber stations.
Radiation Protection Monitoring: Work place monitoring for external radiation levels, air born contamination, surface & personnel contamination, monitoring instruments, collection of air & swipe samples & their counting, Individual monitoring of external exposure - TLD, film badge, monitoring for internal exposure - whole body counting, bioassay, dose records, collective dose equivalents. Radiation emergency; onsite and offsite procedure of handling emergencies, early phase, intermediates, late phase and counter measure.

Industrial Safety (8 Lectures)
Introduction: Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques
Hazards due to physical agents: UV and IR radiation, Lasers, Microwave radiation; noise, heat
Chemicals hazards: Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals
Evaluation: Instrumental methods, air sampling methods, liquid effluent monitoring
Occupational exposure limits: Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50
Handling, storage and control: Engineering control measures and safety features, Safety management techniques such as safety audit, Personal/ administrative control, and Medical control
Fire and explosion hazards: Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits, USNFPA Classification of Flammable/combustible liquids: flammable gases; Engineering safety for prevention of fire and explosion, Hazard area classification, selection of equipment, detection and extinguishing systems

Contd....

Hazard identification, assessment and control: Hazard identification: Concept of risk and Risk management; Formal methods of hazard identification and assessment: Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies, Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation. Specific hazards in HWPs and various facilities of NFC. Area classifications for hazardous chemicals, types of protection & Protective equipments. Safety work permit system

Management of major hazard Installations: (6 Lectures) Plant Layout and Engineering Design Considerations, Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic. Releases, Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment, Emergency Planning Guidelines, Development of On-site & off site emergency preparedness plans

Health and safety regulatory aspects: Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate. EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

Environmental Engineering & Environment Protection: (8 Lectures)

PRINCIPLES: Population, economic growth, industrialization, urbanization and energy-use, as causes of environmental pollution. Application of environmental principles (technical and non-technical) to: water resource management, water and wastewater treatment, air pollution control, solid waste management, environmental impact assessment, and environmental ethics. Thermal pollution, noise pollution, greenhouse effect, acid precipitation, ozone depletion, air toxics, and ground-level ozone and fine particulates (photochemical smog). Sustainable development, life cycle analysis, and principles of environmental quality objectives, standards and guidelines.

Environment Impact assessment, various effluents generated from HWPs & NFC and their treatment methods strategies, Limiting concentration of pollutants and pollution control measures. MSDS, toxic releases; Emission & dispersion

Reference Books:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection
(Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7.Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.
10. Source Book of Atomic Energy - Gtasstone
11. Introduction to Atomic & Nuclear Physics H. Semat & J.R. Atbright
12. Introductory Nuclear Physics - D. Haliday
13. Introduction to Nuclear Physics & Chemistry G.G.Harvey
14. Nuclear Physics - 1.Kaptan
15. Nuclear Radiation Detection - W.J. Price
16. Perspectives of Modern Physics - A. Beisser.
17. Radiation Detection & Measurement - G.F.KNOLL.
18. Principles of Instrumental Analysis (2nd Ed.) - D.A. Skoog & D.M. West
19. Atomic and Nuclear Physics - K. Gopalakrishnan.
20. Goel P.K., "Advances in Industrial wastewater Treatment", ABD Publishers, 2005
21. Arvind, Goel P.K., "Industrial Environment & Pollution", ABD Publications, 2003
22. Masters, Gilbert M, "Introduction to Environmental Engineering & Science", 2nd Edition, Prentice Hall of India

BARC Training School
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Syllabus

Subject: Nuclear Power Plant Engineering	Code: NE 05 -CMEI-30
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	No. of Lectures: 30

a) PHWRs (12 Lectures)

Description of schematic of NPP; siting requirements; Layout of Nuclear Power plant- Zoning requirements, layout within Reactor Building; Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting. Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
Reactivity control mechanisms - Zone control / Regulating rods, Absorber rods and shim rods; Shut down System.
Fuel Transfer System.
Auxiliary systems - Ventilation, Annular gas, Process water & Fire water systems.
Secondary System - Description of flow sheet and major components, Comparison of operating conditions, Thermal Cycles and Major Components of thermal and nuclear units.
Power Plant Control and Instrumentation: Reactor Power control (neutronic and thermal signals), Coolant and Steam pressure control, Integration with grid for base load operation. Control and protection channels with typical examples.
Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system. Brief description of systems components like Bus bar, Switchyard, Circuit Breakers, Switchgear, Bus duct, Generator, Transformer, Cables and their selection, Layout and Scaling.
Nuclear Power Plant Safety: Design principles for providing nuclear safety :-Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

Safety Evaluation and Safety Criteria Description of Deterministic and Probabilistic approaches. Safety Monitoring of Operating Plants- IAEA Classification, NUSS Codes. Safety systems, Description of Safety Systems (shutdown system, ECCS, Containment and Engineered Safety Description of features) Exclusion Zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.

Description of a typical Design Basis Accident Scenario - build up event tree to describe sequential role of safety features. Broad description of TMI, Chernobyl accident, NAPS fire incident.

Advanced reactor concepts with passive safety features.

Nuclear Architecture: Design of integrated layout of Equipment, Piping, Electrical/ Instrumentation Cables etc. to provide Operation and Maintenance Convenience (to minimize man rem and meet safety objectives), Non propagation of incidents/ accidents.

Contd...

b) PWRs / BWRs (8 lectures)

Pressurized Water Reactors : Reactor pressure vessel and internals, reactor core and fuel, methods of reactivity control, reactor coolant system & equipments, pressurizer, Engineered Safety features, reactor auxiliary systems including turbine & generator.

Boiling Water Reactors; Introduction, reactor vessel and internals, neutron monitoring, reactor coolant recirculation systems including secondary steam, reactor protection system, turbine generator.

c) Fast Breeder Reactors (10 Lectures)

INTRODUCTION: Breeding, definition & reactions; Breeders as an Inexhaustible Energy Source; Fast reactors as breeders: Classification of power reactors; Characteristics & types of fast reactors: Comparison of some characteristics of fast and thermal reactors; Role of Fast Reactors in Indian Nuclear Power Programme.

Fuel: Fuel pin diameter, number of fuel pins per sub-assembly, reactivity worth of sub-assembly, Sub-assembly outlet temperature.

Shielding Principles: Special features of sodium cooled reactor shielding, reactor shielding, shield for activation products, shielding for fuel management.

Thermal analysis: Sodium heat transfer coefficient (empirical relation), calculation of temperature of fuel pin, hot spot analysis (brief outline).

Coolant for fast reactor: General requirements for fast reactors coolant; Comparison of various coolants & choice of sodium as coolant; Properties of sodium: Physical & chemical; Methods of sodium purification & purity control: Cold & hot traps; Oxide measuring & indicating devices.

Reference Books

1. WakiL M.EL, "Nuclear Power Engineering", McGraw - Hill.
2. Strosal and Vapet., "Power Plant Engineering & Economics".
3. Lews E.E., "Nuclear Power Reactor Safety", Wiley Inter Science
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von- Nostrand, 1981.
5. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors, Pergamon Press.
6. Yevick J.G., "Fast Reactor Technology", Plant Design, H.I.T, Press.
7. John R Lamarsh, "Introduction to Nuclear Engineering", Addison Wesley, 1975
8. Rajan Babu V, "Fast breeder Reactor"
9. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor Design Basics", 4th Edition, Vol.1, CBS, 1998
10. Glasstone S and Sesonske A, " Nuclear Reactor Engineering : Reactor System Engineering", 4th Edition, Vol.2, CBS, 1998

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Syllabus

Subject: Material Science In Nuclear Engineering	Code: NE 06 -CMEI-25
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 25**

Shri. Chittaranjan Das

Properties of Engineering Materials: (21 Lectures)
Metals, alloys, ceramics, metal cladding semiconductors, polymers, and composites. Mechanical properties and their evaluation as per ASTM or equivalent standards. Stress-strain diagram, Principle stresses, Biaxial stresses, creep, fatigue and fracture toughness. Material testing for tensile strength, hardness, fracture, creep, fatigue wear.
Material Processing: Metal forming, casting, cutting and joining: ASTM standards, quality control during processing.
Metallurgy of Steels: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, Austenitic and Martensitic S.S. Selection of Steel for hydrogen services, different types of corrosion aspects in heavy water plants (Ammonia based & Sulfide based); their protection method and the selection of structural material. Selection of steel for high temperature and radiation environment, Welding and heat treatment. Powder Metallurgy for fuel fabrication

Shri. R. Tewari

Nuclear Materials: Fabrication, properties and application of nuclear materials like Zircoloy, Zr-Nb alloys, Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and application.
Decontamination, radiolysis, specification for chemistry parameters in process systems of BWRs & PHWRs.

Shri. Kamalesh Chandra

Corrosion Engineering: Corrosion, activation of corrosion products.
Chemical properties: Oxidation, corrosion, gaseous corrosion, stress corrosion, corrosion prevention, chemical degradation.
Basic Corrosion principles, types of corrosion & their mechanism and prevention; Crevice corrosion, SCC, IGSCC and other under deposit corrosion, Electro- chemical corrosion and erosion corrosion, cathodic protection of pipelines and vessels; Corrosion in chemical process industries and their prevention methods.

Smt. K.S. Lakshmi

Non Destructive testing: (4 Lectures)
Covering basic aspects of various types of NDT Techniques like UT, Radiography, Edycurrent, Magnetic Particle testing, Dye penetrant testing & Visual Inspection Methods.

Reference Books

1. "Introduction to Materials Science for Engineers, James Shackelford
2. "Physical Metallurgy Principles & Practice", V. Raghavan
3. "Introduction to Solids", L.V.Azaroff
4. "Structure and Properties of Materials, Wultff Series, Wiley Eastern, New Delhi
5. 'Materials in Nuclear Application'-C.K.Gupta
6. Carter G F and Paul D E G, " Material science and engineering", Published by ASM, 1991
7. Baldev Raj et al, Practical Nondestructive Testing", 2nd Edition, Narosa, 2005
8. Fontana, Mars G, "Corrosion engineering" 3rd Edition, McGraw hill, 1987
9. Uhlig, Herbert H and Revie R Wniston, "Corrosion and Corrosion Control- An Introduction to Corrosion Science Engineering", 3rd Edition, John Wiley, 1984

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Syllabus

Subject: Nuclear Fuel Cycle And Water Chemistry	**Code: - NE 7-FC07 FC08-CMEI-50**
Discipline: Mechanical, Chemical, Electrical, Electronics and Instrumentation Engineering	**No. of Hours: 45**

Nuclear Fuel Cycle: (19 Hours) General description for different types of reactors. Front end and back end processes. Three stage Nuclear Power Programme of DAE.
Basic considerations of Fuel Design. Types of Nuclear Fuels, Research/Power Reactors Fuels, Thermal/ Fast Reactor Fuels. Metallic, ceramic fuels, cermet and dispersion fuels, Advantages/ disadvantages. Cladding Materials, zirconium alloys,stainless steels, aluminum and alloys.
Manufacturing processes for Uranium. Uranium ore mining and milling, Production of Uranium metal, alloying of U, Fuel for CIRUS & Dhruva; their properties and fabrication methods, methods of fuel plate fabrication. Uranium oxide powder preparation, compaction, sintering. Problems with U Fuel, Oxide Fuels, Mixed Oxide and Carbide fuels, properties of Pu Fuels, U & Pu Carbide fuel plate fabrication, FBTR fuel pin fabrication method,
Manufacturing processes for production of nuclear grade zirconium
Production of nuclear grade Zirconium Oxide, Iodide Process and Kroll process for production of sponge. Thermal decomposition, electrolysis etc., Specification of Zr-Sponge in Nuclear reactor applications. Melting Practices: Arc Melting, plasma melting and Electron beam melting methods for producing zirconium alloy ingots.

Fabrication: Cold working & hot working, Forging, rolling, extrusion, pilgering, tube drawing, rod fabrication, wire drawing and metal joining (Resistance welding, TIG welding and EB welding), Heat treatment of Zirconium alloys; Vacuum annealing & Stress relieving, Pickling & finishing of zirconium alloys. Manufacture of Fuel Tubes, Coolant Tubes, Calandria Tubes and other structurals
Irradiation effects in fuel and cladding materials. Pellet Clad Interaction & Stress Corrosion Cracking. Delayed hydride cracking, Performance of pressure tubes Advanced Fuels, Canflex, Dupic, thorium utilisation

Heavy Water Production (8 Hours)
Heavy Water: Properties and importance of Heavy Water in Nuclear Power Generation, scenario of D2O requirement, Unique features of deuterium separation, details of various methods of production, distillation and electrolysis processes of D2O and their comparison. Chemical exchange processes: H2S - H2O, NH3-H2 processes, description of sulphide process, separation factor, flow sheet, utilities, effluent treatment, special components.
Ammonia - H2, mono-thermal and bi-thermal processes description, flow sheet, effluents, NH3 – H2O front end process, salient features of equipments like ejector tray towers, etc. Ammonia-Hydrogen Front end process

Reprocessing of spent Nuclear Fuels. **(4 Hours)** Introduction to radiochemistry, difference between conventional & radiochemical plant, process and equipment limitations, criticality, safety and other hazards, ventilation and shielding. Spent fuel storage, decontamination, solvent extraction, Purex process, Reprocessing of thorium based fuels.

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Nuclear Waste management: (4 Hours) Sources, Characteristics and classification of radioactive waste, general philosophy of radioactive waste management. Methods of treatment for low, intermediate and high level solid, liquid and gaseous wastes with examples. Conditioning of radioactive waste, cementation, bituminisation and vitrification methods. Storage for primary/secondary solid waste and ultimate disposal.

Aspects of Heavy Water and its Analytical Chemistry (6 Hours)

Fundamentals of analytical chemistry, IR, UV, Neutron scattering, atomic absorption spectrophotometry, GC, GLC, HPLC, Mass spectrum.

Specific analytical instruments used in process & mineral plants, Measurements of impurities in gas / liquid like CO, CO2 , SO2, H2S, NH3 etc.

Measurement of SPM in stack, ambient air etc.

Online measurement of O2, sulfides (for H2S), pH etc.

Water source and Impurities, External treatment: Aeration, chlorination, clarification, filtration, precipitation softening processes, Ion exchange and DM water production

Boiler water systems & treatment

Cooling water systems & treatment

Industrial waste water treatment

Isotope separation Process (4 Hours)

Equilibrium and non Equilibrium Processes,

Thermodynamic minimum work for separation

Value function separative work

Cascade theory, Ideal cascade and squared of cascade.

Various reversible separations processes

Isotopic separation systems

Reference Books

Fundamentals of Analytical chemistry- Douglas, A.S.; Donald, M. W., Fourth edition

BETZ handbook of Industrial Water conditioning, eighth edition, 1980

Chemical engineer's Handbook- Perry J.H. and Green, Seventh edition

Nuclear Reactor Engg – Reactor Design basics 4th edition, Vol.1

Nuclear Reactor Engg – Reactor Systems Engg 4th edition Vol.II

By Glasstone, Samuel , Pub: Sesonske, Alexander, Pub: CBS, New Delhi

Nuclear Radiation Detectors by Kapoor S.S. & Ram Murthy, V.S. Pub: New Age, New Delhi

Advances in Industrial waster water treatment by P.K. Geoel Pub: Jaipur

Essentials of Nuclear chemistry 4th edition by H.J. Arnikar Pub: New Age, New Delhi

Technology of Zirconium by Miller.

Villani , Stelio, " Isotopic separation (An ANS Monograph)", American Nuclear Society, 1976

Skog , Douglas A et al, " Principles of Instrumental Analysis "5th Edition , Harcourt Asia , 2001

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Syllabus

Subject: Advanced Chemical Reaction Engineering	**Code: CEM:E 30:C-25**
Discipline: Chemical Engineering	**No. of Lectures: 25**

Review of basic concepts of reaction engineering
Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
Reactor design: counter-current moving bed reactors, fluidized bed reactors.
Advanced topics in reaction engineering- three phase reactors, integral reactor-separators, complex systems.
Examples from nuclear chemical engineering.

Reference Books:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)
6. Hartland, Stanley, "Counter-current Extraction: An Introduction to Design & Operation of Counter-current Extractors", Pergamon Press, 1970
7. Smith Robin, "Chemical process Design, MGH (New York), 1995
8. H. Scott Fogler, " Elements of Chemical Reaction Engineering" 4th Edition, Pearson, 2006

Core Engg. Module

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Syllabus

Subject: Advanced Mass Transfer, Equipment Design and Solvent Extraction	Code: CEM-04:E32 AC03:C 45
Discipline: Chemical Engineering	**No. of Lectures: 45**

Theories of mass transfer: 15 Hrs

Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fiber extractors. Adsorption and ion exchange equipment. Membrane separation and other advanced mass transfer processes. Process intensification approaches.

Mass Transfer Equipment Design: 10 Hrs
Different types of mass transfer equipment for gas liquid operations. Selection criteria for tray v/s packed columns. Design of cross flow and multiple d/c type sieve trays, Ejector Trays Hydro dynamics of trays & packed columns, Structured & random packings Performance evaluation of plate & packed column, spray, packed & tray columns trickle bed reactors.

Solvent extraction: 20 Hrs
Introduction to liquid-liquid extraction: Molecular and eddy diffusion, inter phase mass transfer, Lewis-Whitman theory calculation of No. of stages for cross flow and counter current flow, selection of solvent. Three component system. One pair partially soluble, two pairs partially soluble Binodal solubility curve, Representation in equilateral triangular coordinates, interpretation of equilibrium curves, extraction in multi component systems, use of "pinching " in extraction & scrubbing operation.

Dispersion & Coalescence: axial and radial dispersion, Factors influencing dispersion, Primary and secondary break ,types of impellers, dispersion in spray columns, sieve plate column packed column and in agitated systems. Factors affecting coalescence, coalescence in spray column, packed column in settlers.

Equipment for solvent extraction: Selection criteria for contractors, classification of contractors, contractors effectiveness, spray columns, packed columns, sieve tray, pulsed sieve plate column, mixer-settlers, centrifuge.

Contd...

Design of mixer settlers: Design from 1st principles, Batch and continuous equipment, (Design of batch mixer settler), Principles of scale up of designs, mixer and scale up hydrodynamic balance and location of aqueous ,mixed and organic parts.

Chemistry of Uranium Extraction: Different solvents, Mechanism of Uranium extraction, diluents, third phase formation, Phase or diluents modifiers.

Extraction processes in Nuclear industry: Ore concentration, DDPA process, DEHPA, AMEX process, TBP-UO_2 $(NO_3)_2$ refining ,PUREX process, Thorex Process, TBP-$Zr(NO_3)_4$ process

Reference Books:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)
8. Treybal, R.E., "Mass Transfer Operation" 3rd Edition, Tata McGraw Hill, 2005
9. J.M.Coulson et al, "Coulson & Richardson's Chemical engineering- Fluid Flow, Heat Transfer & Mass Transfer" 6th Edition, Vol.1, Oxford Univ. 2007
10. Hartland, Stanley, "Counter-current Extraction: An Introduction to Design & Operation of Counter-current Extractors", Pergamon Press, 1970
11. Joshi M.V., "Process Equipment Design" McMillan, New delhi, 1976
12. Perry Edmond S.Ed. et al, "Separation & Purification Methods", Marcel Dekker, New York, 1974

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Syllabus

Subject: Basic Process Instrumentation and Control	Code: CEM:CC03-M - 20
Discipline:Mechanical, Chemical & QA Engineering	No. of Lectures: 20

Instrument terminology, symbols & performance:
Instrument terminology: Accuracy, Precision, Resolution, Repeatability, Reproducibility, Drift, Dead band, Flow sheet symbols, Instrument performance, Standard unit of measurements, P&I diagrams.

Measurements: **Flow measurement**:
Mechanical type flow meters: Orifice meter, Venture meter, Pitot tube, Elbow meters.
Variable area flow meters, Magnetic flow meters, Turbine flow meters, Ultrasonic flow meters

Level measurements:
Level gauges, floats, Differential pressure type level detectors, Displacer type level detectors, Conductivity type, Capacitance type, Ultrasonic type, Radiation type

Temperature measurement: Filled-bulb and glass type thermometers, Bimetallic type, Resistance temperature detectors, Thermocouples, Pyrometers

Pressure measurement:
Bourdon & helical type pressure sensors, Bellow type pressure sensors, Diaphragm type, Differential transmitters, Manometers,Vacuum sensors.

Panel display instruments: Indicators, Recorders, Controllers
Signal transmission methods & Annunciations.

Automatic control theory: Control basics, Control modes, Closed loop response, Feed back & feed forward control, Tuning of PID controllers.
Final control elements: Control valve sizing, Control valve types, Actuators, Accessories & positioners

Control & Instrumentation, Sensors and Transmitters
Final control elements. Control valves, actuators, and positioners Controllers Automatic controllers

Distributed Digital Control System
(a) Signal conditioning, (b) Data acquisition system (c) PC based instrumentation (d)Organisation of distributed control system; (e) Control software and qualification aspects (f) Data processing and SCADA.

Contd....

Reference Books:

1. Fundamentals of Temperature. Pressure and Flow Measurements – Benedict
2. Measurement Engineering – Stein P.K. Pub-fished by Stein Engineering Services
3. Mechanical Measurements – T.G. Backwith and N. Leins Suck, Addison Wesley
4. instrument Technology, Vols. 1 to 5, - E.B. Jones, Butterworth and London
5. Experimental Methods for Engineering – J.P. Holman, McGraw Hill
6. Measurement in Applied Physics – A.A. Burr K.J. Dean, Chapman and Hall
7. Mechanical and Industrial Measurements – R.K. Jain, Khanna Publishers, NewDelhi.
8. Instrumentation for Scientific Research – Kurt S. Lion, McGraw Hill
9. Industrial Instrumentation Fundamentals – A.E. Fribance, Tata McGraw Hill
10. Measurement system, Application and Design, Ernest D. Deophhlin, McGraw Hill
11. Process control – P. Harrict, Tata McGraw Hill
12. Automatic Process Control – Donald P. Beckman, Wiley Eastern Ltd., New Delhi
13. Industrial Instrumentation – Donald P. Beck-Man, Wiley Eastern Ltd. New Delhi
14. Fluid Meters – Their Theory & Application Edited by H.S. Bean, ASME Publication
15. Principles and Practice of Flow meter Engineering – L.K. Spink, Published by the Foxboro Company.
16. Manual on the use of Thermocouples in Temperature Measurement, ASSE Publication
17. Process Instruments and Control Handbook Edit-by D.M. Considine McGraw Hill
18. Handbok on Applied Instrumentation : Edited by D.M. Considine McGraw Hill and S.D. ROSS McGraw Hill
19. D.Patranabis, "Principles of Process Control" McGraw Hill, 2007
20. Harriott, Peter, "Process Control", TataMc Graw Hill, New Delhi, 1998
21. Seborg, Dale. E, "Process Dynamics & Control" 2nd Edition, Wiley, Singapore, 2005

BARC Training School
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Syllabus

Subject: Computational Fluid Dynamics and Heat Transfer	Code: CEM:E 21:CM-40
Discipline: Mechanical and Chemical Engineering	**No. of Lectures: 40**

Basics of Fluid Flow, Heat Transfer and Numerical Analysis: 15 Hrs

Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.

Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.

Classification of Partial Differential Equations (PDEs)

Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.

Temporal integration: explicit, implicit scheme

Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method

Discretization of convection-diffusion problem: exponential scheme, power-law scheme

Laminar Boundary Layer and Forced Convective Heat:

Formulation of differential equation for hydrodynamic and thermal boundary layer

Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.

Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory

Convective heat transfer for internal and external flows

Low and high Prandtl number limits and different thermal boundary conditions

Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer:

Reynolds decomposition for turbulence ; Prandtl's mixing length theory, Mixing length models

Structure of turbulent boundary layer over flat plate and through circular cylinder ; Calculation of friction factor and drag coefficient ; Analytical and semi-analytical correlations for calculating heat transfer coefficients ; Analogy between heat and momentum transfer ;Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:

Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model

Reynolds stress models: algebraic and differential models,Low Reynolds number models

Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

Natural Convection :

Basic Equations of natural convection : Boussinesq approximation : Derivation of Dimensionless groups from basic equations : Analytical approximations : Numerical solution of approximate equations

Contd....

Numerical Solution of Complete Fluid Flow and Energy Equation : 6 Hrs
Formulations of governing equations used in numerical simulation:
Streamfunction-temperature formulation
Streamfunction-vorticity-temperature formulation
Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
Primitive-Variable (P-V-T) formulation
Pressure velocity coupling for incompressible flow:
Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
Simple grid generation techniques for structured grid:
Elliptic, parabolic and hyperbolic equation method
Grid adaptation
Domain decompositions in CFD and heat transfer
SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer : 10 Hrs
Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Heat Transfer With Phase Change : 9 Hrs
Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model); Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation) ; Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.Critical Flow: Models for single – phase and two-phase critical flow.

Contd….

Reference Books:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag
23.John D Anderson, " Computational Fluid Dynamics: The Basics with Application"
24. Bernard, Jng C.J., " handbook of Fluid flow Metering", The Trade & Technical press, 1988
25. Kern, Donald Q, "Process Heat Transfer", Tata McGraw Hill, 2000
26. Mc Adam, W H, "Heat Transmission", McGraw Hill, 1954
27. " Fundamentals of Two-phase Heat Transfer", Chapter 10
28. j.H.Ferziger & Milovan Peric, "Computation Methods for Fluid Dynamics" John Wiley Sons, 2006
29. J.M.Coulson et al, "Coulson & Richardson's Chemical Engineering-Fluid Flow, Heat Transfer & Mass transfer", 6th Edition, Vol.1, Oxford Univ., 2007
30. Sengupta Tapan K, "Fundamentals of Computational fluid Dynamics", New Delhi, Elsevier, 2006

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Process Dynamics, Analysis and Control	Code: CEM:E31 E29:50
Discipline: Chemical Engineering	**No. of Lectures: 40**

Review of Basic Control: 40 Hrs

Dynamic models, Transfer function Transient analysis - Rouths criteria etc., Stability, Frequency analysis - Nyquist criteria with examples using MATLAB etc., Discrete models, z-transforms, Sampled data control, Introduction to state space control, State feed back, Pole placement, Controllability, Observability, Stochastic Processes, Kalman filtering. Process identification from plant data; SISO with PID control, Inadequacies; Cascade, feed forward, dead time compensation; Introduction to adaptive control, non-linear control; Poorly defined system, and fuzzy control. Multivariable systems, Model predictive control: internal model control, Dynamic matrix control, multivariable control, and optimal control. Introduction to Fault Detection and Diagnosis. The assignments include problem solving with simulation software.

Reference Books:

1. W.L. Luyben, Process Modeling Simulation and Control for Chemical Engineers, McGraw Hill, 1990.
2. D. Burghes and A. Graham, Introduction to Control Theory including Optimal Control, John Willey & Sons,
3. Stephanopoulos, Advanced Process Control
4. Coughanowr and Koppel
5. K. Ogata, Modern Control Systems, Prentice Hall (India)
6. K.S. Astrom and B. Wittenmark, Computer Control Systems, Prentice Hall (India)
7. Douglas Considine, Handbook of Process Instrumentation and Control,
8. E. O. Doebline, Instrumentation and Measurements

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Syllabus

Subject: Process Modeling, Simulation and Optimization	**Code: CEM-5:E 33:C-20**
Discipline: Chemical Engineering	**No. of Lectures: 20**

Process Simulation: 10 Hrs
Introduction to process modeling, simulation and optimization. Deterministic versus stochastic models. Dynamic and steady state models.
Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
Approaches to Plant Simulation: Sequential modular; Equation oriented; Simultaneous modular
Steady-State Sequential Modular Simulators:
Concepts of partitioning, tearing and nesting as applied to flow sheets: Methods of representation of plant topology; recycle detection and calculation ordering algorithms; recycle convergent methods.

Steady State Equation Oriented Simulators:
Strategies for formulation of plant models; sparse systems and Solution procedures; Solution methods for simultaneous modular approach; General Approaches For Non-Linear Systems; Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eign-value method. Examples of solving non-linear systems; Commercial Simulators ;Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization: 10 Hrs
Classification of optimization problems, necessary and sufficiency conditions for optimum; Search procedures for unconstrained optimization problems; Non-linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator; Case Study: Simulation and modeling of heavy water cascade, use of lumping and de-lumping strategies, application on Optimisation techniques. Decomposition of complex topology, rate base model versus equilibrium base model for tower internals, evaluation of transport co-efficients using mass transfer with reaction models, use of analogies for evaluation of interface co-efficient introduction, Recent Developments: Multi-objective optimization, Plant optimization by Genetic Algorithms and Neural Network.

Reference Books:
1) Process Modeling, Simulation And Control for Chemical Engrs. 2nd Edition: Luyben William L, Publisher: McGraw-Hill, New York .
2) Optimization of Chemical Processes ; Edgar, Himmelblau & Lasdon

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Syllabus

Subject: Applied Process Instrumentation and Control	Code: CEM :E 50:CEEI-45
Discipline: Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 45**

Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: **15 Hrs**

Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annular, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices, venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flow meter; Ultrasonic flow meters- transit time, Doppler type, Clamp on type ultrasonic flow meters, Coriolis and thermal mass flow meters. Applications and limitations of various flow meters. Two phase flow measurements.

Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermo well, thermo well installation aspects. Surface temperature measurement techniques; Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

Pressure: 15 Hrs

Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.>Analytical Instrumentation: Conductivity, pH, ORP and Turbidity measurement.

Automatic Control Theory: Control busses, Control Modes, closed looping response, PID controllers, feed back & feed-forward control, timing of PID controllers. Auto tuning and self adaptive controls. Operational amplifiers and its applications.

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Instrumentation Field Busses: HIRE Foundation Field Bus, profi bus, mod bus, TCP/IP, Industrial Ethernet, device net & CAN

Introduction of Advance Sensor Technology: Wireless sensors.

Basics of Pneumatics : Instrument Air Quality, Air requirement, Flaper nozzle mechanism, signal booster.

Other Measurements: Relative humidity; viscosity and density measurement

Introduction to Neural Network and Fuzzy Logic : 5 Hrs

Control valves: 10 Hrs

Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve range ability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings; P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

Reference Books:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12.Murthy, D.V.S ,"Transducers and Instrumentation ", Prentice Hall, 1995
13. Liptak, Bela G.Ed, "Instrumentation Engineers Hand Book: Process Measuring & Analysis", 3rd Ed., Buter Lurth
14. Nakra, B.C & Choudhary K.K. "Instrumentation, Measurements" ,Tata Mc Graw Hill, 2004
15. ECK Man, D.P. " Industrial Instrumentation Measurements" , CBS, 2004
16. Anderson, Norman A, "Instrument for Process Control", 3rd Ed., CRC Press, 2005

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Electrical Engineering Practices- I	Code: CEM:AC13:E -30
Discipline: Electrical Engineering	**No. of Lectures: 30**

1. **EHV Switchyard Design**: Switching schemes; clearance; Comparison between types of switchyards; Brief introduction to equipments in switchyard and their functions; Lighting arrestors and insulation co-ordination; Lightning protection, Maintenance of Switch yards, Selection of instrument transformers for measurement and protection.
2. **Selection Of Transformers**: Types & classifications; Special design features; Accessories; Specifications and testing; Voltage regulation calculations, Maintenance, Transformer oil, requirements, specifications and maintenance.
3. **Motor & Their Applications**: Types of motors; System requirements; Performance requirements, Drives, Selection of starters, Installation and maintenance, Insulation classes and maintenance.
4. **Station Auxiliary Systems**: Class 1, II , III and IV systems classifications.
5. **Introduction to DG Sets, Ups & Batteries**: DG sets: Engine, auxiliaries, Generator, Electrical equipment, brush-less and static excitation systems and introduction to SCADA
6. **UPS:** Types, different configurations, selection.
7. **Batteries**: types, selection criteria, charging methods, Testing methods
8. **Cabling, Lighting & Grounding**: Cabling: Types, sizing, laying and de-rating factors, terminations, fault location Grounding systems; Bus ducts.
9. **Selection of MV & LV Switchgear:** Types ; specifications and testing MCCs; Distribution boards; ELCB, Internal protection, Maintenance.
10. **Electrical Equipment**: Requirement In Hazardous Areas: Specific requirements for safety related electrical equipments & systems in Chemical Industries. Fire wall, barrier and stops.
11. **Electrical Control Circuits**: Symbols, development of control circuit, Single-line/schematic diagram Latest Trends In Electrical Engineering
12. **Protection**: Line protection; generator protection; Transformer protection; Motor protection.

Reference Books:

Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey, Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey
Source book of Electronic circuits by Markus John, Pub: McGraw Hill, New York
Electrical control for machines 3rd edition, by Rexford, Kenneth B, Pub: Delmer
Elec Engg materials by A.J. Dekker, Prentice Hall, New Jersey
Basic Elec. Engg 2nd edition by D.P. Kothari & I.J. Nagrath Pub: Tata McGraw Hill, New York

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Syllabus

Subject: Electrical Engineering Practices - II	Code: CEM: EEP-II: E:20
Discipline: Electrical Engineering	**No. of Lectures: 20**

Electric Drive: Advantages of electric drive; Factors governing selection of motors; Nature of electric supply; Nature of the drive: Individual drive, group drive: Nature of load: Starting torque, behavior of load with respect to speed, high inertia loads, Electrical characteristics of motors: Starting Characteristics, running characteristics, speed control, braking characteristics

Size and rating of motors: Sizing calculation, Duty cycle of motor, continuous, intermittent, over load capacity and pull out torque: Mechanical considerations: Type of enclosure, type of bearings, transmission of drive, noise level Cost: Capital cost, running cost.

Electric Heating: Advantages of electric heating Methods of heating Resistance heating; direct resistance heating; indirect resistance heating; types of heating elements, selection of heating elements, requirements of a good heating material, causes of failure of heating elements, temperature control resistance furnaces, introduction to design of heating element. Introduction to refractory materials for furnaces.

Illumination Engg: Fundamentals of radiation, visible range of light, colour temperature, Eye end vision. Laws of illumination and units. Various light sources: incandescent and discharge lamps. Illumination system: Luminnaire, Ballast and starters. Colour and glare, Interior and exterior lighting applications and controls. Lighting calculation and design. DC Power surfaces for industrial applications

Electric Arc Furnaces: Definition and Characteristics of arc, power supply and control of arc furnace.

Plasma furnaces: Definition and characteristics of plasma, start plasma, power supply and control of plasma furnace.

Electron beam melting: Introduction, generation of electron beam, power supply and control of electron beam

High frequency heating Induction heating: skin effect, aspects of power supply Di-electric heating, Introduction, advantages

Electric Welding: Electric arc welding, Electric resistance welding, Electron beam welding

Contd....

Electrolytic Processes: Laws of electrolysis, electroplating,
Earthing & lightening protection-effect of current to human body.
Introduction to power quality:

Perspective on power quality--Categories and origin of power quality--
Power system harmonics--Non linear loads--
Effect of power quality on industrial loads--
Motor issues--Electro magnetic interaction--
VFD issues

Reference Books:

Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey,
Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey
Source book of Electronic circuits by Markus John, Pub: McGraw Hill, New York
Electrical control for machines 3rd edition, by Rexford, Kenneth B, Pub: Delmer
Useful IS Codes for Electrical Engrs.

a) Code of practice of earthing : IS 3043:1987
b) Chart and treatment of electric shock : SP 31:1986
c) Guide on effects of current passing through human body: IS 8437 (Part 1 & 2)
d) Three phase induction motor: IS 325
e) Power transformers : IS 2026 (Part 1 to 5)
f) Code of practice of industrial lighting : IS 6665
g) Code of practice for interior illumination : IS 3646 (Part 1 to 3)

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Subject: Modern Electronic Control of AC and DC Drives	Code: CEM:JNTU:30
Discipline: Electrical Engineering, Electronics Engineering and Instrumentation Engineering	**No. of Lectures: 25**

A. Power Control of DC Drives

UNIT-I Three phase naturally commutated bridge circuit as a rectifier or as an inverter Three phase controlled bridge rectifier with passive load impedance, resistive load and ideal supply – Highly inductive load and ideal supply for load side and supply side quantities, shunt capacitor compensation, three phase controlled bridge rectifier inverter.

UNIT – II Phase controlled DC Motor drives
Three phase controlled converter, control circuit– Two quadrant, Three phase converter controlled DC motor drive – DC motor and load, converter

UNIT – III Current and Speed controlled DC Motor drives
Current and speed controllers – current and speed feedback – Harmonics and associated problems – sixth harmonics torque.

UNIT – IV Chopper controlled DC motor drives
Principle of operation of the chopper – Four- quadrant chopper circuit – Chopper for inversion – Chopper with other power devices – model of the chopper – input to the chopper – rating of the devices – Pulsating torque.

UNIT – V Closed loop operation of DC motor drives
Speed controlled drive system – current control loop – pulse width modulated current controller – hysterisis current controller

B. Power Control of A.C. Drives

UNIT I Introduction to AC Drives
Introduction to motor drives – Torque production – Equivalent circuit analysis – Speed-Torque Characteristics with Variable voltage operation, Variable frequency operation, constant v/f operation – Variable stator current operation – Induction motor characteristics in constant torque and field weakening regions

UNIT II Control of Induction motor drives at Stator side
Scalar control – Voltage fed inverter control – Open loop volts/Hz control – speed control slip regulation – speed control with torque and flux control – current controlled voltage fed inverter drive – current-fed inverter control – Independent current and frequency control – Speed and flux control in Current-Fed inverter drive – Volts/Hz control of Current-fed inverter drive – Efficiency optimization control by flux program

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UNIT III Vector control of Induction Motor Drives

Principles of Vector control – Vector control methods – Direct method of vector control – Indirect method of vector control – Adaptive control principles

Techniques of motor drive configuration.

Reference Books:

1. Power Electronics and motor control – Shepherd, Hulley, Liang – II Edition, Cambridge University Press
2. Electric motor drives modeling, Analysis and control – R.Krishnan – I Edition, Prentice Hall India
3. Power Electronic circuits, Devices and Applications – M.H.Rashid – PHI – I Edition – 1995
4. Fundamentals of Electric Drives – G.K. Dubey- Narosa Publications -1995
5. Power Semiconductor drives – S.B.Dewan and A.Straughen - 1975
6. Electric Motor Drives Pearson Modeling, Analysis & Control – R.Krishnan – Publications – 1st edition – 2002
7. Modern Power Electronics and AC Drives – B.K.Bose – Pearson Publications – 1st edition
8. Power Electronic control of AC Motors – MD Murphy & FG Turn Bull Pergman Press(For Chapters II, III, V) – 1st edition
9. Power Electronics and AC Drives – B.K.Bose – Prentice Hall, Eagle wood diffs New Jersey(for chapters I, II, IV) – 1st edition
10. Power Electronic circuits, Devices and Applications – M.H.Rashid – PHI - 1995
11. Fundamentals of Electrical Drives – G.K.Dubey – Narora publications - 1995 (For Chapter II)
12. Power Electronics and Variable frequency drives – B.K.Bose – IEEE Press – Standard publications -1st edition – 2002
13. Sen P.C., " Power Electronics", Tata McGraw Hill, 1988

BARC Training School
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Syllabus

Subject: Networking Communications	**Code: CEM-9:E61: Etrn-I-20**
Discipline: Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 20**

Data Communication Topics: Basic Concepts, V.24 and V.35 standards, Dial up modems, xDSL technology, Techniques of Flow Control, Error Control, Switching, Multiplexing, and Routing. (4)

Digital Networks: ISDN BRA, ISDN PRA, Introduction to Frame Relay and ATM. (2)

Topologies: OSI Layer Model

Link Layer Communication: Types of Local Area Networks, Types of Ethernet, Ethernet frame structure, CSMA/CD, Hubs, Switches, Wireless LAN, Point-to-point Protocol. (3)

Internetworking: Repeater, Bridge, Router, Spanning tree Algorithm, Tunneling, Packet Fragmentation. (3)

TCP/IP: IP packet format, IP Addressing, Subnets, Introduction to CIDR and DHCP, IPv6,TCPsegment format,TCP Call Control. (3)

IP Routing: IP Routing Algorithm, ARP, and ICMP. IP Routing Protocols: RIP, OSPF, and BGP. Domain Name System. (2)

Network Application and Security: Half/full Association, Client Server and peer-to-peer working, Unix socket programming, E-mail, http, concepts of firewall and proxies, Encryption, Digital signatures. (3)

Reference Books:

1. Data and Computer Networks: William Stalling. Prentice Hall of India
2. Internetworking with TCP/IP – D.E Comer, Vol. I. Prentice Hall of India
3. Unit Network Programming – W.R Stevens. Prentice Hall of India.
4. Practical Data Communications: Roger L. Freeman. John Wiley and Sons
5. Basandra, Suresh K, "Local Area Networking", Galgotia, 1995
6. A.S.Tanenbaum, "Computer networks", 4th Edition, Pearson, 2003
7. B.A.Forouzan etal, "Data Communications & Networking", Tata McGraw Hill, 2001

BARC Training School
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Syllabus

Subject: Programmable Logic Controllers and Applications	Code: CEM:EEI-40
Discipline: Electronics, Electrical and Instrumentation Engineering	**No. of Lectures: 30includes Practical Demos**

20 Hrs
Unit 1: PLC Basics: PLC system, *VO* modules and interfacing, CPU processor, programming equipment, programming formats, construction of PLC ladder diagrams, devices connected to *VO* modules.

Unit 2: PLC Programming: Input instructions, outputs, operational procedures, programming examples using contacts and coils. Drill press operation.

Unit 3: Digital logic gates, programming in the Boolean algebra system, conversion examples. Ladder diagrams for process control: Ladder diagrams & sequence listings, ladder diagram construction and flow chart for spray process system.

Unit 4: PLC Registers: Characteristics of Registers, module addressing, holding registers, input registers, output registers.

Unit 5: Sensors as input devices to PLC- Various types of proximity sensors: Inductive, capacitive, photo electric, magnetic, laser, UV and ultra sonic sensors. Brief discussion on other input devices like pressure switch, flow switch etc.
20 Hrs
Unit 6: PLC Functions: Timer functions & Industrial applications, counters, counter function industrial applications, Arithmetic functions, Number comparison functions, number conversion functions.

Unit 7: Data Handling functions: SKIP, Master control Relay, Jump, Move, FIFO, FAL, ONS, CLR & Sweep functions and their applications.

Unit 8: Bit Pattern and changing a bit shift register, sequence functions and applications, controlling of two axis & three axis Robots with PLC, Matrix functions.

Unit 9: Analog PLC operation: Analog modules & systems, Analog signal processing, multi bit data processing, analog output application examples, pm principles, position indicator with pm control, pm modules, pm

Unit 10: Introduction to CNC controls

Reference Books:

1. Programmable Logic Controllers - Principle and Applications by John W. Webb & Ronald A. Reiss, , Fifth Edition, PHI
2. Progranunable Logic Controllers - Programming Method and Applications by JR. Hackworth & F.D Hackworth Jr. - Pearson, 2004.

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Syllabus

Subject: Digital Signal Processing and Machine Vision	**Code :CEM : New**
Discipline: Electronics and Instrumentation Engineering	**No. of Lectures :30**

Digital Signal Processing:

Introduction : Basic elements of a digital signal processing system, Fourier series and fourier transform, Z-transform, convolution, correlation, sampling theory, aliasing anti-aliasing filter, quantization noise and signal reconstruction. (4 Hrs)

Discrete Fourier Transform(DFT) : Interpretation of DFT, Properties of DFT, DFT of real signals, convolution and correlation using DFT (2 Hrs)

Fast Fourier Transform (FFT) : Efficient computation of DFT, Inverse FFT algorithm, Use in linear filtering and correlation. (2 Hrs)

Design of Digital Filters : IIR & FIR filters, design techniques and realization. (2 Hrs)

Overview of DSP Processors : Harvard architecture, pipelining, general purpose, fixed point and floating point processors. (2 Hrs)

DSP Applications : in Nuclear and other fields (2 Hrs)

Image Processing:

Fundamentals of Image Processing : Image acquisition, Image model, sampling, quantization, relationship between pixels, distance measures, connectivity, Histogram : definition, decision of contract basing on histogram, image stretching, sliding, histogram equalization. (4 Hrs)

Image transforms, Image enhancement by spatial domain methods and frequency domain methods (1Hrs)

Applications of digital image processing. (1 Hrs)

Machine Vision:

- Image Model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflection, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, boundary representation, Mathematical Morphology ;
- Intermediate Vision: Line, Circle, Elipse and Polygon detection, Hough Transform for detection, Corner detection, Generalized Hough Transform;
- High level Vision: Scene interpretation;

• Contd....

- Texture - Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & Pattern classes, Classifiers in general, Distance Metric, Classification and recognition, various methods of recognition & interpretation, Template matching and area correlation, matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

Reference:

1. Johnny R Johnson, Introduction to digital signal processing, Prentice-Hall of India, 2000
2. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice-Hall of India, 1995
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice-Hall of India, 1988 .
4. Fundamentals of Digital Image Processing – A.K. Jain, Prentice Hall of India.
5. Digital Image Processing – R.C. Gonzalez & R.E. Woods.
6. Refel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
7. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis and Machine Vision, Vikas Publishing House, 2003.
8. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc.2004.
9. Davies E.R., Machine Vision Theory Algorithms Practicaltities, Academic Press.
10. D.A. Forsyth & J.Ponce, Computer Vision A Modern Approach, Prentice Hall, 2003.
11. Horn B.K.P., Robot Vision, The MIT press, 1987.
12. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
13. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

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Syllabus

Subject: Embedded and Computer Based Systems Design	Code: CEM:E 54:Electrn-40
Discipline: Electronics Engineering	**No. of Lectures: 40**

Microprocessor Based Hardware Design: 14 Hrs

Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Microcontrollers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
Industry Standard Bus Systems: ISA, PCI, VME, PXI: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, and testability.
Embedded computer system design example.

Computer Communication and Networks: 7 Hrs

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables,hub,switch,routers etc.)
Fault Tolerant and Distributed Architectures : Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues; Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

Real-Time System Design: 15 Hrs

Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.
Overview of LINUX and Embedded NT.

Introduction to VLSI Design: 4Hrs

Reference Books:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, And 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Microcontroller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices

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4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill
17. Hofacker, W., "Microcomputer Hardware handbook", 1982
18. Leventhal, Lance A, "Introduction to Microprocessor: Software, Hardware programming", Prentice Hall, 1986
19. Basandra Suresh K, "Local Area Networks", Galgotia, 1995
20. James F Kurose & Keith W.Ross, " Computer Networking: Atop Down Approach Featuring the Internet" 2nd Edition, Pearson, 2003

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Computer Aided Design and Manufacturing	Code: CEM-14: M-35
Discipline: Mechanical Engineering	**No. of Lectures: 35**

Introduction to CAD & CAM: 35 Hrs

Extensive definition of CE - CE design methodologies - Organizing for CE - CE tool box collaborative product development. IT support - Solid modeling - Product data management -Collaborative product commerce - Artificial Intelligence- Expert systems - Software hardware co-design. Life-cycle design of products - opportunity for manufacturing enterprises - modality of Concurrent Engineering Design - Automated analysis idealization control - Concurrent engineering in optimal structural design - Real time constraints. Manufacturing competitiveness - Checking the design process - conceptual design mechanism – Qualitative physical approach - An intelligent design for manufacturing system - JIT system - low inventory - modular - Modeling and reasoning for computer based assembly planning - Design of Automated manufacturing Lathe Machining, Milling Machining, EDM Wire Cut, Turret Punch Press, Absolute & Incremental Prog., Canned Cycle, Tool Selection, G / M code programming, CNC maintenance & macro programming, Generative machining. FEA, Mechanisms and Sheet Metal, CNC Technology, Robotics. Life Cycle semi realization - design for economics - evaluation of design for manufacturing cost concurrent mechanical design - decomposition in concurrent design - negotiation in concurrent engineering design studies - product realization taxonomy - plan for Project Management on new product development – bottleneck technology development.

Modeling : 3D Solid Modeling, Surface Modeling, Advance Surfacing, Assembly & Animation, Drafting & Detailing. Model Generation, Loading & Solution, Post Processing, Structural Analysis, Thermal Analysis using I-deas code for 2-D and 3-D cases using ANSYS.

Reference Books:

1) Proceedings of the 4th International Conference on CAD, CAM, Robotics & Factories by Indian Istitute of New Delhi : Edited by Juneja B L : Pub: Tata Mc Grew Hill, New Delhi, Vol. I, II, III

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Subject: Engineering design and FEM	Code: CEM:AC09,
Discipline: Mechanical & Quality Assurance Engineering	No. of Lectures: 45

Introduction (2 lectures):

Failure modes of pressure vessels and heat exchangers: yielding,Tensile instability,creep effects,fatigue,flow induced vibration, uckling,etc. Type of stress, significance of stress, theories of failure, stress intensities, ASME Sec.VIII Div. I and ASME Sec.111 omparisons

Theories of failure, Stress invariants and yield surfaces (3 lectures):

Mohr's circle, state of stress and invariants (2 D and 3 D) Hydrostatic state (dilatational) and distortional (Pure shear) state. Vonmises failure theory based on second invariant of distortional stress tensor and based on distortional energy theory; Tresca theory and comparison with Vonmises theory. Yield surfaces of Vonmises theory and Tresca theory in 3 - D with respect to O1, O2 and O3 axes.

Collapse load assuming elastic perfectly plastic material (3 lectures)

Long thick cylindrical shell under internal pressure. Pressure at I which yielding starts, pressure at which interface radius is p and collapse pressure (full section yielding) by Vonmises and Tresca theories. Limiting moment or collapse moment of beams of various cross sections (Rectangular, circular) and reduce shape factor. Collapse moment of a straight pipe (Treating as a beam) and deduce shape factor for pipe section.

Design aspects of cylindrical pressure vessel (3 lectures)

Major design options: Vertical, horizontal, choosing length and diameter of a vessel, support options (Lug! Bracket Vs skirt support), choice of closures. Formulae for thickness as per Sec. VIII, Div. I and numerical problem. Background to external pressure charts, effect of ovality / imperfection and plasticity, factor of safety for cylinders and factor of safety for sphere under external pressures. Sizing of stiffening ring. Flange design as per code: Bolt design and flange thickness calculation.

Heat exchangers: (3 lectures):

Shell and tube plate types heat exchangers. Tubesheet
thickness as per TEMA, Sec VIII Div 1 and see III (including concept of equivalent solid plate and modified elastic constants). Effect of axial rigidity of tubes in tubesheet thickness. Methods of joining tube to tubesheets. (rolled/expansion joints and welded joints); Pullout load. (strength of tube to tubesheet joint) Accomodating differential expansion among tubes and shells: Bend tube, U tube and Bellows. Buckling strength of tube and FIV of tubes (FIV mechanisms: Vortex shedding (lock-in), Fluid elastic instability and a acoustic resonance.

Stress and Strain concentration factors (Ka and K €) - 3 lectures:

Importance of local strain (peak strain) variation - fatigue damage rules (Coffin Mansion and Cumulative fatigue damage). Stress concentrations (i) elliptical holes in the center of a

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large plate subjected to uniaxial load (ii) circular hole in a plate subjected to uniaxial/biaxialloading (iii) circular hole in a cylindrical shell subjected to pressure loading. Stress and strain uncertain due to a small hole in an infinite plate subjected to hydrostatic in plane loading (based on thick shell formula for external pressure) and based on component stress and equivalent stress. (Elastic factors) and plastic stress and strain concentration factors. Approximate methods to obtain local plastic strain at point of interest: Nueber's rule and Molshy-Glinka rule. (Analytical equations and graphical representation and comparisons); Introduction to simplified elastic plastic analysis as per ASME.

Fracture Mechanics, Non ductile failure and Hydrostatic test (3 lectures):

Introduction to fracture mechanics, stress Intensification factors, fracture toughness, Paris' Law, concept of plastic domain at crack tip, J - integral, JIC, Transition temperature, (RTNDT), Methods to prevent brittle fracture, Integrity assessment diagram, appendix: G of ASME, Sec III Div 1, Maximum postulated defect, allowable pressure as a function of (T -RTNDT) and Hydrostatic test temperature.

Introduction to FEM and Modelling: 25hrs:

Historical Background - Weighted Residual Methods - Basic Concepts of FEM - Variational Formulation of B.V.P - Ritz Method - Finite Element Modeling - Element Equations – Linear and Quadratic Shape functions - Bar, Beam Elements - Applications to Heat Transfer. Basic Boundary Value Problems in 2 Dimentions - Triangular, quadrilateral, higher order elements - Poissons and Laplace Equations - Weak Formulation - Elements Matrices and Vectors - Application to Solid mechanics, Heat transfer, Fluid Mechanics. Natural Co-ordinate System - Lagrangian Interpolation Polynomials - Iso- parametric Elements - Formulation - Numerical Intergration - 1D -2D Triangular elements – rectangular elements - Illustrative Examples. Introduction to Theory of Elasticity - Plane Stress - Plane Strain and Axisymmetric Formulation - Principle of virtual work - Element matrices using energy approach. Dynamic Analysis - Equation of Motion - Mass Matrices - Free Vibration analysis - Natural frequencies of Longitudinal - Transverse and torsional vibration - Introduction to transient field problems. Non linear analysis. Use of software - h & p elements - special element formulation.

References Books:

1. O.C. Zienkiewicz., & R.L. Taylor., "The Finite Element Method", VoL.1 and Vot.2, McGraw-Hill, 4th Edition, 1991.
2. R.D. Cook., D.S. Malkus., & M.E.Plesha., "Concepts and Applications of Finite Element Analysis", John Wiley and Sons, 3rd Edition, 1989.
3. C.S.Desai & J.F.Abet., "Introduction to Finite Element Method", Affiliated East West Press Pvt. Ltd., 1972.
4. Larry J. Segerlind., "Applied Finite Element Analysis", John Wiley & Sons, 2nd Edition, 1984.
5. K.I.Rate., "Finite Element Procedures in Engineering Analysis", Prentice-Hall of India, Pvt. Ltd., NewDelhi,1990.
6. Mendleson A, 'Plasticity 'theory and Application'
7. Harvey J.F 'Pressure Vessel Design' CBS Publication
8. Process Equipment Design by 'Brownell and Young'
9. ASME Pressure Vessel and Boiler code Sec VIII Div 1., Div II, Div 111,Sec III Div1 (Including appendices)
10. Reddy, J.N., "Introduction to Finite Element Method", 2nd Edition, tata McGraw Hill, 2003
11. Rao Singiresu S., " The Finite Element Method in Engineering" 4th edition, Butterworths, 2005.

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Syllabus

Subject: Pressure Vessel and Piping Design	Code: CEM-13:E 20 CC08:M-30
Discipline: Mechanical Engineering	**No. of Lectures: 30**

20 Hrs

Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference among Sec. VIII Div.1, Div.2. and Div.3
Difference between metallic pressure vessel and FRP pressure vessels

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Piping Design & Engg :10 Hrs

Fundamentals of piping, pipe sizing and their economics, selection of pipe diameter, Pipe design pressure and input parameter.
Selection of pipe materials, Galvanizing of pipes, piping lining techniques & uses
Pipe classification, piping specification, and pipe schedule, ratings
Pipes and pipe fittings, branch connection criteria
Evaluation of bill of materials in piping & estimation
Pipe flexibility analysis, Expansion loops, Bellows
Pipe stress analysis
Pipe safety in two-phase flow and other flow induced vibrations
Valves
Insulation & painting of pipe lines, costing of piping schemes
Pipe supporting arrangements
Spring hangers, spring boxes, Pipe jointing, C.I. pipe caulking, Threaded piping, Construction welding of piping, Isometric drawings preparation & reading, Piping GA drawing preparation & reading, Inch-dia, Inch-M concept, Rack piping philosophy, under ground piping, coating-wrapping of underground pipe line, Holiday detection of coating & wrapping.

Reference Books:

1 Harvey J.F., "Pressure Vessel Design", CBS Publication
2 Brownell L.E., and Young E.D., "Process Equipment Design" Wiley Eastern Ltd., India
3 :ASME" Pressure Vessel and BoilerCode", Sec. VIII, Div. I and Div. II, 1985
4 "American StandardCode for Pressure Piping", - B31.1, 1972
5 "American Standard Code for Pressure Piping", - Petroleum, Refinery Piping, B31.1, 1972
6 "Standard of Tubular Exchanger Manufactures Association", 7th Edition, 1988.
7 Chemical engineer's Handbook- Perry J.H. and Green, Seventh edition
8 Plant design and economics for Chemical engineers- Peters and Timmerhaus, 2nd edition., McGraw-Hill, New York, 1968

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Syllabus

Subject: Vibrations	**Code: C EM :E26: M:20**
Discipline: Mechanical Engineering	**No. of Lectures: 20**

Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.

Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.

Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N

Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinery.

Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required, vibrations with special reference to vibrations of reciprocating systems.

Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, a periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

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Reference Books:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.
16. S.Kraham Kelly, "Fundamentals of Mechanical Vibrations", 2nd Edition, McGraw Hill, 2000 (CD is available)
17. Victor Wowk, "Machine Vibration: Alignment", McGraw Hill, 2000

BARC Training School
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Syllabus

Subject: Design aspects of Nuclear Fuel and Structurals	Code: CEM:QA-03
Discipline: Quality Assurance Engineering	**No. of Lectures: 30**

Fuel Bundle Design Approach (10 hrs) :

Design basis, Applicable codes, Material selection, Bundle design and analysis, Physics calculation, Radial flux depression across the bundle, Axial flux peaking, Engineering of the fuel bundle assembly, Pellet design, Dimensional requirements, Surface finish, UO2 chemical composition, UO2 density, Oxygen to Uranium ratio, UO2 microstructure and visual standard, Sheath (clad) design, Collapse behavior of sheath, Mechanical properties, Corrosion, Hydriding, Manufacturing process, Graphite coating, End plug design, Fuel bundle assembly design, End plate design, Bearing pad, Bearing spacer and Spacers design, Fuel bundle packing, Design analysis of fuel assembly, Thermo-mechanical analysis, Temperature distribution, Fission gas, Fuel thermal expansion, Stresses and strains in sheath, Sub channel analysis, CHF estimation, Stress analysis, Fuel bundle assembly, Analysis of end plate, Bundle droop, Fuel sheath collapse, Power ramp analysis, Fuel temperature during spent fuel transfer, Built-in safety features, Testing requirements and Type testing

PHWR Fuel Bundle operation (8 hrs):

Environmental condition, Primary coolant system requirements, Coolant channel / Linear tube region requirements, Fuel movement in Fuel handling system, Normal operation, Operational transients, Fuel thermal power, Fuel bundle power envelopes, Duty envelopes, Bundle power operating limit envelope derived from design, Linear heat ratings (LHR) and ∫Kdt (Integral Kdt), Fuel burnup, Fuel residence time in the reactor, Power ramps, Fueling machine compressive loads on fuel bundle, Refueling impact load on bundle, Defueling, Fuel bundle decay heat, Shutdown refueling, Fuel bundle operation during upset condition, Abnormal thermal power, Abnormal fueling machine loads, Sheath overheating, Sheath over-straining.

Pressure Tube Operation and design approach (8 hrs):

Operating Environment for fuel Channel, Material Selection for Pressure tube, manufacturing process for pressure tubes, degradation and failures modes for pressure tube like irradiation diametric and axial Creep, Growth, corrosion, Delayed Hydride Cracking, Design approaches based on degradation and failure mechanisms, Leak before Break (LBB) criteria, mitigation irradiation changes in the pressure tube, interaction of pressure tube with fuel bundle during operation.

Calenderia tube and Garter Spring (4 hrs):

Operating Environment, Material Selection for calandria tube and garter spring, manufacturing process, Failures modes, PC-CT contact, irradiation induced changes, Design approach, mitigation irradiation changes, corrosion mechanisms, interaction of pressure tube with Calanderia tube and Garter Spring.

Reference:

1. Corrosion of Zirconium Alloys in Nuclear Power Plants, IAEA-TECDOC-684, January, 1993
2. Assessment and Management of Ageing of Major Nuclear Power Plant components Important to Safety: Candu Pressure Tubes, IAEA-TECDOC-1037
3. Materials in Nuclear Energy Applications, Volume-I & II, C.K.Gupta, 1989
4. Nuclear Reactor Engineering, Samuel Galsstone
5. Thermo Physical Properties Data Base of Materials for Light Water Reactors and Heavy Water Reactors, IAEA-TECDOC-1496,2006
6. Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies-Operational Behavior, IAEA Nuclear Energy Series No.NFT-4.3, 2012
7. Advanded Fuel Pellet Materials and Fuel Rod Design for Water Cooled Reactor, IAEA-TECDOC-1654, 2010
8. Handbook of Nuclear Engineering, Volume-I, Dan Gabriel, 2010
9. Status of Fast Research Reactor and Technology Development, IAEA-TECDOC-1691, 2013

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Syllabus

Subject: Materials characterization and Applications	Code: CEM:EN713,
Discipline: Quality Assurance Engineering	**No. of Lectures: 25**

Microscopy Techniques (10 hrs)

Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Importance lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, Sample preparation, Etching of samples and Etchants for various materials. Quantitative analysis using optical microscopy (Grain Size, Inclusion Analysis-Size and Distribution etc.) , Interpretation of Micrograph for defects.

Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.

Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast,. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice, and Ewald sphere construction, indexing of selected area diffraction patterns, High resolution electron microscopy.

Scanning electron microscopy : interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and focus Other modes of operation, Application in failure analysis, fracture surfaces etc.

Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, field ion microscopes.

X-Ray Diffraction and Applications (10 hrs)

Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production, and detection of x-rays. Intensity of diffracted beams - scattering by an electron by an atom, by a unit cell, structure-factor calculations; factors to be considered in calculating the intensities.
Experimental methods in x-ray analysis; Laue methods, power photographs diffractometer and spectrometer measurements.

Applications: orientation of single crystal, crystal structure of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline aggregates, crystal size crystal perfection, crystal orientations:

Analytical Techniques: (5 hrs)
Methodologies of Chemical Characterization of Nuclear Materials by Wet chemical and instrumental methods. Introduction on principles of spectroscopic techniques Analysis of Uranium based materials produced at NFC for metallic impurities by spectroscopic techniques Analysis of Zirconium based materials produced at NFC for metallic impurities by spectroscopic techniques Analysis of steel based materials produced at NFC for metallic impurities by spectroscopic techniques

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Introduction on principles of wet chemical methods, Analysis of Uranium based raw materials and process intermediates by wet chemical methods, Analysis of Zirconium based raw materials and process intermediates by wet chemical methods, Analysis of steels by wet chemical methods

Introduction to Gas Analyzers, Analysis of Uranium based materials produced at NFC for non-metallic impurities by Gas Analyzers, Analysis of Uranium based materials produced at NFC for non-metallic impurities by Gas Analyzers, Analysis of zirconium based materials produced at NFC for non-metallic impurities by Gas Analyzers, Analysis of steels for non-metallic impurities by Gas Analyzers

Reference:

1. Physical Metallurgy Principles and Practice, V.Raghavan, III Edition
2. Transmission Electron Microscopy by David B.Williams, C.Barry Carter
3. Electron Microscopy and Analysis, Peter J.Goodhew, John Humphreys, Richand Beanland
4. Introduction to Optical Microscopy, Jerome Mertz
5. Metallography Principles and Practice, Vander Voort
6. Vogel's Quantitative chemical analysis: J. Mendham, R.C. Denney, M. J. K. Thomas, David. J. Barnes, (2009), 6th edition, Pearson.
7. Vogel's Text book of Qualitative inorganic analysis (2013), G. Svehla, B. Sivasankar, 7th edition, Pearson.
8. Principles of instrument Analysis(2014), 6th Edition, Douglas A. Skoog, F. James Holler, Stanely R. Crouch, 6th edition, Cengage
9. Skoog and West's fundamental of analytical chemistry(2012), F. James Holler, Stanely R. Crouch, 9th edition, Cengage
10. Analytical chemistry, Qualitative analysis; F.P Treadwell, William. T. Hall, S.B , Volume 1, John Wiley and sons; London
11. Chemical Analysis, Modern Instrument methods and Techniques; Francis Rouessac and Annick Rouessac; University of Le Mans, France, 2nd edition,; John Wiley and Sons, London
12. Modern Analytical Chemistry (2000), David Harvey; McGraw Hill Publication;
13. Analytical chemistry of zirconium and hafnium, Anil K. Mukherji, (1970), 1st edition, Pergaman press
14. Determination of Gaseous elements in Metals, Chemical Analysis (1974), P.J.Elving and I.M
15. Analysis of Non-Metals in Metals- Proceedings of International Conference Berlin (West), June 10-13, 1980; Editor Gunther Kraft, Walter de Gruyter.

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Syllabus

Subject: NDT and QC of Nuclear Fuel and structural components	Code: CEM:QA-02
Discipline: Quality Assurance Engineering	**No. of Lectures: 40**

NDT Techniques for Inspection of Materials: (28 hrs)

Ultrasonic testing (UT) : Principle and propagation of ultrasound, Properties of Ultrasound, Types of Transducers, Ultrasonic Testing Methods, UT Techniques, Calibration of Equipment, Instrument Control, Method for Evaluating Discontinuities, UT Procedures for casting, forging, tubes, bars and welds, Limitation, Code Requirement, Acceptance Criteria for Weld Metals.

Eddy current testing (ECT) : Physical Principles, Electricity, Magnetism, Electromagnetic Induction, Factors effecting Induction, ECT probes, Practical Characteristics of Probes, Design of Probes, Instrumentation of ECT equipment, Testing Procedures, Reference Standards, Applications, Presentation of Results

Radiography (RT) : Type of Industrial Radiation sources and Application, Radiographic Exposure Factors and Technique, GAMA Ray and X-Ray Equipment, Type of film and Screens, Image Quality Indicators Section, Radiographic Techniques, Film Processing, Viewing of Radiographs, Radiograph Interpretation, RT Procedure Qualification, RT Procedures for welds, RT Acceptable Level of Welds and radiation safety Codes.

Leak testing : Theory and Principle of Leak Testing, Equipment, Techniques and Calibration, Interpretation and Evaluation of Results, Leak Testing Procedures, Leak Testing Specifications.

Visual testing and Liquid Penetrant testing (LPT): Overview, Physics of light, Light Sources, Optical Aids, Measuring/Inspection Equipment, Surface Condition, Interpretation of Results and Evaluation. Principle of LPT, Equipment, LPT Procedures, Materials, Evaluation of Indication, Application of LPT, Hazards Precautions, Code Requirements.

Magnetic Particle Testing (MPT) : Principle of MPT, Type of Magnetization, Type of Magnetizing Current, MPT Equipment, Method of De-Magnetization, MPT, MPT, MPT Procedures, Evaluation of Indications.

Applicable Codes and Standards for NDT

Quality Checks during Fabrication of Tubes, Components, Fuel and Structurals (5 hrs)

Fuel Fabrication: Qualification of machine, material and men, Quality checks during PHWR fuel fabrication, viz Powder, pellet and Fuel bundles, Quality checks during BWR fuel fabrication, Quality checks for Fast reactor fuel and components.

Zircaloy Tubes and Components: Process Qualification, Types of Defects and Origin, Testing Procedures, Inspection of Ingot, Billets, Blanks, Dimansional and visual Inspection of Tubes,

Pressure Tubes and calandria Tubes: Process Qualification, Types of Defects and Origin, Testing Procedures, Inspection of Ingot, Billets and blanks. Specifications, relevance and final Inspection of tubes, Report Generation and Documentation.

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Introduction to Metrology (5 hrs):

Drawing symbols and methods of measurement, Linear metrology instruments viz. vernier caliper, vernier height gauge, micrometers, bore gauges etc., Measurement of straightness, flatness, squareness, parallelism, roundness, surface finish, Taper measurement, angle measurement, radius measurement, end squareness measurement, Introduction to CMM and non contact measurement system, Documentation

Advanced NDT Techniques (2 hrs)

Acoustic Emission, Infrared Thermography etc

References:

1. General dynamics (NDT techniques), ASNT Level-III Study Guide,
2. Handbook on NDT, Volumes 1 to 10, III and IV Editions, ASTM & ASME Hand Books
3. Practical Non-destructive testing, Baldev Raj et al, 1997
4. Practical radiography-Baldev Raj, B.Venktraman, 2004
5. Non-destructive testing of Welds-Baldev Raj, T.Jayakumar, 1999
6. Practical Eddy Current Testing, BPC Rao, 2007
7. Eddy Current Testing, Theory & Practice, ASNT reference Manual 1995
8. General Dynamics, Non-destructive Testing, General Dynamics, IV Edition
9. ASNT Level-III Study Guide, Electromagnetic Testing, Radiography, Ultrasonic Testing, Visual Testing
10. Acoustic Emission Testing, Leak Testing, Materials and Processes for NDT Technology, III Edition.

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Syllabus

Subject: Statistical Quality Control for QA	**Code: CEM:QA-01**
Discipline: Quality Assurance Engineering	**No. of Lectures: 30**

Introduction and Planning for Quality (3 hrs)

Concepts of quality, Inspection , Quality control , Quality Assurance, Total Quality Management, Cost of quality. Quality Policy, Quality plans, Quality control Instructions, Quality Audit and Surveillance.Factors Effecting Quality, Tools for quality improvement viz. Pareto Analysis, Cause and Effect Diagram, Failure Mode & Effect Analysis, SQC tools and Six sigma. Report generation and documentation

Descriptive statistics (5 hrs)

Sample, population, parameter, qualitative and quantitative characteristics etc., summarization of data; frequency distributions; histograms; visual methods of representation of data; measures of central tendency and dispersion; Skewness and Kurtosis; regression and correlation.

Probability Theory (2 hrs)

Classical definition of probability, conditional probability, independence, random variables, expectation, Hypergeometric, Binominal, Poisson and Normal distributions.

Inference (6 hrs)

Sampling distributions : Chi-square, t and F. Estimation of parameters; point and interval estimates standard error of estimates. Tests on proportions, means and standard deviations, simple non-parametric tests, introduction to analysis of variance.

SQC Techniques (6 hrs)

Theory Control Charts Concepts of quality and meaning of control, basic philosophy and principle of rational subgrouping. Different types of control charts (Xbar-R, np, p and c-charts). Specification and process capability. Economic centering of the process; Setting approval, statistical concepts of fits and tolerances. Modification of Control Charts - Group control charts, sloping control charts, modified control charts, median and midrange charts, narrow limit gauging, Control Chart to eccentricity, Cumulative sum charts, Master control charts.

Contd...

Acceptance Sampling (5 hrs)

Sampling Vs. 100 percent inspection, basic concepts of sampling inspection, conflicting interests of producer and customer, attributes inspection, producer's and consumer's risk, AQL, LTPD, OC curves, AOQL, ATI, Single, Double, Multiple and Sequential sampling plans. Published sampling plans –, MIL-STD 105D, IS-2500 (PartI), variables inspection plans, MIL-STD 414, IS-2500 (Part-II), Hamilton Lot-Plot Method.

Industrial Experimentation (3 hrs)

Principles of experimentation: randomization, replication, local control. Introduction to factorial experiments and Orthogonal Array Designs.

References :

1. Montgomery, Douglas C (2013). Introduction to Statistical Quality Control, 7th edition. John Wiley & Sons (ISBN: 978-1-118-14681-1).
2. Statistical Quality Control, McGraw-Hill Series, Eugene L.Grant, 1996 Edition
3. Juran's QUality Handbook, J.M.Juran & Joseph Defeo, Indian Edition, VI Edition, 2017
4. Juran's Quality Handbook, Joseph Defeo, VII Edition, 2016

Core Electives Module

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Syllabus

Subject: Systems Management : A B C D and E	Code: C Elect :AC06,AC08, CC10: CEEIM:50
Discipline: Chemical, Electrical, Electronics & Instrumentation and Mechanical Engineering	**No. of Lectures: 45**

A: Project Management: 10 Hrs
B: Operations Management: 10 Hrs
C: Maintenance Management: 10 Hrs
D: Quality, Environment, Health & Safety Management: 5 Hrs
E: Reliability Engg. : 10 Hrs

A) Project Management AC06 (10 Lectures)
Introduction, terminology, definitions: Differences between Project Management and other functions management: special safety aspects for Nuclear Projects., legal requirements.

Project life cycle – important stages, activities in each flow-chart of clearances/ approvals at each stage: Project conceptualization, pre feasibility, Techno economic feasibility report (TEFR): Detailed Project Report (DPR) – major contents.

Time value of money, Investment Criteria, Economic evaluation methods for Project alternatives/ investments –(ROI, IRR, DCF): cost estimation methods – unit rates, factoring, data capture fran close-out reports : Items of cost in procurement of major equipments (imported) (duties, customs' clearance, receipt, octroi, insurance etc): Site selection for project – quantitative and qualitative aspects numerical problems using Brown – Gibson model for choice.

Organisation structure for projects – Matrix type –adv/limitations, responsibility allocation, team building, HR aspects.

Project scheduling: Gantt charts, Network diagrams, PERT – CPM, Numerical problems, Float, Crashing, Work breakdown structure, time monitoring / contour.

Resource planning, optimization, leveling, monitoring, control through budgets, 'S' curves, Bell curves, histograms, use of milestones, reports, meetings, communication

Use of computer software like MS Project, PRIMAVERA, Capabilities, reports, decision support / monitoring & control tools hands on working of simple projects.

Analysis of failures / delays of earlier projects – reasons, case studies, recommendation to avoid repletion for future.

Presentations by small groups of small typical project including PLC stages, CPM, resources, monitoring / control reports.

Contd….

B) Operations Management CC10 (10 Lectures)

Quality Management System (QMS) as per ISO.9001-2008
Environment Management System (EMS) as per ISO.14001

Principles of Auditing of QMS & EMS
Operations (systems) function in the organization, conversion process, operations management-definition, different views- classical, behavioral and modeling views of management. Frame work of managing operations - planning, organizing and controlling, operations objectives.

Planning: Strategic Planning for Production! Operation, Forecasting in operations, forecasting models, forecasting requirements, constraints setting production targets! capacity planning, materials requirement planning, MRP objectives, MRP system components - Master Production schedule, inventory status, Bill of materials manpower, maintenance spares, scheduling of production targets.

Organizing: Implementation of operations plans, startups, shut down of process systems under normal & abnormal conditions. Operations procedures, Technical specifications, safety manuals, emergency preparedness plans. Monitoring of plant parameters, evaluation of plant performance indicators, plant trips/ failures analysis and feed back, energy & utility consumptions, Inter group coordination for plant maintenance, prioritizing the maintenance activities, safe handling of process system for maintenance safety work permit system & ensuring safety during maintenance, handling emergency conditions.

Controlling: Controlling the conversion process inventory control fundamentals, inventory concepts, multistage inventories, multiechelon inventories, inventory systems, inventory costs, inventory models managing for quality, product quality, quality management system, analysis for improvement, quality costs or pay. (2 Hr)

C) Maintenance Management AC08 (10 Lectures)

Meaning of the term 'Maintenance' - nature of failures of components and systems in different contexts like civil, electrical, electronics (both hardware items and software systems), instrumentation, and mechanical engineering. Objectives of the Maintenance function.

Manufacturing process and production equipment - study of relation between failure rate of a component population and the related component life-time - causes of failures, remedial strategies for different periods of the component life (infant mortality / useful life / wear-out periods).

Concept of availability and related definitions, failure statistics, repair statistics - various terms used in maintenance engineering and their definitions / explanation.

Study of various maintenance techniques — Break Down Maintenance (or Reactive / Unplanned / Run-to-failure / Emergency Maintenance), Preventive Maintenance, Planned Maintenance, Routine Maintenance, Predictive Maintenance (or Condition-Based Maintenance - CBM), Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM), Total Quality Maintenance (TQMain).

Contd...

Spare parts management.

Computerized Maintenance Management Systems (CMMS).

Maintenance organization, fundamentals of maintenance planning, work scheduling, safety in maintenance - work permit system, work flow and control, establishing basic values in maintenance, maintenance audit, performance metrics in the maintenance function - the role of management & leadership.

Organization of the Maintenance Function at NFC.

D: Quality & Environment Management: 5 Hrs

ISO Systems

- **Systems Standards vs product standards**
- **ISO 9000 Family of Standards for Quality Management System**
  Genesis, Purpose, Scope, Quality Management Principles, First release, Revisions, Terms and definitions, clauses of ISO 9001:2008, Customer satisfaction, continual improvement, Documentation requirements, Policy Manual, Control of documents, Control of records, Responsibility, authority and Communication, Management review, Human resources, product realization, Design & Development, Purchasing, Control of Production, Validation of processes, Identification & traceability, Monitoring & measurement, Calibration, Analysis of data, Corrective and preventive actions etc.

- **ISO 14000 family of Standards for Environmental Management System**
  Ozone depletion, Global warming due to Green House Gases, Pollution, Social responsibility, Sustainable development, Statutory requirements Public hearing, Environmental policy, conservation of resources; control of discharges to air, land and water bodies; Environmental aspects, evaluation of impact of environmental aspects, Environmental objectives, Management programs for prevention of pollution, Emergency preparedness and response, Environmental monitoring, Management review of environmental performance, Continual improvement of environmental performance etc.

- **OHSAS 18001:2007 Specification for Occupational Health & Safety Management System:**
  Statutory requirements, Hazards, Evaluation of risk associated with hazards, Safety indices, Incidents, Accidents, Near Misses, Loss prevention, designing for safety, PPEs, Management programs for minimizing risk, Safety training, Mock drills and Emergency handling

- 3rd party certification of the Management Systems of an organization as per the international standards (ISO 9001, 14001, 18001 etc...)
  Internal audits, external audits, certification, validity of certificate, need and benefits of certification.

Contd....

E: Reliability Engg: 10 Hrs

Reliability mathematics: Probability, Distribution functions, some discrete and continuous distributions in Reliability, Definitions of Reliability, Availability, Life characteristic curve, Exponential Law of reliability.
System Reliability: Systems with components in series/parallel, Redundancy techniques, failure Mode & Effect Analysis (FMEA),Boolean methods, Cut-Set Tie Set methods, Fault-Trees and Event Trees, Design for Reliability including Fail Safe concepts, single failure criteria etc.

Probabilistic Risk/Safety Assessment: Risk, PSA of Nuclear Power Plants, identification of initiating Events, dominating IEs.
Reliability Testing: Environmental Testing, confidence interval Estimation, Time Terminated, and failure terminated tests.
Human Reliability Analysis: Human errors, Skill, Rule and Knowledge Based Actions, Human Reliability during Emergency conditions, cognitive errors.
Economics of Reliability Engineering: Manufacturer's cost, consumer cost, life cycle cost, Economic Decision Models.

Reference Books:

1. Reliability Engineering for Nuclear and other High Tech Systems by Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg by Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis by Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design by Parag K. Lala, Prentice Hall, (1985)
6. Reliability for the Technologies by Leonard A. Doty, 2nd edition
7.Environmental Engineering :Peavy. Howard.S - MC Graw Hill, New York
8. Introduction to Environmental Engineering & Science 2nd Edition: Masters Gilbert M - Printice Hall of India, New Delhi
9. Industry Environment & Pollution: P K Goel & Arvind Kumar - ABD Publishers, Jaipur
10. ISO-9001 - 2008 standard
11. ISO-14001 - 2004 standard
12. OHSAS-18001-2007 standard
13. Production & Operations Management
14. Essentials of Mgt - An international perspectives 7th edition Harold, Koontz Tata McGraw Hills, New York
15. Practical Project Management: Ghattas. R G and Mckee Sanda L - Pearson Singapore
16. Project Management with CPM & PERT. 2nd Edition: Moder Joseph J & Philips Cecil R - Van Nostrand, Newyork
17. Project Management Vol-1, 2, 3, 4, 5: ICFAI - The Indian Institute of Chartered Financial Analysis of India
18. Project Planning Scheduling and Control: Hands on Projects in on time and Budget: 3rd Edition: James P Lewis - MGH, New York
19. Project Planning Scheduling and Control: Hands on Guide to Bringing Projects in on Time and on Budget - James P Lewis - MGH, New York
20. Rase Howard F & Barroe M H, "Project Engineering of Process plants", John Wiley, 1968
21. S.N. Chary, "Production & Operation Management", Tata McGraw Hill, 2009
22. Richard B Chase et al, "Operations management for Competitive Advantage", 11th Edition, Tata McGraw Hill, 2009
23. Maintenance Engineering Handbook, by Keith Mobley & others, McGraw Hill Education, 8th edition (2014)
24. Handbook of Maintenance Management and Engineering, by Mohamed-Ben-Daya & others, Springer, 2009.

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Syllabus

Subject: Electrical Engineering Practices in Process Industries	Code: CElect:FC09:E -20
Discipline: Chemical Engineering	**No. of Lectures: 20**

Fundamentals of electricity: DC/AC , Concepts of Active, reactive & apparent power Power factor & methods to improve the system power factor, Electricity tariff, Maximum demand, average demand, Load and capacity factor

Power Supplies: Classification of power supplies (Class I,II,III,IV) – batteries and their types, battery chargers, invertors & uninterrupted power supply system, diesel generator, protection to be given to batteries, UPS and DG sets.

Electrical Machines : Transformers, losses in Transformers, efficiency, Induction & Synchronous Motors, Technical Specifications, Characteristics Operations & Maintenance, Motor Starters calculation of percentage loading of motors, Motor efficiency calculations, factors affecting performance of motors,

Variable Speed AC drives: Need & selection, advantages

Industrial Electrical Heating Systems: Types of furnaces, Selection of heating elements, Thermal Insulation & System heat losses.

Classification of electrical equipment in hazardous areas, properties of hazardous gases, selection and installation of electrical equipment in hazardous areas, standards applicable for electrical equipment in hazardous areas.

Circuit Brakers : Types and applications

Safety Aspects: Electrical Shock ---- Various definitions-Let Go Current, Touch Voltage, Time current curves/zones for AC and DC currents, Effect of frequency, Resistance of the human body

Likely effects of current flow through human body, Risk of electric shock from various sources such as batteries, domestic mains, industrial mains, power distribution system and lightning, protection against electric shock, Methods of earthing, Earth grid, Soil resistance, Use of ELCBs on appliances.

Cables & Cables Trays: Types of cables, Power & Control Cables, PVC, HRPVC & XLPE cables, FRLS cables (their properties), Fire survival cables.

Reference Books:

Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes

Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
Contd……
Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey, Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey

Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey

Source book of Electronic circuits by Markus John, Pub: McGraw Hill, New York

Electrical control for machines 3rd edition, by Rexford, Kenneth B, Pub: Delmer

Elec Engg materials by A.J. Dekker, Prentice Hall, New Jersey

Basic Elec. Engg 2nd edition by D.P. Kothari & I.J. Nagrath Pub: Tata McGraw Hill, New York S.Rao, "Testing, Commissioning, Operation & Maintenance of Electrical Equipment", Khanna Publishers, 2008

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Syllabus

Subject: Energy Conservation and Demand Side Management	Code: CElect:AC07-CMI-20
Discipline: Chemical and Electrical Engineering	**No. of Lectures: 20**

Energy Scenario: Primary energy sources, commercial energy production in the world and in India, energy needs of growing economy, long term energy scenario, energy security, energy conservation & its importance, Global environmental concerns, UN Framework convention on climate change (UNFCC), sustainable development, Kyoto Protocol, Clean Development Mechanism (CDM), Energy Conservation Act – 2001 and its features.

Thermodynamic Analysis: Concept of energy, energy analysis, min. energy requirements, energy flow diagram/sankey diagram, Bench marking of energy consumption in the chemical process units…etc. Energy Economics, energy saving and cost involved, evaluation through pay back period, cost-to–benefit ratio.

Energy Conservation Techniques:
Energy efficiency in thermal utilities:- Boilers, steam distribution system, Furnaces, insulation & refractories, cogeneration, waste heat recovery, heat exchanger Networking, Energy saving potential & identification.

Energy Efficiency in Electrical utilities: Electric load management & maximum demand control, power factor improvement, distribution & transformer losses, energy efficient motors. Losses in compressed air system, Refrigeration system, pumping systems, cooling towers, lighting system. Energy efficient technologies – max. demand controllers, automatic Power factor controllers, energy efficient motors, variable speed drives, and energy efficient transformers.
Energy Audit: Purpose of Energy Audit, steps involved in energy audit, measurement of important parameters, collection of data & analysis, preparation of audit reports, energy index calculation, recommendation.

Reference Books:
1)Energy Auditing made simple by P.Balasubramanyam: Aug 2004 : Bala Consultancy Services
2) Electrical Engrs. Ref book 5th edition by G.R.Jones & others, Pub:Newnes
3) Standard Handbook for Elec. Engrs. 14th edition, Donald Fink & HW.Beaty,Pub:McGraw Hill, New York
4) Hand book of Basic Electronic Trouble shooting by Lenk John D, Pub: Prentice Hall, New Jersey, Directory of Electronics Circuits with a glossary of terms by Mandal, Methew, Pub: Prentice Hall, New Jersey
5) Encyclopedic dictionary of Electronic terms by Traister, John & Traister, Robert J Prentice Hall, New Jersey

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Syllabus

Subject: Vacuum Technology	**Code: CElect :M-13 :New-C-20**
Discipline: Chemical and Mechanical Engineering	**No. of Lectures: 20**

1. INTRODUCTION TO VACUUM

Basic terms and concepts in vacuum, Units used Pressure ranges in vacuum and their characterization.

2. VACUUM PHYSICS

Gas laws and models. Continuum theory. Kinetic gas theory. Types of flow and conductance.

3. VACUUM GENERATION & IMPORTANCE OF SEQUENCE OF OPERATION

Classification of pumps based on the operating Principle. Compression pumps. Water ring pumps, steam ejector pump, mechanical rotary pumps (rotary vane and rotary piston), diffusion pumps, mechanical booster pump, oil vapor booster pump, turbo molecular pumps, seals for vacuum pumps. Condensation and getter type pumps. Cryopumps, sputter ion pumps, sorption pumps.

4. VACUUM MEASUREMENT

Fundamentals of low-pressure measurement. Classifications of different gauges. Hydrostatic gauges. McLeod gauge, bourdon tube, capsule gauge and u-tube manometer. Thermal energy gauges. Thermocouple and pirani gauges. Electrical energy gauges
Hot cathode and ionization gauge, cold cathode ionization (penning gauge)

5. CONSIDERATIONS IN SYSTEM DESIGN

Calculations of conductance values. Gas and vapor load. Matching pump combination.

6. LEAK DETECTION OF SYSTEMS & MEASUREMENT

Leak location by rough methods.Penetrant dye, spark tester etc. Leak location by over pressure methods. Bubble methods, halide torch etc.
Leak location by vacuum methods. Discharge tube, mass spectrometer etc.

7. APPLICATIONS

Low-pressure applications (e.g. mechanical handling based on rubber suction pads)
Low molecular density applications (e.g. removal of impurities during chemical processes) Vacuum metallurgy. Decrease in energy transfer applications (e.g. thermal insulation, electrical insulation) Large mean free path applications (e.g. electron tubes, nuclear physics)

8. QUALIFICATION OF VACUUM SYSTEMS

9. INTER LOCKS & SAFETY IN VACUUM SYSTEMS

10. VACUUM CASE STUDIES

Reference Books:

1) Guide to the measurement of Pressure and Vacuum : The Institute of Measurement and Control, London
2) Introduction to Vacuum Technology by Dr. K G Bhushan under the Indian Vacuum Society
3) A.Chambers et al, "Basic Vacuum Technology", 2nd Edition, Oversees Press, 2005

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Syllabus

Subject: Statistics for Engineers	**Code: C.Elect 10:New M C:20**
Discipline: Chemical and Mechanical Engineering	**No. of Lectures: 20**

1. Treatment of data – Graphical methods: Stem – and – Leaf, Box plots, etc. Descriptive methods: Sample mean, median, mode, variance, percentiles
2. Basic probability: Counting, basic laws, and elementary theorems; independent events
3. Discrete random variables and distributions – Binomial , hyper geometric, poisson, mean and variance, poisson process
4. Continuous random variables and distributions – normal , normal approximation to binomial, gamma exponential , probability plots
5. Random sampling and sampling distributions : "t" distribution, chi square and "F" distributions
6. Estimation: Confidence intervals, sample size determination, prediction and tolerance levels
7. Tests of hypothesis for one and two means, sample sizes, paired sample tests
8. Simple linear regression: Curve fitting, Linear correlation, and models
9. Control charts : X- bar , R and "p" charts

Reference books:

1. Probability and statistics for engineers and scientists (7^{th} edition by Walpole , Myers and Ye-2002)
2. Minitab software

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Subject: Industrial Instrumentation Practices and Human Machine Interface	Code: CElect 17:E51 E50:I-30
Discipline: Electrical, Electronics and Instrumentation Engineering	**No. of Lectures: 20**

Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems. Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices. Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design-relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.

PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. OPC Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Contd….

Overview of plant automation. (1 lecture)
Design of HMI, Soft Console versus Conventional control panels (1 lecture)
Guidelines for design of HMI displays (1 lecture)
Case study of a commercially available Professional HMI package. (10 lectures)
Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
Practical (2 lectures)

Reference Books:

1. Biomedical Instrumentation and Measurements : Cronwell Leslic - Prentice Hall, New Jersy
2. Tranducers and Instrumentation: Murthy DVS – Prentice Hall, New Delhi
3. Instruments Engineers Handbook: Process Measurement: Liptak, Belag –Chilton Books
4. Instruments Engineers Handbook: Process Measurement & Analysis: Liptak, Belag Butter Worths
5. Instruments Engineers Handbook Vol - II: Process Control - Liptak, Belag –Chilton Books
6. Process / Industrial Instruments & Control Hand Book : Considne DM – MGH, New York
7. Considine, D A, "Process Instruments and Controls Handbook", McGraw Hill, 1957
8. A.D.Helfric & W.D.Cooper, "Modern Electronic Instrumentation and Measurement Techniques"

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Subject: Mechatronics	Code: CElect. AC14:EEMI :20
Discipline: Electrical, Electronics, Mechanical and Inst Engineering	No. of Lectures: 20

Pneumatic control engineering: - Introduction, compressed air line installation, Pneumatic equipment like cylinders, seals, control valves and accessories. Graphical symbols for energy conversion, control valves, energy transfer and conditioning, actuators, converters, counters and sensors. Classification of cylinders based on operating medium, functions performed, basic construction, mounting style etc., various types of seals, materials, usage. Different type of directional control valves, classifications based on usage, functions and actuation, flow control valves and pressure control valves. Pneumatic circuits, electro-pneumatic circuits, bi-selector systems. Cycle times, Applications of pneumatics and trouble shooting. Standard vendor list.

Hydraulic control engineering: - Introduction, Pump, reservoir, valves and actuators. Selection of pump, tank, Air breather, Baffle plate, pipelines, relief valves, Simple valves, Directional control valves, Flow control valves, special valves, un loading valves, counter balance valves, pressure reducing valves. Filters, selection and location. Hydraulic circuits, basic, regenerative, sequencing and counter balancing circuits. Rotary motion. Hydraulic accessories like accumulator, hydraulic intensifier, pressure switches Pressure gauges and flow meter. Introduction on Hydro pneumatics and electro-hydraulic (servo) systems. Trouble shooting. Standard vendor list

Electrical/electronics control engineering: Introduction and applications of diode, transistor, thyristor, LED's, Opto-isolators, etc. Solenoid valves DC and AC selection of solenoid valves, rating, stepper motors, servo motors, encoders: rotary and linear, transducers, positional sensors.

Cont...

Mechanization: Introduction. Handling: gripping, feeding, Forging, Inserting, positioning, clamping, working, removing, transferring Etc., Orientation: Position control, turning, rotation, division. Feeding, Assembly operations, linear indexing, rotary indexing, Door control. Bulk feed like Conveyors, industrial vehicles, over head equipment's, Containers and supports, Positioning weighing and control equipment.

Introduction to Industrial Robotics: CNC

Reference Books:

1. Mechatronics: Electronics in Products and Processes:Bradeley. DA - Eswar Press, Chennai / Chapman Hall, U K
2. Mechatronics : HMT Ltd – Tata MGH. New Delhi
3. Mechatronics : Electronics Control Systems in Mechanical and Electronical Engg. 3rd Edition : W.Bolton - Pearson

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Subject: Robotics	Code: Celect:M14:New-EC:20
Discipline Electrical, Electronics, Inst Engineering	**No. of Lectures: 20**

Pneumatic control engineering: - Introduction, Pneumatic equipment like cylinders, seals, control valves and accessories. Graphical symbols for energy conversion, control valves, energy transfer and conditioning, actuators, converters, counters and sensors. Classification of cylinders based on operating medium, functions performed, basic construction, mounting style etc.,
Different type of directional control valves, classifications based on usage, functions and actuation, flow control valves and pressure control valves.
Pneumatic circuits, electro-pneumatic circuits, bi-selector systems.
Applications of pneumatics and trouble shooting. Standard vendor list.
(2 Lectures)

Hydraulic control engineering: - Introduction
Simple valves, Directional control valves,
Flow control valves, special valves, un loading valves, counter balance valves, pressure reducing valves.
Hydraulic circuits, basic, regenerative, sequencing and counter balancing circuits.
Pressure gauges and flow meter. Introduction on Hydro pneumatics and electro-hydraulic (servo) systems. Trouble shooting. Standard vendor list
(2 Lectures)

Electrical/electronics control engineering:
Solenoid valves DC and AC selection of solenoid valves.
Stepper motors, Servo motors, encoders: rotary and linear, transducers, positional sensors.
(1 Lecture)

Mechanization: Introduction. Handling: gripping, feeding, Forging, Inserting, positioning, clamping, working, removing, transferring Etc., Orientation: Position control, turning, rotation, division. Feeding, Assembly operations, linear indexing, rotary indexing, Door control. Bulk feed like Conveyors, industrial vehicles, over head equipment's, Containers and supports, Positioning weighing and control equipment.
(3 Lectures)

Industrial Robotics: Fundamentals. Classification of Robots. History of Robotics. Advantages and Disadvantages of Robots. Robot Components. Robot Degrees of Freedom. Robot Joints. Robot Coordinates. Robot Reference Frames. Programming Modes. Robot Characteristics. Robot Workspace. Robot Languages. Robot Applications. Social & Safety Issues
(8 Lectures)

Trajectory planning: Path vs. Trajectory. Joint Space vs. Cartesian-Space. Basics of Trajectory Planning. Joint space trajectory planning, Cartesian space trajectories.
(4 Lectures)

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Subject: Modern Control Systems	Code: CElect:E52A-EC -20
Discipline: Electronics and Instrumentation Engineering	**No. of Lectures: 20**

State Variables Descriptions Introduction, The concept of State, Elementary Definitions, State space Representations of continuous-time and discrete-time systems, State diagrams, Illustrative examples, Solution of state equation, State transition matrix, Properties of state transition matrix, Computation methods of state transition matrix, relationship between state equations and transfer functions, , Characteristic equations

Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability criteria, Principle of Duality, Controllability and Observability of discrete-time systems

Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR Technique

Reference Books:

1. John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design-Conventional and Modern" , 2nd Edition, McGraw Hill Book Co., 1986
2. Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Wintson, 1984
3. M.Gopal, "Modern Control System Theory", 2nd Edition, Wiley Eastern Ltd., 1993
4. Gene F. Franklin et al, " Feedback Control of Dynamic Systems", 3rd Edition, Addison- Wesley Publishing Co., 1994
5. B.Friedland, " Introduction to State space Methods"
6. K.Ogata, " Modern Control Engineering", Prentice-hall

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Subject: Design of High Temperature Components	**Code: CElect 11: New : Mech-20**
Discipline: Mechanical Engineering	**No. of Lectures: 20**

Introduction: Plasticity, Viscoplasticity and mechanism of creep deformation
Deformation & fracture behavior at high temperature (HT), Creep curve, Creep rupture, Life estimation parameters, Low cycle fatigue, creep-fatigue interaction.
Material selection for HT application: Thermal stability, strength, oxidation, carburization etc.
Design codes & standards: ASME codes historical background, loading categories, stress classification,
Sub-section NB & NH: Low & High temperature failure modes and limits, Design and construction rules of RCC-MR, Efficiency diagram and Bree diagram, Life assessment as per CEGB-R5.
NDE & ISI: Surface and volumetric examinations
Models for creep crack initiation and growth
Design by analysis: FEM analysis, stress categorization, time & strain rate dependent stress-strain relations, unified treatment of plastic, creep & thermal strain, theory of viscoplastic flow, elasto-plastic and creep analysis of simple geometries, time stepping algorithm etc.
Life assessment: Remaining life prediction, API 579, inspection & interval determination, integrity of steam pipes, reheat pipes and bends, super heater tubes, gas turbine parts etc.
Reference books :

1) High Temperature Component life assessment. : George A Webster, R A Ainsworth 1994 – Technology & Engg.
2) Creep & Fracture in High Temperature Components. Design & Life assessment issues, : I A Shibli & S R Holdsworth
3) Welding Technology & Design By V M Radhakrishnan

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Welding and Quality Assurance of welds	Code: C-Elect :CC06-M-20
Discipline: Mechanical Engineering	No. of Lectures: 20

Introduction To Soldering, Brazing & Different Types Of Welding Like: Arc Welding, Gas Welding, Resistance Welding, Thermit Welding, Electron Beam Welding, Plasma Welding, Laser Welding, Explosion Bonding, Ultrasonic Welding.

Manual Metal Arc Welding: TIG/MIG & Submerged Arc Welding

Weld Joint & Geometry: (Lap/Butt/Fillet/Corner Joints: Square Butt, Single-V, Double-V, Single-U, Double-U, J-Joint, Special Joints)

M.S. Electrodes & Filler Wires: (Designation, Codes & Classification, Specifications, Fluxes & Electrode Coating – their effect on weld quality)

S.S. Electrodes: (Designation, Codes & Classification, Specifications, Electrode Coating, their effect on weld quality)

S.S. Welding: (Inter-Pass Temperature, Sensitisation & Inter-Granular Corrosion & its control, Delta Ferrite & its effect on hot cracking & Sigma Phase, Delta Ferrite Measurement – Schafflar / Delong Diagram / Magna Guage / Magnetic Saturation Method, Hard facing, Stelliting, Carburizing, Nitriding

Welding Technology:

Polarities (AC, DC(+), DC(-), Pre Heating & Carbon Equivalent , Inter-Pass Temperature, Post Weld Heat Treatment & Hydrogen Embrittlement, Stress Relieving & Solution Annealing, Distortion Monitoring, Weld Sequencing & Balanced Welding Parameters & their effect on weld quality, Weld Defects - their causes & Acceptance Criteria. Role of flux on weld quality improvement. Welding of dissimilar materials.

ASME Code Section IX

Welding Procedure Specification, Welding Procedure Qualification, Procedure Qualification Record, Welders' Qualification, Welding Machine Specification, Essential & Non Essential Variables, Positions of Welding & Their Importance

Non Destructive Testing of welds:

Radiography & Ultrasonic Examination of butt welds

Destructive tests:

All Weld Tensile Test, Transverse Tensile Test, Bend Tests, Ferrite Test, Corrosion Test, Creep Test, Micro & Macro Examination / Etching Test, Metallography Examination.

Maintenance Welding: Limitations, Difficulties, Selection of Welding Consumables. Cold welding, Powder metal spraying, underwater welding.

Reference Books:

1) Welding Metallurgy: Kou, Sindo : John Wil, New York
2) Practical Non-Destructive Testing – 2nd Edition: Baldev Raj : Narosa
3) Principles of Welding Technology-3rd Edition:Gound LM:Viva Books,New Delhi

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Syllabus

Subject: Manufacturing And Industrial Engineering	Code: C-Elect- JNTU, M -20
Discipline: Mechanical Engineering	**No. of Lectures: 20**

Fundamentals of hot and cold working processes: Forging, extrusion, wire drawing, sheet metal working, punching, blanking, rolling, pilgering, bending, deep drawing.

Machining Processes and Machine Tool Operation: Mechanics of metal cutting, single and multipoint cutting tools, geometry and machining aspects, tool life, machinability, and economics of machining.

Inspection: Limits, fits and tolerances, linear and angular measurements, comparators, gauge design, interferometer, form and finish measurement, measurement of screw threads, alignment and testing methods.

Tool Engineering: Principles of work holding, design of jigs and fixtures, design of press working tools.

Machine Design: Machine development concepts

Advanced Manufacturing Processes: E–Manufacturing, Fundamentals of Nanotechnology, Micro-machining and High Speed Machining.

Reference Books:

1) Sensors and Control Systems in Manufacturing : Soloman, Sabrie – Mc Graw Hill, New York
2) Precision Engineering in Manufacturing : R K Murthy – New Delhi

BARC Training School
NFC, Hyderabad
Syllabus

Subject: Corrosion Engineering	**Code: CElect : C**
Discipline: Chemical Engineering	**No. of Lectures: 20**

BASICS OF CORROSION: Electrode processes – free energy, electrode potential, emf series, Pourbaix diagrams and their practical use, Chemical Vs electrochemical mechanisms of corrosion reactions, Introduction to corrosion – Wet and dry corrosion – Theories of corrosion - corrosion rate expressions; Passivity, factors affecting passivity.

(4 h)

CORROSION AND ITS FORMS: General corrosion – atmospheric corrosion, galvanic corrosion, biological corrosion, High temperature corrosion; Localized corrosion– pitting corrosion, crevice corrosion, Intergranular corrosion, de-alloying; Mechanically assisted corrosion – erosion corrosion, cavitation corrosion, fretting corrosion, corrosion fatigue, stress corrosion cracking and hydrogen embitterment.

(5 h)

CORROSION IN REACTOR SYSTEMS: Corrosion in various reactor systems; Effect of high temperature water, cooling water, sea water; nitric acid – effect of flow, environment and metallurgical variables of materials.

(4 h)

PREVENTION AND CONTROL OF CORROSION: Corrosion control by design; Selection of corrosion resistant materials – alloying, coatings and surface treatments; Oxidation resistant materials, control of high temperature corrosion; Cathodic and anodic protection methods; Use of inhibitors-types.

(3 h)

CORROSION MONITORING & INSPECTION: Ccorrosion coupons, Electrical resistance, linear polarization resistance, electrochemical noise analysis; Inspection - liquid penetration inspection, ultrasonic testing, radiography testing, eddy current testing.

(4 h)

BOOKS FOR STUDY AND REFERENCE:

1. Herbert H. Uhlig and R.Winston Revie, "Corrosion and corrosion control", Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, "Corrosion Engineering", Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.
4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

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Syllabus

Subject: Image Processing and Machine Vision	**Code: CElect:EN-710**
Discipline: Quality Assurance	**No. of Lectures: 20**

Image Processing & Machine Vision (20 hrs)

Introduction : Digital image model representation, Image sensor, Digitalizer, Computer, Standard file format;

Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening. Histogram Modification, Colour image processing;

Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;

Boundary extraction and representation;

Morphological operations;

Image Restoration-PSF, Deconvolution, Restoration using inverse filtering. Wiener filtering & maximum entropy-based methods:

Image Compression: Models, Error free compression, Lossy compression, Standards;
Machine Vision:

Imaging model, Scene radiance and image irradiance, Reflectance model of a surface. Lamberitan and specular reflection; Photometrix stereo;

Early Vision : Low level processing for noise suppression, Segmentation by thresholding; Edge detection; representation, Mathematical Morphology;

Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, Generalized Hough Transform;

Contd....

High level vision: Scene interpretation;

Texture - Statistical, Structural and Spectral approaches;

Stereo vision and correspondence problem; Structured light; Optical flow;

Image representation: Invariants;

Unstructured objects: Snakes

Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, classification and recognition; Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
Introduction to image understanding;

Robotic applications of machine vision, Camera calibration.

Reference Books:

1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing. Addison Wesely, 1999.
2. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine, Vision Vikas Publishing House, 2003.
3. William K Pratt, Digital Image Processing, John Wiely & Sons Inc.2004.
4. Davies E.R.Machine Vision Theory Algorithms Practicalities, Academic Press.
5. D.A.Forsyth & J.Ponce, Computer Vision A Modern Approach, Prentice Hall, 2003.
6. Horn B.K.P.,Robot Vision, The MIT Press, 1987;
7. D.Ballard and C.Brown, Computer Vision, Prentice hall, 1982.
8. Wesley E.Snyder & Hairon QI, Machine Vision, Cambridge, 2004.

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Syllabus

Subject: Data Base Management system and Web Technology	Code: CElect:EN-705
Discipline: Quality Assurance	No. of Lectures: 20

Data Base Management System and Web Technology (20 hrs)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to Postgre SQL and MySQL (3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(!)
- Content Management Systems(!)
- Web 2.0 I Semantic Web(2)

Reference Books:

1. Fundamentals of Database Systems Sixth Edition Ramez Elmasri , Shamkant B. Navathe, Addison-Wesley Publication 2010
2. Database Systems: A Practical Approach to Design, Implementation and Management 2014 by Thomas Connolly , Carolyn Begg
3. An Introduction to Database Systems 8th Edition by C.J. Date
4. Web Technologies: A Computer Science Perspective 1st Edition by Jeffrey C. Jackson
5. Web Technologies Paperback 2010 by Uttam K. Roy

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Syllabus

Subject: Advanced Computational Techniques	Code: CElect:EN-701
Discipline: Quality Assurance	No. of Lectures: 20

Advanced Computational Techniques (20)
Programming Language C++

C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.

C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initializers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogonal Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO

Contd….

- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions, parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MP! Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for ID, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

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Syllabus

Practicals on Material Science & Engineering and Corrosion Engg.

Sl. No.	Name of the Experiment
1.	To evaluate the hardness of materials
2.	To evaluate the Tensile properties of materials
3.	Preparation of specimen for Metallography for microstructure evaluation
4.	To detect susceptibility to inter granular attack (associated with the precipitation of chromium carbide)in S.S. samples (Corrosion Test)
5.	Measurement of wall thickness by Ultrasonic test
6.	Familiarisation of Procedure and interpretation of indications in liquid penetrant test principle

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Syllabus

Practicals on Health Physics

Sl.No.	Name of the experiment
1	α – particle counting
2	β- particle counting
3	- particle counting
4	Whole body counting

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Syllabus

List of Experiments to be carried out in Process Control & Instrumentation Lab

Sl.No	Name of the Experiment	Branch
1	**Study of Flow and Level control system** a) Mention different types of instruments/equipments used in the system with their tag nos. specifications and applications b) Write the details of different material used for the system (structure & pipe lines etc).	**All**
2	**Study of control system (PLC & Control Panel)** a) Control system architecture b) PLC Unit (configuration & specifications) c) Control Panel (Instruments used with specifications)	**All**
3	**Calibration of Control Valve**	**All**
4	**Calibration of Level Transmitter**	**All**
5	**Calibration of Flow Transmitter**	**All**
6	**Calibration of Differential Pressure Transmitter**	**All**
7	**Studying the characteristics of Control Valves**	**All**
8	**Single tank liquid level control using PID controller**	**All**
9	**Calibration checking of RTD/Thermocouple**	**All**
10	**Study of Field instruments**	**All**

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Syllabus

List of Experiments on PLC Demo unit

Sl.No	Name of the Experiment
1	Direct On Line (DOL) Starter
2	Star Delta starter
3	Up – Down Counter
4	ON – Delay Timer
5	OFF – Delay Timer
6	Arithmetic Functions
7	Number Comparison Functions
8	Paint Spray process system
9	Speed control of AC Motor through MODBUS Communication
10	Temperature controlling using PID controller of PLC

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Syllabus

List of Experiments to be carried out in Structural Dynamics &Vibration Laboratory

Sl.No	Name of the Experiment
1	Dynamics of a three storied building frame subjected to harmonic base motion
2	Dynamics of a one-storied building frame with planar asymmetry subjected to harmonic base motions.
3	Dynamics of a three storied building frame subjected to periodic (non-harmonic) base motion.
4	Vibration isolation of a secondary system
5	Dynamics of a vibration absorber.
6	Dynamics of a four storied building frame with and without an open ground floor
7	Dynamics of one-span and two-span beams.
8	Earthquake induced waves in rectangular water tanks
9	Dynamics of free-standing rigid bodies under base motions
10	Seismic wave amplification, liquefaction and soil-structure interactions.

BACK TO MAIN

IGCAR

M.Tech.

(PROGRAM CODE: ENGG01)

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
ME1	Code Design for Pressure Vessels and Piping	30	4
ME4	High Temperature Design and Inelastic Analysis	25	2
ME6	Computational Fluid Dynamics	30	4
ME8	Finite Element Method	30	4
ME10	Advanced Heat and Mass Transfer	30	4
ME13	Reliability Engineering	20	2
ME14	Manufacturing Technology	40	4
Total		**205**	**24**

SPECIALISED/ELECTIVE COURSES

(Any three of the seven listed courses)

Course Code	Course Name	Hours	credits
ME3	Machine Design	25	2
	Structural Integrity Assessment Methods and NDE	30	4
	Vibration Engineering and condition Monitoring	20	2
ME5	Seismic Design of Nuclear Reactors and Facilities	20	2
	Plant Dynamics	20	2
	Experimental Mechanics	20	2
ME15	Process Control and Instrumentation	20	2

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-001-P	Project	Duration : 9 Weeks	
2.	02ENGG04-001-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

1. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
2. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
3. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
4. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
5. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
6. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
7. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity

2 **Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor

3 **Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors

4 **Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation

5 **Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions

6 **Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization

B BASIC REACTOR PHYSICS-STATIC

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety
Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down
Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
7. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology (NRST)

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flowmeter: Electromagnetic pumps and flowmeter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6.	Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7.	Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Code Design for Pressure Vessel & Piping (ME1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11.	Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , ‘Pressure vessel design’ CBS publication
2. Brownell. L. E & Young. E. D , ‘Process equipment design’, Wiley Eastern Ltd., India

3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Finite Element Method (ME8) (30 hours)

S.No.	Course content
1.	Introduction to FEM as applied to solid mechanics. Energy principles in structural mechanics and principles of minimum potential energy
2.	Element Shape and Shape Functions: Generalised co-ordinates. General requirements of shape functions; Lagrangian and Hermitian interpolation functions – CO, C1 continuity; Natural coordinate system; Derivation of shape functions for Bar, Beam, Plane, Brick and Plate elements.
3.	Bar Element: Derivation of elemental stiffness matrix and load vector; Transformation from element to global coordinate system; Assembly of Global stiffness matrix and load vector; Solution of typical 2D-plane Truss problems to evaluate Displacements and Member forces/stress; Thermal stress evaluation in Bars/Truss.
4.	Beam Element: Derivation of elemental stiffness matrix and load vector; Solution of simple Beam problems to evaluate Deflections/rotations; BM/SF distribution and determination of stresses, Shear deformation in beams. Curved Beam Element: Derivation of elemental stiffness matrix and load vector; Derivation of stiffness matrix for elbow.
5.	Axisymmetric Thin Shell Element: Strain-displacement and stress-strain relationship; Derivation of stiffness matrix and load vector for 2 noded axisymmetric thin shell element. 2D Plane Elements – 3 Noded Triangular Element: Derivation of elemental stiffness matrix and load vector, Plane Stress/Plane Strain & Axisymmetric elements: Evaluation of Strain/Stress.
6.	2D Isoparametric Element – 4, 8 and 12 noded quadrilateral Element: mapping of parent element to global space; Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of stiffness matrix for plane & axisymmetric elements; Evaluation of strain/stress at Gauss points.
7.	Introduction and Application of 3D Elements: Strain displacement and stress-strain relationship; Tetrahedron, Triangular prism and Hexahedron elements.
8.	Plane Bending Elements: Thin and Thick plate theory; Elements based on Kirchoff's Theory; Elements based on Mindlin Theory; Shear locking and Reduced Integration.
9.	Shell Element: Strain-displacement and stress-strain relationship; Flat plate and curved shell elements; 4 and 8 noded degenerated thick shell Elements, basic assumptions, degree of freedom, shape functions and shear locking.
10.	Incompatible Displacement Model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral element.
11.	Introduction to Nonlinear Problems. Meshing and Errors: Finite Element Modeling and Discritization Criterion, Adaptive meshing, classification of FEM stresses per ASME code, sources of potential error in the finite element solution

Books Suggested:

1.Finite Element Procedures-K.J.Bathe, Prentice Hall, 1996.
2.Concepts and Applications of Finite Element Analysis, R.D.Cook,D.S.Malkus & M.E.Plesha, 4th Ed., Prentice-Hall India, 2003.
3.An introduction to the Finite Element Method-J.N.Reddy, 2nd Ed., McGraw Hill Education (ISE editions)-1993.
4.Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.1, Butterworths-Heinemann,2000.
5. Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.2, Butterworths-Heinemann,2000.

6.The Finite Element Methods: its basics and fundamentals- O.C.Zienkiewicz ,R.L.Taylor &J.Z.Hu, Elsevier,2005.
7.The Finite Element Method: Linear,Static and Dynamic Finite Element analysis-T.J.R.Hughes, Dover Publication,2000.
8.Fundamentals Finite Element Analysis and Applications-M.Ashghar Bhatti, John-Wiley & Sons, NJ,2005.

3. Advanced Heat and Mass Transfer (ME10) (30 hours)

S.No.	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes & Bemoulli equations.
2.	**Laminar Boundary Layer and Forced Convective Heat:** Formulation of differential equation for hydrodynamic and thermal boundary layer. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory. Convective heat transfer for intemal and extemal flows. Low and high Prandtl number limits and different thermal boundary conditions Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method.
3.	**Turbulent Flow and Heat Transfer:** Reynolds decomposition for turbulence**.** Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical. correlations for calculating heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
4.	**Turbulence Modeling:** Eddy diffusivity models: k-£ and k-w) models, RNG based k- £ model. Reynolds stress models: algebraic & differential models. Low Reynolds number models Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
5.	**Natural Convection:** Basic Equations of natural convection. Boussinesq approximation. Derivation of Dimensionless groups from basic equations. Analytical approximations
6.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Moment, porosity, permeability etc.., homogenization method, continuity equation & energy equation, introduction to 2 phase flows & heat transfer in fluid flows.
7.	**Heat Transfer With Phase Change** : Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post dryout heat transfer. Various models available for calculation of heat transfer coefficient.. Critical Flow. Models for single - phase and two-phase critical flow.
8.	**Radiation heat transfer:** Radiation heat transfer. Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Books suggested:

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.

3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

4. Computational Fluid Dynamics (ME6) (30 hours)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme
B.	**Numerical Solution of Complete Fluid Flow and Energy Equation:**
1.	Formulations of governing equations used in numerical simulation:
2.	Stream function-temperature formulation
3.	Stream function-vorticity-temperature formulation
4.	Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5.	Primitive-Variable (P-V-T) formulation
6.	Pressure velocity coupling for incompressible flow.
7.	Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8.	Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9.	Simple grid generation techniques for structured grid:
10.	Elliptic. parabolic and hyperbolic equation method
11.	Grid adaptation
12.	Domain decompositions in CFD and heat transfer
13.	SIP and preconditioned conjugate gradient methods for solution

14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Books suggested:

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

5. Reliability Engineering (ME13) (20 hours)

S.No.	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.\
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY.

6. Manufacturing Technology (ME14) (40 hours)

S.No.	Course content
	Curriculum for Metal Forming
1.	**Uniaxial tensile test**: a. Engineering stress, engineering stain, true stress, true strain; b. Extraction of plastic stress-plastic strain data from load – elongation data of uniaxial tensile tests; Hollomon type and Voce type constitutive relations; c. Tensile instability and significance of strain harkening exponent; d. Determination of strain rate sensitivity index and the significance of strain rate sensitivity;
2.	Stress matrix and the derivation of the Cauchy relation from the law of conservation of linear momentum; concept of principal stress;
3.	Small strain matrix and rotation matrix obtained from the displacement functions;
4.	**Elements of the theory of plasticity**: a. Decomposition of stress matrix to hydrostatic and deviatoric matrices; b. Yield surfaces as a function of the second and third invariants of the deviatoric matrix with von Mises and Tresca criteria being examples; concept of equivalent stess; c. Normality flow rule and convexity of the yield surface; concept of equivalent strain
	Curriculum for Materials Joining
1.	**Welding Processes** a. Fusion Welding Processes: Arc Welding Processes like SMAW, GTAW, GMSE, GVSE etc. and Beam welding process like EB welding and Laser Welding b. Solid state Welding Process like Friction Welding, Friction Stir Welding, Diffusion bonding, Explosive welding c. Resistance Welding Processes
2.	**Thermal Cycle during welding** a. Weld Thermal Cycle, Dependence of bead shape with welding speed, prediction of weld thermal cycle
3.	**Residual Stress and Distortion** a. Generation of residual stress, Effect of residual stress on performance, removal of residual stresses, measurement of residual stresses b. Origin of Distortion, Control of distortion

7. High Temperature Design & Inelastic Analysis ME4: (25 hours)

S.No.	Course content
1.	Introduction: Modes of failure, material selection, criteria to assess creep effect, creep law, creep-fatigue interaction, thermal striping
2.	Design Practice: Loading category, primary, secondary and peak stress intensity, allowable stress intensity (S_m), assessment of basic wall thickness, strain limits

3. Analysis: strain range under multi axial state of stress, Nuber's rule, triaxiality, elastic followup, fatigue damage, allowable numbers of cycle, creep damage, creep life prediction, creep rupture strength, creep fatigue interaction, ratcheting, efficiency diagrams and creep buckling
4. Fracture mechanics, creep crack growth, introduction to RCC-MR A16
5. In elastic Analysis: General principles for constitutive models, non unified model (plastic + creep), flow rule, creep strain hardening, classified models, viscoplastic material model, non-linear kinematic hardening, isotropic hardening, plastic strain memory, finite element Implementation, automatic time integration

Books Suggested:

1.Creep Analysis – H.Krauss
2.Mechanical Metallurgy-G.E. Dieter
3.Creep in Structures-A.R.S.Ponder and Drkhayhurst
4.Advances in Creep Design-Ed.A.I.Smith and A.M.Nickelson
5.ASME Section3 Subsection NH-1
6.French Design Code-RCCMR-Subsection RB

SPECIALISED/ELECTIVE COURSES

1. Machine Design (25 hours)

S.No.	Course content
1.	Principles of Machine Design: Objectives of machine design, general design rules, design methods, variable loads, Lightening of parts and rational design schemes, Rigidity of structures, Cyclical/Contact/Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs. Introduction to inventive problem solving.
2.	Design and Drawing Practices: Drawing standards, selection of tolerances, fits, and positional tolerances. Introduction to Drawing Practices: (matter from various drafting standards), Introduction to CAD (including introduction to various drafting and solid modelling softwares)
3.	Sealing Methods: Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric `O' rings, mechanical seals, labyrinth, valve packings. Methods of sealing for high and ultra high vacuum.
4.	Special Dimensional Inspection Techniques: Description of special dimensional inspection techniques, gauging techniques including composite and paper gauging, advanced inspection tools including co-ordinate measuring machines and form measuring machines.
5.	Advanced Manufacturing Techniques: Precision machining, super finishing, advanced manufacturing, Micro machining.

Books suggested:

1) Mechanical engineering design (In SI Units) - Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2) Design Of Machine Elements Edition 7 - Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3) Machine Elements in Mechanical Design - Mott (R L), Columbus, Charles E Merril, 1985.
4) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.

5) Mechanical Engineering Design (In SI Units) – Joseph E Shigley & Charles R. Mischke, New Delhi, Tata Mcgraw Hill, 2001.
6) Design of Machine Elements - Ed. 7 – Spoots M F, Shoup T E, New Jersey, Prentice Hall 1998
7) Machine Elements in Mechanical Desgin – Moot R L, Columbus, Charles E Merril, 1985.
8) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.
9) Fundamentals of machine design – Oriov, Mir Publishers, Moscow.
10) Fluid power applications – Anthony Esposito, Pearson education
11) Precision engineering manufacturing – Murthy R.L., New Age International
12) MEMS and Microsystems design and manufacture – Tai-Ram Hsu, Tata McGraw Hill.

2. Structural Integrity Assessment Methods and NDE (ME3) (30 hours)

S.No.	Course content
1.	Fracture Mechanism in Metals
2.	Linear Elastic Fracture Mechanics
3.	Elastic Plastic Fracture Mechanics
4.	Low Cycle Fatigue
5.	Assessment of Creep damage and creep-fatigue interaction
6.	Creep crack growth models
7.	Experimental determination of fatigue and creep curve CTOD, KIC, KIa, J-R curve and C*
8.	Basis of ASME Sec. XI Reference Curve and its use in Pressurised Thermal Shock
9.	CTOD design method
10.	J-Estimation Schemes and J-based failure assessment diagram
11.	Net Section Collapse Criteria and Reference Stress approach
12.	R-6 method and its application
13.	Thermal background of international assessment procedure
14.	RCCMR code/A-16 method and its application
15.	CEGB codes
16.	Application of R-5/R-6 for design of high temperature components
17.	Failure Assessment Diagram of PD-6493 and BS-7910
18.	J-Estimation Schemes and J-based failure assessment diagram
19.	Leak-Before-Break design method
20.	Analysis of numerical techniques/Computational fatigue, Fracture and creep
21.	Probabilistic Fatigue, Fracture and creep
22.	Bench Mark solutions
23.	Manufacturing and process-induced defects that influence structural integrity -
24.	Principles, capabilities and applications of surface examination NDE techniques
25.	Principles, capabilities and applications of volumetric examination NDE techniques
26.	Quality assurance of nuclear components with relevant codes and standards and quality concepts
27.	Structural integrity, in-service inspection and life assessment of nuclear components using NDE
28.	NDE Lab visit and Practicals

Books Suggested:

1. Practical Non-destructive testing- Baldev Raj, Jayakumar.T. and Thavasimuthu. M., Narosa publishing house, New Delhi, 1997
2. Advances in NDE for structural integrity, - Nichols. R.W., Applied Science Publishers, London, 1982.
3. Non destructive Evaluation: A tool in Design, Manufacturing and Service and Francis – Don E.Bray and Roderick K. Stanley, Taylor, CRC Press, New york, 1996.
4. Non-destructive testing, R. Halmshaw, Edward Arnold, 1991.
5. Electrical and Magnetic Methods for Non-destructive testing, - J. Bllitz, Adam Hilger, Bristol, 1997.
6. Ultrasonic testing of materials, - Josef Krautkramer, Herbert Krautkramer, Springer-Verlag. January 1983.

3. Vibration Engineering and Condition Monitoring (20 hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems’ Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml’s Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
7.	Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum,

coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

4. Seismic Design of Nuclear Reactors and Facilities (ME5) (20 hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
7.	**Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.

Books Suggested:

1. Chopra, A.K., “Dynamics of Structures, Theory and applications to Earthquake Engineering”, Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures”, New York, McGraw-Hill Book Company.
3. Mariopaz, “Structural Dynamic (Theory and Computation)”, CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., “Numerical Methods in Finite Element Analysis”, Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, “Seismic Analysis of Safety Related Nuclear Structures and Commentary”, ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, “Engineering Seismology”, IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, “Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, “Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites”. AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design”, BIS, New Delhi.

5. Plant Dynamics (20 hours)

S.No.	Course content
1.	**Pressure drop** in fuel Subassembly, friction, local acceleration and elevation pressure drop in wire-wrap. Flow zoning
2.	**Hot spot factors**: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors. Subchannel analysis of fuel subassemblies, mixing parameters, introduction to computer codes.

3. **Event analysis**: General safety features, General Considerations on Design Basis Events, Thermal and Hydraulic Modeling for Analysis, Safety Criteria, Design Criteria for Selection of SCRAM Parameters, Sympathetic Safety Actions, Primary Sodium Flow Halving Time, Maximum Permissible Absorber Rod Speed.
4. **Results of Analysis of Major DBE:** One Primary Sodium Pump Acceleration, Both Primary Sodium Pumps Acceleration, One Secondary Sodium Pump Acceleration, Both Secondary Sodium Pumps Acceleration, Feed water Flow Increase Events, Continuous Withdrawal of One CSR, One Primary Sodium Pump Trip, One Primary Sodium Pump Seizure, Off-Site Power Failure with Emergency Backup for PSP, Primary Pipe Rupture, One Secondary Sodium Pump Trip, One Secondary Sodium Pump Seizure, One Boiler Feed Pump Trip, Loss of Feed Water Flow to Steam Generator, Intermediate Heat Exchanger Sleeve Valve Closure, Loss of Heating in High Pressure Feed water Heaters, Spurious SCRAM. Reactor start-up, BFP Trip and over speeding at full power, Turbine Generator -Trip and subsequent plant operating actions, power setback.
5. **Decay Heat Removal:** Decay Heat Removal through OGDHRS, Decay Heat Removal through SGDHRS, Need for Forced Convection Core Flow, Decay Heat Removal during Station Blackout Situation, Adequacy of SGDHRS Capacity.
6. **Energy Release In Beyond Design Basis Events:** Local Events: Subassembly Accident, Whole Core Events: Pre – disassembly Phase, Disassembly Phase, Mechanical Energy Release / System Response Phase, Analysis of Transient Over Power Accident, Computer Codes, Analysis of Loss of Flow Accident (LOFA), Sodium Void Worth, Consequences of Fuel - Coolant Interaction

Books Suggested:
Material will be provided during the course

6. Experimental Mechanics (20 hours)

S.No.	Course content
1.	Stress & Strain: State of stress, strain, plane stress, plane strain, Thermal stress, Hydrostatic & Deviatoric Component of stress, Elastic stress-strain relationship, Elastic-Plastic strain relations, Von-mises plasticity criteria, plastic flow rule, strain hardening law, perfectly plastic material, Isotropic strain hardening material, kinematic strain hardening, combined strain hardening stress concentration, cyclic stress, Fatigue, Endurance limit, Creep, Larson Miller parameter.
2.	Photo elasticity: Polarisation, polariscope, diffused light and lense polariscope, stress optics law, plane polariscope, circular polariscope, criteria for model material selection, Isochromatic fringe pattern, Iso fringe pattern, scaling model to prototype stress.
3.	3D photo elasticity: locking of model deformations, scaling model and interpretation of the resulting fringe pattern, effective stresses, Birefringent coating, scattered light and its relation to photo elasticity, scattered light polariscope.
4.	Strain measurement methods: strain gage, basic characteristics, types of strain gages, factors in gage selection, electrical resistance strain gage, potentiometer for strain measurement, strain gage circuit, wheat stone bridge

5. Recording Instrument: galvanometer with oscillograph, transient response galvanometer, frequency response of the wheatstone bridge and galvanometer, cathode ray oscilloscope and potentiometer recorder.

Books Suggested:

1.Mechanical engineering design (In SI Units)', Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2.Design Of Machine Elements Edition 7, Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3.Machine Elements In Mechanical Design, Mott (R L), Columbus, Charles E Merril, 1985.
4.Experimental methods for engineers- J.P.Holman, McGraw Hill.
5.Theories of engineering experimentation-Hilbert Schenck, McGraw Hill.

7. Process Control & Instrumentation (Co-ordinator: A. Venkatesan) (20 hours)

S.No.	Course content
1.	Basic Concepts
2.	Units of measurements, Definitions (accuracy, precision, repeatability, span, range, hysterisis, drift, sensitivity, resolution, lag etc.) -- Sensors, transducers, Transmitters, PI diagrams, Symbols., Digital and analog devices.
3.	Sensing, Transmission, Receiving of the following Process Variables
4.	Temperature: classification, thermocouples, RTD, Thermistors, Pyrometers.
5.	Flow: Direct type, inferential type, constant area sensors, differential pressure meters, variable area meters, magnetic, ultrasonic, vortex type flow meters, and mass flow meters.
6.	Level: Direct type (Float, gauge glass, torque tube, piston tube, reflex etc) indirect type (Pressure gauge, purge, d/p with open/closed tanks, Ultrasonic, nucleonic, capacitance & conductivity).
7.	Pressure: Manometers, Bourdon, bellows, diaphragms, D/P Tx, (electronic & pneumatic), strain gauges, load cells.
8.	Analytical: pH, viscosity, conductivity, humidity, isotopic purity, and turbidity.
9.	Control System: Feedback Control theory, Modes of control, generation of control modes, Controllers, feedback & feed forward control, final control elements and valve positioners.
10.	Safety principles: Trip logic, annunciators, simple logic circuits, and smoke/fire detectors.
11.	Current Trends In Instrumentation: Smart transmitters, Instrumentation for a process loop, Paperless recorders, DAS, PLC, DRS, etc.

Books Suggested:

1. Instrument Technology Vol. I to V E.B. Jones.
2. Mechanical & Industrial Measurements, R.K. Jain
3. Automotive Process Control, Donald P. Eckman
4. Measurement Systems Application & Design, Ernest Doebelin.
5. Process Instrument & Control Handbook, Douglas Considine.
6. Instrument Engineers Handbook, Vol. I&II, Dela G. Liptak
7. Instrumentation for Process Measurement & Control, N.A. Anderson

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
ELECTRONICS AND INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
EL2	Reactor Control Engineering	20	2
EL3	Nuclear Instrumentation	20	2
EL4	Reliability Engineering	20	2
EL5	Software Engineering	20	2
EL8	Human Machine Interface for Reactor Control Instrumentation	45	6
EL10	Modern Control of Dynamic Systems	30	4
Total		**155**	**18**

SPECIALISED COURSES

Course Code	Course Name	Hours	Credits
EL6	Artificial Intelligence and Digital Signal Processing	40	4
EL7	Process Instrumentation	35	4
EL9	Embedded and Computer based systems Design	45	6
EL11	Analytical Instrumentation	25	2
Total		**145**	**16**

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-002-P	Project	Duration : 9 Weeks	
2.	02ENGG04-002-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. **Engineering Mathematics (EM) (35 hours)**

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

8. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
9. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
10. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
11. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
12. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).

13. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
14. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

Sl.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

13. Introduction to Materials Science for Engineers - James Shackelford
14. Physical Metallurgy Principles & Practice - V.Raghavan
15. Introduction to Solids - L.V.Azaroff
16. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
17. Materials in Nuclear Application - C.K.Gupta
18. Nuclear Chemical Engineering - Benedict and Pigford
19. Physical Metallurgy, Reed - Hill
20. Heat treatment of steel - Avener
21. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
22. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
23. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
24. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Fast Reactor Physics and Shielding (RP) (35 hours)

S.No.	Course content
A	NUCLEAR THEORY BASICS :
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units
2	**Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

8. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
9. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
10. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
11. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
12. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
13. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
14. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics and Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

13. Introduction to Health Physics – Herman Cember
14. Introduction to Radiation Protection – Alan Martin
15. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
16. Nuclear Radiation Detection - W.J. Price
17. Radiation Detection and Measurement - G.F. Knoll
18. Biological Effects of Radiation – J.E. Coggle
19. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
20. Atoms, Radiation and Radiation Protection by James E. Turner 1986
21. Problems and solutions in Radiation Protection by James E. Turner, 1988
22. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
23. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
24. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) – (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :**
	Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR’s, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology (NRST)

1 **Properties of Sodium:** Physical and chemical properties, (hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

11. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
12. Steam Power Station, G.A. Gassort.
13. Power Plant Engineering & Economics, Strosal & Vapet.
14. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
15. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
16. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
17. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
18. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
19. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
20. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Reactor Control Engineering (EL2) (20 hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (EL3) (20 hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (EL4) (20 hours)

S.No.	Course content
12.	**Introduction: Reliability Engg. Applied to C&I Systems** Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors. Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems. Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
13.	**Reliability Maths/Statistics:** • Mathematical and statistical expressions required for reliability study. • Types of failures in electrical, electronic and computer components • Failure probability concept, statistical distribution models_ • Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions • Chi-square distribution and its use in confidence and risk factors • Baye's theorem • Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software. • Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions. • Derivation of exponential reliability expression_ • R(t)=[exp-(lt)] for electronic components and systems. • Examples to solve

14. **Fault Tolerance and Systems Reliability:**

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model

Example from C&I system in the NPPs

15. **QA/QC Concepts in Brief:**

- QA/QC Concepts in the components, systems procurement, manufacture and
- Site installation for C&I systems in the NPPs.

16. **Environmental Qualification and Reliability Testing:**

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

17. **PSA/PRA Concepts in NPPs:**

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

18. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Software Engineering (EL5) (20 hours)

S.No.	Course content
1.	Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work- products of different phases
2.	Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics, CASE tools.
3.	Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalization, composition, polymorphism. Modeling structure and behavior, Use case diagrams, class diagrams, state diagrams, sequence diagrams, architectural and detailed design., Modeling real-time software. Introduction to Object Oriented Languages. CASE tools.
4.	Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities.
5.	Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods. Testing principles, unit testing, Integration testing, acceptance testing., Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing.
6.	Software Configuration Management: Configuration items (with examples), baselines, libraries, version control
7.	Software Engineering Standards

Books suggested:

1. Software Engineering by Roger S. Pressman, McGraw Hill International Students Edition
2. Software Engineering by Ian Sommerville, 5th Edition, Addison Wesley
3. An Integrated Approach to Software Engg. by P. Jalote, Springer/Narosa Publishers
4. Unified Modeling Language User Guide by G. Booch, J. Rumbaugh, I. Jacobson, Addison Wesley
5. Real-time UML, second edition, Bruce P. Douglass, Addison Wesley

5. Human Machine Interface for Reactor Control Instrumentation (EL8) (45hours)

S.No.	Course content
A .	**Reactor Instrumentation:**
1.	Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification
2.	RPS & RRS for FBRs : Core Temperature Monitoring System, Diversified Safety Logics, Control Logics for CSRDM & DSRDM
3.	Supervision Systems : Startup systems, Discordance supervision systems for SCRAM signals & CSRs, Alarm Generation system, ESR & PDA
4.	Component Handling Systems: I & C for Rotatable plugs, Transfer Arm, IFTM, CTM, Under Water Trolley and Storage Bays, HMI in HCR for Component handling and fuel movement monitoring.
5.	Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, low selector, high selector, median selector, voting logics, Interfaces with electrical Control gear.
6.	C & I Cables : Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
7.	Incident monitoring & mitigation systems : RCB Isolation, I&C for SGDHR, Seismic Instrumentation, Post Accident monitoring system, Video monitoring system
8.	Special systems: Fire Alarm System, Physical protection systems, Biometric Sensors, etc.
9.	Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station, DDCS for PFBR. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards, PLCs for package systems.
10.	PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

11. Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

B. Human Machine Interface (HMI)

1. Overview of plant automation.
2. Design of HMI, Soft Console versus Conventional control panels.
3. Guidelines for design of HMI displays.
4. Case study of a commercially available Professional HMI package.
5. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package
6. Practical.

Books suggested:

1. Intellution Ifix documentation
2. NPC Guidelines for development of soft consoles.

6. Modern Control of Dynamic Systems (EL10) (30 hours)

S.No.	Course content
1.	**1.** State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	**.** Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	**.** Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

SPECIALISED COURSES

1. Artificial Intelligence & DSP (EL6) (40 hours)

S.No.	Course content
	A. Introduction to Artificial Intelligence
1.	Introduction – Nature of AI problems
2.	Search – State space search
3.	Robotics – Kinematics and dynamics
4.	Knowledge Representation – Predicate logic
5.	Neural Networks – Feed forward vs Feedback
6.	Fuzzy Logic – membership functions
7.	Reinforcement Learning – Intelligent agents
8.	Genetic Algorithm – Solution representation
9.	Engineering applications including in Robotics
	B. Digital Signal Processing
1.	Introduction: Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, convolution, correlation, sampling theory, aliasing, anti-aliasing filter, quantization noise, signal reconstruction.
2.	Discrete Fourier Transform: Interpretation of DFT, properties of DFT, DFT of real signals, periodic & linear convolution and correlation using DFT.
3.	Fast Fourier Transform: Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, computation of Inverse DFT using FFT algorithm, efficient computation of the DFT of two real sequences and a 2N-point real sequence,

spectrum analysis using the FFT, windows in spectrum analysis, use of FFT algorithm in linear filtering and correlation.

4. Digital filters: FIR and IIR filters, design techniques for FIR and IIR filters, realization of FIR and IIR systems, overview of DSP processors.
5. DSP Applications: Applications of digital signal processing in nuclear and other fields.

Books suggested:

1.Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
2.John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice- Hall of India,1995.
3.Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.

2. Embedded & Computer based systems Design (EL9) (45 hours)

S.No.	Course content
A.	**Microprocessor Based Hardware Design:**
1.	Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Micro-controllers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
2.	Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3.	Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
4.	Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
5.	IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, testability.
6.	Embedded computer system design example.
B.	**Computer Communication and Networks**
	Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.)

C. **Fault Tolerant and Distributed Architectures**

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. **Real-Time System Design**

1. Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.
2. Overview of LINUX and Embedded NT.

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.

3. Process Instrumentation (EL7) (35 hours)

S.No.	Course content
7.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors,

flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.

8. Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
   Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

9. Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

10. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

11. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

12. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type-Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,
    Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

13. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
    Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
14. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.
    Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
15. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrment Engineer’s Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Fieldbus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

4. Analytical Instrumentation (EL11) (25 hours)

S.No.	Course content
	Measurement related issues
1.	Sensitivity, detection limit, signal-to-noise ratio enhancement
2.	Absorption and Emission Spectroscopy
3.	UV-VIS-IR Spectrophotometry
4.	Atomic Absorption Spectrophotometry
	IR absorption methods for detection of Carbon, Sulphur, Oxygen, Nitrogen
5.	**Fluorescence Spectrometry**
6.	Generation of X-Rays
7.	X-Ray Fluorescence Spectrometry
8.	X-Ray Diffraction Spectrometry
9.	Laser florescence
10.	**Mass Spectrometry**
	Applications and importance of mass spectrometry
	Various types of ion sources
	Various types of mass analysers
	Various methods of detection
	Computer based automation and measurements
11.	**Thermo analytical methods**
	Thermal analysers-DTA and TG
	Differential Scanning Calorimeters
12.	**Electro analytical instruments**
	Voltametry, amperometry and Coulometry
	Conductivity and pH

Books Suggested:

1. Instrumental methods of analysis, - Willard & Others, Pub: CBS, New Delhi, 7th Ed.
2. Principles of instrumental analysis, - Douglas A.Skoog and James J. Leary, Saunders College Publishing, Harcourt Brace College Publishers. (IGCAR Acc. No. 063944)

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
CHEMICAL ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING (CHEMICAL)
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE1	Nuclear Chemical Engineering	35	4
CE2	Chemical Engineering Thermodynamics	40	4
CE3	Transport Phenomena	40	4
CE4	Multi Phase Flow Systems	40	4
CE5	Code Design for Pressure Vessels and Piping	25	2
CE6	Computational Fluid Dynamics and Heat Transfer	40	4
CE7	Advanced Chemical Reaction Engineering	25	2
Total		**245**	**24**

SPECIALISED COURSE
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE8	Process Analysis and Control	25	2
CE9	Advanced Mass Transfer	25	2
Total		**50**	**4**

ELECTIVE COURSES
(One course amongst the three to be chosen)

Course Code	Course Name	Hours	credits
CEEL	Preparedness &Response to Nuclear Emergencies	30	4
	Artificial Intelligence Methods &Applications	30	4
	Membrane/ Separation Process and Technology	30	4

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-003-P	Project	Duration : 9 Weeks	
2.	02ENGG04-003-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers. B-splines,Bezier curves, Response surface method, different levels of factorial design.

Book suggested

15. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
16. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
17. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
18. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
19. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
20. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
21. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
9.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
10.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
11.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
12.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
13.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
14.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
15.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
16.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

25. Introduction to Materials Science for Engineers - James Shackelford
26. Physical Metallurgy Principles & Practice - V.Raghavan
27. Introduction to Solids - L.V.Azaroff
28. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
29. Materials in Nuclear Application - C.K.Gupta
30. Nuclear Chemical Engineering - Benedict and Pigford
31. Physical Metallurgy, Reed - Hill
32. Heat treatment of steel - Avener
33. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
34. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
35. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
36. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

15. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
16. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
17. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
18. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
19. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
20. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
21. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

25. Introduction to Health Physics – Herman Cember
26. Introduction to Radiation Protection – Alan Martin
27. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
28. Nuclear Radiation Detection - W.J. Price
29. Radiation Detection and Measurement - G.F. Knoll
30. Biological Effects of Radiation – J.E. Coggle
31. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
32. Atoms, Radiation and Radiation Protection by James E. Turner 1986
33. Problems and solutions in Radiation Protection by James E. Turner, 1988
34. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
35. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
36. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. **Thermal Power Reactors :**

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. **Fast Power Reactors :**

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology**

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

21. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
22. Steam Power Station, G.A. Gassort.
23. Power Plant Engineering & Economics, Strosal & Vapet.
24. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
25. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
26. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
27. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
28. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
29. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
30. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.

9. Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.

10. Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.

11. Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.

12. Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements

2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.

3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types

4. Design criteria, Loadings to be considered, Analysis method and validation methodology

5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features

7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Nuclear Chemical Engineering (CE1) (30 Hours)

S.No.	Course content
1.	**An Introduction to Nuclear Chemical Engineering** General Introduction and course schematics
2.	**Production of Nuclear Materials** Production of nuclear fuels (i.e.)uranium, thorium and zirconium form ores. Alternate sources for uranium Isotope separation technologies for uranium and water Fuel fabrication technologies for various types of reactors Less common nuclear materials like Zr, Hf, Th, Be,V, Nb and Ta
3.	**Solvent Extraction of Nuclear Materials** Introduction to archival extractants and flowsheets Science and technology of primary extractant (TBP) Alternate extractants for fuel reprocessing applications Extractants for nuclear waste management applications Classical and novel nuclear solvent extraction equipment Criticality and its prevention. Other safety aspects
4.	**Nuclear Fuel Reprocessing** PUREX, Advanced PUREX, SuperPUREX processes Reprocessing of thermal reactor (PHWR and AHWR) Fuels Reprocessing of fast reactor (FBTR & PFBR) Fuels UREX process and its variants Supercritical Fluid Extraction based Superdirex Process Pyrochemical and other non-aqueous processes for reprocessing
5.	**Nuclear Waste Management** Characterization of nuclear wastes Conditioning and remediation. Post-PUREX and Post-UREX processes for isolation of important radionuclides (TRUEX, UNEX, ARTIST, SETFICS, SESAME etc.) Decontamination and decommissioning
6.	**Modeling and Simulation in Nuclear Chemical Engineering** Generation of SX data by conventional & **AKUFVE** techniques Modeling of solvent extraction data Computer codes for simulation of nuclear SX Simulation of solvent extraction process flowsheets Experimental design based variation analysis of flowsheets

Books Suggested:

1. Benedict M., Pigford T.H. and Lewi H. Nuclear Chemical Engineering, McGraw Hill. 2nd ed. (1981)
2. Long, J.T. , Engineering for Nuclear Fuel Reprocessing, American Nuclear Society, IL (1978)

3. Schulz. W.W, Navratil, J.D. and Talbot A.E., Science and Technology of Tributyl Phosphate, Vol.1, CRC Press Inc., Boca Raton, FL (1984)
4. Schulz. W.W, Burger, L.L.,Navratil, J.D. and Bender K.P., Science and Technology of Tributyl Phosphate, Vol.3, CRC Press Inc., Boca Raton, FL (1984)
5. Knief, R.A. Nuclear Energy Technology, Hemisphere Publishing corporation, NY, (1981)
6. Vilani, J., Isotope Separation, (IGCAR library)
7. Selected IGCAR Reports Concurrent literature on AFCI, UREX and allied processes

2. Chemical Engineering Thermodynamics (CE2) (30 Hours)

S.No.	Course content
1.	Classical thermodynamics - the scope of classical thermodynamics, basic concepts and definitions. Laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures.
3.	Multicomponent systems: the chemical potential, fugacity, activities, and activity coefficients.
4.	Solubilities of gases in liquids, solids in gases and in liquids.
5.	Vapour liquid equilibria at low and high pressure. (Van Laar, Peng-Robinson equations). Thermodynamics of super critical fluid
6.	Liquid-Liquid equilibria.
7.	Models for Non ideal, Non-electrolyte solutions and ionic liquids.
8.	Solution thermodynamics
9.	Phase Equilibrium: Phase rule, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations, Equilibrium in systems with supercritical components, phase stability applications.
10.	Chemical Reaction Equilibria: Equilibrium constants for Homogeneous and heterogeneous reactions.
11.	Statistical Thermodynamics

Books Suggested:

1.Denbigh, K. G., The Principles of Chemical Equilibrium, Cambridge, 1971.

2.Tester, J. W. and Modell, M., Thermodynamics and its Applications, 3rd ed., Prentice-Hall, 1997.

3.Bejan, A., Advanced Engineering Thermodynamics, Wiley, 1988.

3. Transport Phenomena (CE3) (40 Hours)

S.No.	Course content
1.	Phenomenological description of continuum approach. Reynolds transport theorem. Basic laws of conservation of mass, momentum and Energy and Multicomponent systems.

2. Transport properties. Modeling of Engg systems and the specification of boundary conditions. Shell balances, Navier-Stokes equations; Momentum, Heat and Mass transfer in steady and unsteady viscous flows; turbulent flows; shell and differential thermal energy balances; steady and unsteady conduction; laminar, forced and natural convection; shell and energy balances of mass of species; diffusion under various driving forces, diffusion with chemical reaction; convective diffusion in dilute solutions; integral balances. Transport coefficient and the macroscopic treatment of momentum, Energy and mass transport in complex system.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Multi-phase flow systems (CE4) (30 Hours)

S.No.	Course content
1.	Multiphase flows and Classification of Multiphase, Flow Patterns (gas-liquid, liquid-liquid and gas-solid and gas-liquid-solid) - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum and energy transfer for different models: Multi-dimensional and flow regime specific models.
2.	Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. (Gas-liquid mixture transport in horizontal and vertical pipe.), vapour-liquid flow, flow boiling, sub-cooled boiling, critical heat flux.
3.	Applications of two-phase flow in the design of steam generators, thermo-syphon evaporators, condensers with non condensibles and air lift pumps. Hydrodynamic of liquid-liquid flow design variables such as holdup, characteristic velocity and pressure drop.
4.	Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. (Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile and pressure drop for turbulent slurry flow.)
5.	The phenomena of fluidization and its industrial application. Characteristics of particles. Principle of fluidization and mapping of various regimes. Two phase theory of fluidization. Bubbles in fluidized bed. Entrainment and Elutriation. Fast fluidized bed. Mixing, segregation and gas dispersion. Heat and mass transfer in fluidized bed. Solid-liquid fluidized bed and three phase fluidized bed. Design of fluidized bed reactors

Books suggested:

1. Wallis, G.B. - " One Dimensional Two phase flow", McGraw Hill Book Co., New York, 1969.
2. Govier, G.W. and K.Aziz., - " The flow of Complex Mixtures in Pipes ", Van Nostrand Reinhold Co., New York, 1972.
3. Brodkey, R.S. - " The Phenomena of Fluid Motions ", Addison - Wesley Publishing Co., New York, 1967.
4. Gad Hestsroni, (Ed.in Chief) - " Handbook of Multi Phase Systems ", Hemisphere Publishing Corporation, Washington and McGraw-Hill Book Company London, 1982.
5. Two-phase flow in pipe lines and heat exchangers – D.Chisholm, Longman Inc, NewYork.
6. Fluidization Engineering- Author: Daizo Kunni and Octave Levenspiel, Butterworth-Heinemann
7. Fluidized bed technology in Materials Processing**, -**Author: C. K. Gupta and D. Sathiyamoorthy, CRC Press.
8. Chemical Reaction Engineering, - Octave Levenspiel,Wiley Eastern Limited.
9. Handbook of separation techniques for Chemical Engineers, - Philip A. Schweitzer,: McGraw- Hill

5. Code Design for Pressure Vessels & Piping (CE5) (25 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.

6. Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7. Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8. Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9. Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10. Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

6. Computational Fluid Dynamics & Heat Transfer (CE6 & CE610) (40 Hours)

<u>Syllabus for CE6 : Computational Fluid Dynamics (30 hrs.)</u>

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme

B. Numerical Solution of Complete Fluid Flow and Energy Equation:

1. Formulations of governing equations used in numerical simulation:
2. Streamfunction-temperature formulation
3. Stream function-vorticity-temperature formulation
4. Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5. Primitive-Variable (P-V-T) formulation
6. Pressure velocity coupling for incompressible flow.
7. Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8. Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9. Simple grid generation techniques for structured grid:
10. Elliptic. parabolic and hyperbolic equation method
11. Grid adaptation
12. Domain decompositions in CFD and heat transfer
13. SIP and preconditioned conjugate gradient methods for solution
14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Syllabus for CE610 : Heat Transfer (10 hrs.)

C. Laminar Boundary Layer and Forced Convective Heat:

1. Formulation of differential equation for hydrodynamic and thermal boundary layer
2. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
3. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
4. Convective heat transfer for internal and external flows
5. Low and high Prandtl number limits and different thermal boundary conditions
   Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

D. Turbulent Flow and Heat Transfer:

Reynolds decomposition for turbulence
Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder
Calculation of friction factor and drag coefficient
Analytical and semi-analytical correlations for calculating heat transfer coefficients
Analogy between heat and momentum transfer
Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models
Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

E. Natural Convection:

Basic Equations of natural convection
Boussinesq approximation
Derivation of Dimensionless groups from basic equations
Analytical approximations
Numerical solution of approximate equations

F. Reactor Heat Transfer:

Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.

Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.

Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.

low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.

Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.

Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies

G. Heat Transfer With Phase Change :

Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.

Basic equations of two phase flow; Homogenous & separated flow models for two hase flow; void fraction & phase velocity ratio (Zivi's model)

Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)

Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.

Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept.
Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
Critical Flow: Models for single – phase and two-phase critical flow.

Books suggested:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.

4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

7. Advanced Chemical Reaction Engineering (CE7) (30 Hours)

S.No.	Course content
1.	Stoichiometry rates and thermodynamics of chemical reactions. Influence of concentration and temperature. Reaction mechanism. Generalized balance equation for reactive systems.

2. Collection and analysis of rate data: differential method, Integral method, Graphical method, polynomial fit method, Methods of initial rates, Methods of excess, Methods of half life. Kinetics of homogeneous and heterogeneous reactions.

3. Conservation equations for chemically reacting mixtures; heterogeneous catalytic reactions.

4. Chemical reactions and processes of transport: external diffusion effects on heterogeneous reactions, diffusion and reaction in porous catalysts.

5. Design and analysis of chemical reactors: Isothermal and non-isothermal reacting systems, catalytic and non-catalytic reactions systems.

6. Uniqueness and multiplicity of steady states, stability analysis.
Non-ideal reactors: distributions of residence time for chemical reactors, models for non-ideal reactors.

7. Modeling of multiphase reactors: fixed, fluidized, trickle bed, slurry etc.

Books Suggested:

1. Aris R., Elementary Chemical Reactor Analysis, Prentice-Hall 1969.
2. Foggler, H. S., Elements of Chemical Reaction Engineering, Prentice Hall of India, 1994.
3. Froment G.F. and Bischoff K.B., Chemical Reactor Analysis and Design, John Wiley, 1994.
4. Smith J.M. - " Chemical Engineering Kinetics ", McGraw-Hill, 1981.

SPECIALISED COURSES

1. Process Analysis and Control (CE8) (25 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.
2.	Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3.	Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.

4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

2. Advanced Mass Transfer (CE9) (25 Hours)

S.No.	Course content
1.	Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Film, Penetration & Surface Renewal models, Solvent extraction theory
2.	Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors. Adsorption and ion exchange equipment.
3.	Membrane separation and other advanced mass transfer processes. Process intensification approaches. (few hours for seminar by TSO's).

Books suggested:

1. Transport phenomena in liquid extraction – G.S. Laddha and T.E. Degaleesan. McGraw Hill, 1978.
2. Separation process principles – J.d. Seader, Ernest J.Henley. John Wiley & Sons. 2nd Ed. 2005.
3. Mass transfer – Thomas K.Sher wood, Robert L.Pigford, Charles R. Wilkey. McGraw hill.
4. Mass transfer operations - Robert E. Treybal. Mcgraw-hill (1980)
5. Handbook of solvent extraction – The. C. Lo. Malcolm, H.I. Baird, Carl Hanson (editor), Krieger Pub. Co. Reprint edition (Feb 1991).

ELECTIVE COURSES

1. Preparedness & Response to Nuclear Emergencies (CE-EL) (30 Hours)

S.No.	Course content
1.	Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
2.	Radiation Shielding & Study of Criticality parameters and control
3.	Nuclear Waste Management
4.	Nuclear Accidents/emergencies
5.	Transport of Radioactive material
6.	Radiological accidents/emergencies
7.	Effects of Hiroshima & Nagasaki bombing
8.	Detection of Nuclear detonation

9. Nuclear weapons: effect (Blast, heat, Radiation and EMP)

10. Medical decontamination with demonstration

11. Nuclear weapon tests (atmospheric)

12. Nuclear & Radiological terrorism (Method to contain and control)

13. Chemical warfare & Biological warfare (Method to contain and control it)

14. Emergency Response methodology/ Philosophy

15. Systems and methodology for Radiological impact assessment

16. Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities

17. Emergency Monitoring & Shelters

18. Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment

19. Civil defence WEB plan for Nuclear attack on major cities

20. Monitoring of High radiation field area

21. Lab Visits

Books suggested:

Material will be provided during the course.

2. Artificial Intelligence Methods & Applications (30 hours)

S.No.	Course content
1.	**Robotics** Forward and Inverse kinematics, Jacobians, Manipulator Dynamics, Trajectory generation, Sensors, Manipulator Control, Force control, Path planning, Mapping & Localisation of Mobile robots, Behavior based control, Robot learning.
2.	**Genetic Algorithm** Introduction to GA and its terminology, GA operators and working principle of GAs. Different selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling and elitism. Constraint handling. Multimodal function optimization. Application of GAs, real-coded GAs. Multiobjective optimization, difference with single objective optimization, concept of Dominance and Pareto-optimality. Multiobjective GAs.
3.	**Fuzzy Logic** Introduction;Need, Historical Development and Perspective of applications. Crisp and Fuzzy Sets, Operations on fuzzy Sets. Fuzzy Arithmetic, Fuzzy relations, Fuzzy logic. Possibility Theory and Uncertainty Based information. Construction of Fuzzy Sets (with examples), Approximate Reasoning.

Applications; Pattern Recognition and Process Control (with examples).

Books Suggested:
Material will be provided during the course.

3. Membrane/Separation Processes and Technology (30 hours)

S.No.	Course content
1.	Type of membranes and membrane processes
2.	Membrane transport theory – solution, diffusion model
3.	Membrane and modules
4.	Concentration polarization – boundary layer film model – concentration polarization in liquid separation processes
5.	Reverse osmosis – membranes and materials, RO membrane categories, membrane modules, fouling control and cleaning
6.	Ultra-filtration – characterization of UF, membrane fouling and cleaning – modules and system design
7.	Other membrane processes – microfiltration, nanofiltration, pervaporation and electrodialysis
8.	Application of membranes in water and wastewater treatment
9.	Application of membranes in radioactive waste management

Book suggested:

1. Membrane Technology and Applications (2^{nd} edition) by Richards W. Baker
2. Membrane Filtration Handbook – Practical Tips and Hints (2^{nd} edition) by Jorgen Wagner
3. Application of Membrane Technologies for Liquid Radioactive Waste Processing – IAEA Technical Report Series No. 431.

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
Materials Science

Course Code	Course Name	Hours	Credits
MS1	Engineering Mathematics	35	4
MS2	Computational Methods	30	4
MS3	Materials and Metallurgy	25	3
MS4	Reactor Physics and Fuel Design	30	4
MS5	Health Physics	25	2
MS6	Metallurgical Thermodynamics	30	4
MS7	Experimental Methods for Materials Research	45	6
MS8	Structural Materials for Nuclear Reactors	45	6
MS9	NDE Science and Technology	30	4
MS10	Physical Metallurgy	45	6
MS11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
MS12	Introduction to Materials Science and Engineering	45	6
MS13	Corrosion Science and Engineering	30	4
MS14	Mechanical Behavior of Engineering Materials	30	4
MS15	Manufacturing Technology	30	4
Total		**505**	**65**

1. Computational Methods (MS2 -45 hours)

S.No	Course content
1.	**Programming:** Introduction to programming with C# as the reference language (C# software will be provided for practice), Getting familiarized with Matlab
2.	**Numerical Techniques:** Overview of standard numerical techniques with wpecial emphasis on statistics and solving ordinary and partial differential equations
3.	**Optimization:** Overview of techniques with special emphasis on non-linear optimi9zation using gradient descent, conjugate gradient and genetic algorithm
4.	**Neural network for predictive applications:** Overview of various neural network architectures, Multilayer perceptron model for prediction, need for neuro-fuzzy models
5.	**Atomistic modeling:** Introduction to Monte-Carlo Simulation, Basics of molecular dynamics, prediction of thermo-physical properties by molecular dynamics, computational challenges
6.	**Introduction to application of FEM:** Introduction to FEM and its application, demonstration of few simple application using Abaqus (FEM software)
7.	**Current status in modeling and simulation:** With respect to mechanical metallurgy

Books Suggested:

1. Sams Teach Yourself C# in 21 Days, B.L. Jones, SAMS publications
2. Numarical Recipes in C++: The art of scientific computing, *W.H. Press et al*, Cambridge University Press
3. Numerical Mathematical Analysis *J.B. Scarborough, MacMillan Publishers*
4. Genetic algorithms in search, optimization and machine learning, *D.E. Goldberg, Addison Wesley*
5. Guide to neural computing applications, *L. Tarassenko, Arnold publishers*
6. Monte Carlo Basics, *K.P.N. Murthy, ISRP publishers*
7. Molecular Dynamics Simulation by *J.M. Haile, John Wiley and sons*

2. Fast Reactor Physics and Fuel Design (MS4/CH8- 30 hours)

S.No.	Course content
1.	**Basic Nuclear Physics Concepts:** Properties of nuclei. Nuclear forces, Nuclear models. Nuclear decay, Liquid drop model and nuclear stability, Nuclear reactions including fission, Compound nucleus formation, Microscopic cross-section, Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	**Chain Reaction:** four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.

5. **Reactor Kinetics:**Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.

Books Suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C. Edlund. Van Nostrand, 1952.
2. Introducation to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Physics of Nuclear Reactors, Jakeman D., English Universities Press, 1966.
4. A.E. Walter and A.B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981.

3. Metallurgical Thermodynamics(MS6- 30 hours)

S.No.	Course Content
1.	**Classical thermodynamics -** the scope of classical thermodynamics, basic concepts and definitions. First and second laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures. The chemical potential, fugacity, activities, and activity coefficients, Phase rule
3.	Solubilities of gases in liquids, and solids
4.	**Solution thermodynamics**: Integral and Partial Molar Thermodynamic Properties, Solution Models, Ideal Solution, Regular Solution, Real Solutions
5.	**Phase Equilibrium and Stability**: Phase equilibria in multicomponent systems, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations,
6.	**Chemical Reaction Equilibria**: Equilibrium constants for Homogeneous and heterogeneous reactions.
7.	Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Pourbaix Ellingham Diagrams, Phase Diagrams,
8.	**Experimental Methods**: Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.

Books Suggested:

1.D. Gaskell, Materials Thermodynamics, Talyor and Reid, 1981.
2. O. Kubaschewski, C.B. Alcock and P.J. Spencer, Materials Thermochemistry, Pergamon, 1985

4. Experimental Methods for Materials Research (MS7-45 hours)

S.No	Course Content
1	Vacuum Techniques (3): Fundamentals, Creation & Pressure Measurements, units, Pumps – fore Vacuum, high Vacuum and UHV
2	Thin Film synthesis methods- Physical, Chemical and MBE

3. X-RAY TECHNIQUES - techniques based on measuring the energy or angular distribution of scattered x-rays,

1.1 Wide angle elastic scattering (XRD): Atomistic – form factors; unit cell structure factors, Bragg equation, reciprocal lattice, Laue equations; Expwrimental methods- transmission, reflection, thin film, in-situ; Otjer information-particle size distributions.

1.2 Inelastic scattering- x-ray absorption spectroscopy: Basics- edges and extended fine structure; XANES and EXAFS quantitation; Surface sensitivity; Experimental methods

1.3 Small angle scattering-SAXS: Basics- what SAXS sees; Mathematical modeling;

1.4 X-ray fluorescence spectroscopy: Basics- core hole formation, fluorescence yield, transport ("ZAF"); Experimental realization – Bulk analysis; lab and synchrotron x-ray sources; Surface analysis – TXRF; Microscopy – x-ray beam manipulation.

4. **ELECTRON MICROSCOPIES:**

2.1 Transmission electron microscopy (TEM/STEM):

Electron interactions in solids-elastic and inelastic scatterin, phase change; Contrast generation-bright field, dark field, "high-resolution"; Images-information and resolution; Diffraction; Beam damage; Experimental methods hardware, specimen preparation; Inelastic scattering- electron energy loss; Emitted x-rays – elemental analysis, sensitivity, spatial resolution; STEM

2.2. Scanning electron microscopy:

Beam transport in bulk solids; Signals and images- backscattered and secondary electrons; Diffraction- channeling patterns – EBSD; X-ray generation and transport, detection and analysis; Other useful signals; Experimental methods;

EPMA Electron probe micro-analyzer

2.3. LEELS

5. ION BEAM TECHNIQUES

techniques using ions or neutrals made from them as the bombarding species

3.1. Ion beams – production-ion guns; manipulation- ion, filters

3.2. Rutherford (Nuclear) Backscattering Spectroscopy- (RBS):

High energy ions in solids- electronic and nuclear (Rutherford) stopping; Quantitative description; Experimental methods – energy spectroscopy

3.3. Nuclear reaction analysis – elemental specificity – depth profiling

3.4. PIXE (Proton Induced X-ray Emission) Signal to noise ratio – trace element analysis

3.5. Surface Mass Spectriscopy-SIMS:

Ejection of matter by bombardment: sputterin; Fate of ejected materials subsequent reaction, charge state; Mass dedtection – quad, magnetic sector, ToF; experimental issues

6. ELECTRON SPECTROSCOPIES -

techniques based on measuring the energy distribution of emitted electrons

4.1 Photoelectron spectroscopy:

Basics- energy balance, element identification; Not-so Basics- relaxation, chemical states, satellites; Surface sensitivity; Quantitation; UPS- the unfamiliar cousin

4.2 Auger Electron Sepctroscopy:

Electron excitation- why bother ? The Auger spectrum- energy balance; Chemical effects; Quantitation; Imaging- meaning of maps.

4.3 Experimental methods;

Surface of real-world things; Below the surface- profiling, variable energy; Hardware and software; samples and handling.

7. PROXIMAL PROBE MICROSCOPIES

Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM): Basics; Experimental methods; Spectroscopy in Scanning Probe Microscopy

8. NUCLEAR SPECTROSCOPY

Positron annihilation, Mossbauer – Application to defects, radiation damage defects in metals and alloys

9. **VIBRATIONAL SPECTROSCOPIES**

7.1 Vibrations in molecules and solids – normal coordinates, group frequencies

7.2 Infrared spectroscopy;

IR absorption – dipole scattering, selection rules; Optical arrangements-transmission, specular reflectance, diffuse reflectance, attenuated total reflectance, microscopy, in-situ; Signal collection and Fourier transform processing, data analysis

7.3 Raman: Energy transfer, selection rules; Normal, resonance, surface-enhances, Fourier transform, UV

10. **8.RESONANCE ABSORPTION SPECTROSCOPIES**

8.1 Nuclear Magnetic Resonance (NMR):

Fundamentals; Experimental Techniques; Magnetic Resonance Imaging

8.2 Electron Paramagnetic Resonance (EPR): Fundamentals; Experimental Techniques

BOOKS FOR STUDY AND REFERENCE:

1. Cullity Addision, B.D., "Elements of X-ray Diffraction", Wesley Publishing Co., 1967.
2. Williams (D B), Carter (C B), Transmission Electron Microscopy: A Textbook For Materials Science, New York, Plenum, 1996
3. J.R. Tesmer et al 'Handbook of modern ion beam materials analysis' (MRS, Pittsburgh,1995)
4. L.C. Feldman, J.W. Mayer 'Fundamentals of surface and thin film analysis' (North-Holland, N.Y, 1986)
5. Prutton, M., "Surface Science and Technology, Volume27, "Analytical techniques for thin films", Academic Press, Inc.Newyork, 1991.
6. Bacon, G.E., "X-ray and Neutron Diffraction", Pergamon Press, 1966.
7. Concise Encyclopedia Of Materials Characterization Ed. Cahn (R W) and lifshin (E) Ed Oxfod, Pergamon, 1993
8. Advances in Materials Characterization Ed. G. Amarendra, Baldev Raj, M.H. Manghnani, University Press (India), 2007

8. Structural Materials for Nuclear Reactors (MS8)(Coordinator: –45hrs)

S.No.	Course Content
1.	Three stage Nuclear Power Program (Importance of Material Selection)
2.	**Thermal Reactors:** Concept, Selection of Materials – Core and out of core, Processing of Materials, Properties/Performance of Materials
3.	**Fast Breeder Reactors:** Concept, Selection of Materials for different systems, Brief description of different systems, Core materials, Design criteria for clad and wrapper, Radiation damage, Evolution of materials for clad and wrapper, Material performance, Material processing and fabrication, Structural materials, Design criteria, Materials processing and fabrication, Steam generator materials, Design criteria, Selection of materials, Materials processing and fabrication, Properties of materials and performance
4.	**Materials in Reprocessing Applications,** Closing of nuclear fuel cycle, Design concept of reprocessing plant component, Selection of materials, Processing and fabrication, Evaluation of properties and performance
5.	**Materials in Waste Storage Applications**

Books Suggested:

1. Materials research: Current scenario and future projections, Chidambaram R, Banerjee S Ed, Allied Publishers, New Delhi, 2003
2. High temperature reactor materials (workshop La Jolla,CA March18-21,2002), Allen T, Oak Ridge, U.S.Department of Energy, 2002.
3. Nuclear materials: Issues and concerns Vol 2., Bhaskara Rao D Discovery Publishing House, New Delhi, 2001.
4. Materials R & D for PFBR: Compilation of articles: (Eds) S.L. Mannan and M.D. Mathew, IGCAR, Kalpakkam, 2003.
5. An overview of R&D on fast reactor fuel cycle, Baldev Raj, Int. J. Nuclear Energy Science and Technology, Col.1, Nos.2/3, 2005, pp.164-177.
6. Selection of materials for PFBR, S.L. Mannan, S.C. Chetal, Baldev Raj, S.B. Bhoje, Trans IIM, Vol..56, No.2, April 2003, pp.155-178.
7. Development of fuels and structural materials for fast breeder reactors, Baldev Raj, S.L. Mannan, P.R. Vasudeva Rao and M.D. Mathew, Sadhana, Vol.27, Part 5, October 2002, pp. 527-558
8. Input of the atomic energy programme on special materials development in India, C. V. Sundaram, Trans IIM, vol. 41, No.5, Oct 1988, p.407.
9. Recent trends in fast breeder reactor materials, C.V. Sundaram, P. Rodriguez and S. L. Mannan, IE (I) Journal –MM, Vol.67, Sept. 1986, pp.1-11.
10. Radiation effects in nuclear reactor materials – correlation with structure, P. Rodriguez, R. Krishnan and C.V. Sundaram Bull. Mater. Sci. Vol. 6, No.5, May 1984, PP.339-367.

Nuclear Reactor Materials, C.O.Smith, Addison Wesley, 1967

9. NDE Science and Technology (MS9 - 30 hours)

S.No.	Course Content
1.	**Introduction to NDE:**Importance and need for NDE, classification of techniques, origin of defects; material processing related-casting, forging, rolling, welding etc., and service related-fatigue, creep, corrosion, irradiation etc. Detection, characterisation, sensitivity, reliability, accuracy,
2.	**Surface NDE:**Principle, instruments & sensors, capabilities, applications and limitations of visual, liquid penetrant, magnetic particle, eddy current and flux leakage techniques
3.	**Volumetric NDE:**Principle, instruments & sensors, capabilities, applications and limitations of radiography and ultrasonic techniques. Gamma, Micro-focal, LINAC and real-time radiography and tomography. IRIS, TOFD, SAFT, MEMS, Non-linear ultrasonics related to ultrasonics.
4.	**Dynamic NDE:**Acoustic emission, infrared radiography, intelligent processing of materials and continuous monitoring.
5.	**Digital NDE:**Forward and inverse problems, signal processing, numerical modeling, imaging, automation, probability of detection (POD), multiple NDE, data fusion and robotics.
6.	**Industrial NDE:**NDE for quality assurance, structural integrity, material characterization, condition monitoring and in-service inspection, reference standards for calibration, codes & standards, selection of NDE techniques
7.	**Practicals:** 1. Ultrasonic testing – detection of defects in weld/HAZ and measurement of thickness

2. X-radiography of welds and interpretation of radiographs
3. Eddy current testing of plates and heat exchanger tubes for defects
4. ***Seminar***: Preparation and submission of report on a topic in advanced NDE. Presentation and viva-voce

Books Suggested:

1. A practical NDT – Baldev Raj, T. Jayakumar and M. Thavasimuthu, Narosa, New Delhi, 1996.

2. ASNT Volumes on Visual, penetrant, magnetic particle, eddy current, ultrasonic, radiography, acoustic emission, thermography and other techniques, ANST, Ohio, Coloumbus.

3. Grandt, A. F. Jr., Fundamentals of Structural Integrity: Damage Tolerant Design and Non-destructive Evaluation, John Wiley & Sons, Inc. Hoboken, NJ, 2004.

4. Bray, D.E. and R.K. Stanley, 1997, Nondestructive Evaluation: A Tool for Design, Manufacturing and Service; CRC Press, 1996.

5. Peter J. Shull, Nondestructive Evaluation: Theory, Techniques, and Applications, Marcel Dekker Inc., 2002.

10. Physical Metallurgy (MS10- 45 Hrs)

S.No.	Course Content
1.	Structure and Properties of Materials
2.	**Crystalline solids:** Introduction: Engineering materials, materials cycle, application and selection criteria of materials. Significance of microstructure; crystalline defects:- dimensions, origin and their effect on properties; amorphous structure.
3.	**Phase diagrams**: Origin, construction, interpretation and application of binary phase diagrams with reference to a few important metallic and ceramic systems. introduction and classification of phase transformations, calculation of phase equilibria based on thermodynamic principles
4.	Correlation between Free energy, selection of a Phase and order parameter, different thermodynamic classification of phase transformations, order of a transformation
5.	**Diffusional transformations:** Diffusion in solids: phenomenological approach and atomistic approach. Nucleation and growth theories of vapour to liquid, liquid to solid, and solid to solid transformations; homogeneous and heterogeneous strain energy effect during nucleation; interface-controlled growth and diffusion controlled growth; overall transformation kinetics. Principles of solidification, evolution of microstructures in pure metals and alloys. Precipitation from solid solution: types of precipitation reactions, crystallographic description of precipitates, precipitation sequence and age hardening, spinoidal decomposition.
6.	**Iron-carbon alloy system:** iron-carbon diagram, nucleation and growth of pearlite, cooling of hypo-eutectoid, eutectoid, and hyper-eutectoid steels, development of microstructures in cast irons. Heat treatment of steels: TTT and CCT diagrams
7.	**Diffusionless transformations:** martensitic transformation, hardenability, role of alloying elements in steels. Bainitic transformation, Widmanstatten transformation, Massive transformation. Order-disorder transformation.

8. Diffusion, rate theory, mechanisms of, measurement techniques
9. Phase transformations in some nuclear non-ferrous metals and alloys
10. Characterization of microstructure – microscopy techniques, X-ray spectroscopy and diffraction.
11. **Metallographic techniques**: Optical metallography, image analysis, quantitative phase estimation.
12. Properties of X-rays: continuous and characteristics x-rays, absorption, filter, production and detection of X-ray Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.
13. **Electron optical methods**: (a) Scanning electron microscopy and X-ray microanalysis including electron probe microanalysis, electron optics, electron beam specimen interaction, image formation in the SEM; (b) Transmission electron microscopy and analytical transmission electron microscopy: Electron diffraction, reciprocal lattice, analysis of SAD patterns; different electron diffraction techniques, atomic resolution microscopy, analytical devices with TEM, field ion microscopy, scanning tunneling microscopy, advanced techniques.
14. **Introduction to novel materials and processes**: composites, intermetallics, cermets, metallic foams, intelligent materials, Dependence of their properties on structure, Nanocrystalline Materials: Synthesis, Structure and Properties.: Amorphous Materials; Metallic glasses, Glass forming ability, Bulk Metallic Glasses, Properties; Quasi crystalline Materials; Structure, Synthesis, Properties;
15. **Advanced Processes**: Rapid solidification processing, Laser surface Modification, Mechanical Alloying, Rapid prototyping, Self propagating High temperature synthesis, inert gas condensation etc.
16. **LABORATORY** Microstructures of alloys of Fe, Al, Cu and Ti for each type of transformation at different levels of resolution; Crystal structure by diffraction techniques; Defects of different dimensions; Advanced processes – Laser Ablation, Magnetron Sputtering and Plasma and Chemical deposition methods.

11. Fuel Cycle Physics& Introduction to Fuel Cycle (MS11/PY11 - 30 Hrs)

S.No Course content

1. Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2. Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3. Methods of U enrichment:
4. Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5. Advanced ceramic fuels : carbides and nitrides
6. Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7. Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.

8. Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9. U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10. Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11. Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12. Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13. Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14. Isotopic separation operation of bred uranium in thorium cycles to remove U-232. MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Introduction to Materials Science & Engineering (MS12/CH4-40 hours)

S.No.	Course content
1.	**Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.
2.	**Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.
3.	**Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.

5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.

6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.

7. **Phase Diagrams &Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley &Sons, N.Y., 2003.
7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

13. Corrosion Science and Engineering (MS13/CH13 - 30 hours)

S.No.	Course content
1.	Thermodynamics of Aqueous Corrosion: Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.
2.	Kinetics of Aqueous Corrosion: Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.
3.	Forms of Corrosion: General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion. Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.
4.	Corrosion in Reactor and Reprocessing Plants: Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.
5.	Prevention and Control of Corrosion: Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.
6.	**Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.
7.	**Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, "Corrosion and corrosion control – An introduction to corrosion science and engineering", Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, "Corrosion Engineering", Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.

4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, “Corrosion and corrosion protection handbook”, USA, 1983.

14. Mechanical Behaviour of Engineering Materials (MS14- 30 hours)

S.No.	Course Content
1.	**Engineering Materials:** Alloys, intermetallics, ceramics, composites, polymers.
2.	**Basic Crystal Structure of Materials**: Unit cell, packing fractions, planes and directions, slip systems
3.	**Defects in Materials:** Point defect, line defect (dislocation), surface defects (grain boundary, twins, stacking faults), volume defects
4.	**Dislocation:** Types, Burger’s vector, stress field and energy, stacking faults, dislocation glide and slip systems in crystal, interaction between dislocations, interaction between dislocations and point defects, dislocation pile up, dislocation climb, dislocation sources, multiplication of dislocations.
5.	**Elastic Behaviour of Materials:** Stress and strain at a point and their relationship
6.	**Plastic Behaviour of Materials:**
7.	**Tensile Deformation:** single crystal, yield point, CRSS, polycrystalline materials (Schmidt’s factor), grain size effect-Hall-Petch relation, thermally activated deformation, constitutive equation for plastic deformation, strain hardening and dynamic strain ageing (DSA).
8.	**Strengthening Mechanism:**Strain hardening, strengthening from grain boundary, solid-solution strengthening, order-disorder strengthening, precipitation strengthening, dispersion strengthening, strengthening by point defects, martenisitic strengthening, and composite materials.
9.	**Creep:** Creep curve, mechanisms of creep deformation, activation energy for creep deformation, structural changes during creep, deformation mechanism map, super plasticity, presentation of creep data, prediction of long-term creep properties, irradiation creep, grain boundary sliding, nucleation, growth and coalescence on inter granular cavities, effect of impurity segregation on cavitation, creep fracture of weld joint, design of creep deformation and fracture resistance materials.
10.	**Fatigue:** Types of loading, high cycle fatigue, low cycle fatigue, thermo-mechanical fatigue, creep-fatigue interaction, fretting fatigue and corrosion-fatigue of various engineering materials, effect of surface treatment and coating, fatigue behaviour of welds, characterization of fatigue deformation and damage, fatigue under combined stresses, notch sensitivity, design criterion, life prediction techniques, alloy design against fatigue.
11.	**Fracture Mechanics:** Ductile to brittle transition, Griffith’s law, strain energy release rate, introduction to linear and non-linear fracture mechanics, fracture toughness, fatigue and creep crack growth, material design against fracture.

Books Suggested

1. Physical Metallurgy Principle – R. E. Reed-Hill
2. Modern Physical Metallurgy – R. E. Smallman
3. Mechanical Metallurgy – G. E. Dieter
4. Plastic Deformation of Metals – R. K. W. Honeycomb
5. Introduction to Creep – W. W. Evans
6. Fatigue of Materials - S. Suresh, CambridgeUniversity Press.
7. Deformation and Fracture Mechanics of Engineering Materials – R. W. Hertzberg

15. Manufacturing Technology (MS15 - 30 hours)

S.No.	Course content
1.	**Nuclear materials and their melting practices**: Selection criteria for in-core, structural and steam generator materials, Radiation damage, Properties of nuclear materials. Principles of Vacuum melting & casting processes, including general descriptions of vacuum induction melting, vacuum arc re-melting and electro-slag refining.
2.	**Hot and cold working processes and tube making processes**: Fundamentals of mechanical processing, defects during manufacturing, Various techniques for producing seamless pipes, design of tooling for hot extrusion and principles of pilgering and Various presses and their characteristics.
3.	**Special metal forming processes**: High velocity forming processes like explosive forming, pertroforge forming, electro magnetic and hydraulic forming, comparison of HVF methods, Super-plastic forming.
4.	**Powder metallurgy** : Introduction, characterization of metal powders. Manufacturing of metal and composite powders. Compaction and sintering of metal powders. Secondary operations. Applications of typical P/M components.
5.	**Computer aided design:** Role of computers in design and manufacture, Solid modeling – techniques and algorithms for modelling – data structures for solid models; Surface modeling – curves and surface representation – composite surfaces – application to computer aided manufacture; Current developments in CAD – feature based modeling – Design by feature – function, feature linkages – Application of feature based models. Parametric modeling.
6.	**Metal joining principles and processes**: Fusion and non- fusion welding processes, modern welding processes, design of welded joints, Introduction to residual stresses and distortion in welds.
7.	**Weldability of materials**: Welding of austenitic stainless steels, ferritic steels, weldability tests, dissimilar welding and selection of weld consumables and welding defects, principles of post weld heat treatment and stress relieving.
8.	**Welded Fabrication**: Codes and Standards, Procedure and performance Qualification, Evaluation of the welded joints, NDT of welds.
9.	**Hard facing Technology**: Introduction, Need for hard facing, Hard facing processes, Hard facing in nuclear power plants.
10.	**Heat Treatment**: Annealing, normalizing, quenching and tempering, Precipitation hardening, Recrystallisation annealing, Importance of heating and cooling rate and hold time in heat treatment, Heat Treatment furnaces.

Books Suggested:

1.Metal Forming Handbook, Schuler, Springer Verlag, Berlin, 1998.
2.Welding Technology for Engineers, Baldev Raj, Shankar (V) And Bhaduri (A K), Narosa Publishing House, New Delhi, 2006.
3.Fundamentals of Metal Forming, Wagoner (R H), John Wiley & Sons, New York, 1997.
4.CAD/CAM from Principles To Practice, Chris Mcmahon And Jimmie Browne, Addison – Wesley, 1993.
5.Manufacturing Technology: Foundry, Forming And Welding, Rao (P N), Tata Mcgraw-Hill, New Delhi, 1987

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING I

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (MECHANICAL/CHEMICAL)

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE1	Code Design for pressure vessel and piping	30	4
2.	FRE2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	30	4
3.	FRE3	Transport Phenomena	30	4
4.	FRE4	Reliability Engineering	20	2
5.	FRE5	Process Design and Control	30	4
6.	FRE6	Vibration Engineering and Condition Monitoring	20	2
7.	FRE7	Seismic Design of Nuclear Reactors and Facilities	30	4
8.	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**210**	**26**

MODULE III- OPERATIONS

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE9	Plant Dynamics and Control	25	3
2.	FRE10	Turbine Generator Fundamentals	25	3
3.	FRE11	Mechanical and Electrical Equipments	25	3
4.	FRE12	Maintenance Engineering	25	3
5.	FRE13	Regulatory Framework for NPPs	25	3
6.	FRE14	Practical's	**6 Weeks**	**12**
		Total	**125**	**27**
		Total	**510**	**74**
1.	Viva Voce	**Grand Total**		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

31. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
32. Steam Power Station, G.A. Gassort.
33. Power Plant Engineering & Economics, Strosal & Vapet.
34. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
35. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
36. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
37. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
38. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
39. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
40. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :** Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.

2. **Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3. **Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4. **Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5. **Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6. **Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7. **Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8. **Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities
8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II - CORE ENGINEERING (MECHANICAL/CHEMICAL)

1. Code Design for Pressure Vessel and Piping (FRE1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical, spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures. Thermal stresses in plates and shells.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc (WRC-297)
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Design of tube sheets as per TEMA and ASME Sec VIII Div. 1.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Difference between Sec. VIII Div.1 & Sec III-NB.

12. Introduction to design codes (structure of RCC-MRx) both insignificant and significant creep. Service levels and design class. Introduction to shell and piping design. Thin Shell Design Against Buckling as per RCC-MR Appendix A-7, Elastoplastic instability under monotonic loading – linear elastic analysis, Elastoplastic instability under cyclic loading - elastic linear analysis -negligible creep, Elastoplastic instability in significant creep - simplified method.

Books suggested:

11. Harvey J F , 'Pressure vessel design' CBS publication
12. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
13. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
14. American standard code for pressure piping , B 31.1
15. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Heat Transfer and Computational Fluid Dynamics (FRE2) (30 Hours)

S.No	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity, momentum and energy equations) with special reference to Navier-Stokes & Bernoulli equations.
2.	**Laminar Boundary Layer and Forced Convection:** Formulation of differential equations for hydrodynamic and thermal boundary layers. Different analytical methods for reduction of boundary layer equations and theoretical formulation for boundary layer thickness. Study of jets and flow separation in the light of Boundary Layer Theory. Convective heat transfer in internal and external flows. Low and high Prandtl number limits and different thermal boundary conditions.
3.	**Turbulent Flow and Heat Transfer**: Reynolds decomposition for turbulence. Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical correlations for heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy.
4.	**Natural Convection**: Basic Equations of natural convection. Boussinesq approximation. Derivation of dimensionless groups from basic equations. Analytical approximations.
5.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Law, porosity & permeability, homogenization method, continuity equation & energy equation.
6.	**Heat Transfer with Phase Change**: Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling & (b) flow boiling: Heat transfer correlations for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post-dryout heat transfer. Various

models available for calculation of heat transfer coefficient. Critical Flow. Models for single - phase and two-phase critical flows.

7. **Radiation heat transfer**: Radiation heat transfer. Reflection, absorption, transmission and emission; concept of black and grey bodies; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Shape factor & law of reciprocity; Radiation heat transfer between two grey bodies
8. **Numerical Methods in Heat Transfer**: Discretization of conduction equation with Dirichlet & Neumann boundary conditions; Temporal integration: Explicit & Implicit schemes. Discretization of convection-diffusion equations (Upwind & Exponential schemes). Estimation of flow field: stream function-vorticity formulation and primitive variable formulation. SIMPLE family of algorithms. Turbulence Modeling: Eddy diffusivity models: k-ε and k-ω models. Reynolds stress models: algebraic & differential versions. Large eddy simulation and Director numerical simulation.

Books suggested:

AHMT

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974.
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.
3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

CFD

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

3. Advanced Mass Transfer (FRE3) (30 Hours)

S.No. **Course content**

1. **Momentum Transport:**

1.1 Viscosity and Mechanisms of Momentum Transport: Generalized Newton's Law of Viscosity, Pressure and Temperature Dependence of Viscosity, Molecular Theory of the Viscosity of Gases and Liquids, Viscosity of Suspensions and Emulsions, Convective Momentum Transport.

1.2 Velocity distributions with two independent variables: Time-Dependent Flow of Newtonian Fluids, Flow near Solid Surfaces by Boundary-Layer Theory.

1.3 Macroscopic Balances for Isothermal Flows: Macroscopic mass, momentum, mechanical energy balances; Estimation of viscous loss, Performance of Liquid-Liquid Ejector, Thrust on pipe bends**.**

2. **Energy Transport:**

Fourier's Law of Heat Conduction; Thermal Conductivity, its measurement & its dependence on temperature / pressure. Theory of thermal conductivity of gases, gas mixtures and liquids, Effective thermal conductivity of composite solids, Convective transport of energy.

3. **Mass Transport:**

3.1 Diffusivity and the Mechanisms of Mass Transport: Fick's Law of Binary Diffusion, Diffusivity, its measurement & its dependence on temperature / pressure, Theory of diffusion in gases, binary liquids, colloids etc. Molar transport by convection.

3.2 Concentration Distributions in Solids and Laminar Flows: Diffusion through Gas Films, homogenous / heterogeneous chemical reactions, Diffusion into a Falling Liquid Films.

3.3 Equations of Change for Multi-component Systems: Equations of Continuity for a Multi-component Mixture, Multi-component Equations of Change, Multi-component Fluxes and their applications.

3.4 Concentration Distributions with More than One Independent Variable: Time-Dependent Diffusion, Steady-State Transport in Binary Boundary Layers, Boundary Layer Mass Transfer with complex interfacial motion. Concentration Distributions in Turbulent Flows.

3.5 Interphase Transport in Nonisothermal Mixtures: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions, Combined Heat and Mass Transfer by Free Convection, Effects of Interfacial Forces on Heat and Mass Transfer, Transfer Coefficients at High Net Mass Transfer Rates.

3.6 Other Mechanisms for Mass Transport: Equation of Change for Entropy, The Flux Expressions for Heat and Mass, Concentration Diffusion and Driving Forces, Applications of the Generalized Maxwell-Stefan Equations, Mass Transport across Selectively Permeable Membranes, Mass Transport in Porous Media.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Reliability Engineering (FRE4) (20 hours)

S.No	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.
3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY

5. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.

2. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.
4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

6. Vibration Engineering and Condition Monitoring (FRE6) (20 Hours)

S.No. **Course content**

1. Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2. Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3. Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; A seismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4. Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5. Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6. Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

7. Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

7. Seismic Design of Nuclear Reactors and Facilities (FRE7) (30 Hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson’s ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

7. **Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.
15. **High Temperature and Creep Fatigue Interaction:** Damage mechanisms and failure modes, Time-dependent and frequency-dependent damage, Cumulative damage rules, Different approaches for life prediction under creep-fatigue conditions: Frequency-modified approach, strain range partitioning (SRP), Ductility exhaustion method, Creep-fatigue interaction Diagram, Thermomechanical fatigue, Codes and Standards

Books Suggested:

1. Chopra, A.K., “Dynamics of Structures, Theory and applications to Earthquake Engineering”, Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures”, New York, McGraw-Hill Book Company.
3. Mariopaz, “Structural Dynamic (Theory and Computation)”, CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., “Numerical Methods in Finite Element Analysis”, Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, “Seismic Analysis of Safety Related Nuclear Structures and Commentary”, ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, “Engineering Seismology”, IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, “Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, “Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites”. AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design”, BIS, New Delhi.

8. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.

- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.
- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.
- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings, Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.

- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.
- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evolution of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extension of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Independence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.

- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974

11. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

1. **Class room Training**
    a. Reactor System

        Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

    b. Sodium system

        Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

    c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*
    d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

2. **Field training**
    a. Reactor Operation
    b. Maintenance Activities
    c. Technical Service Activities
    d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING II

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (ELECTRICAL/ELECTRONICS)

S. No.	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE15	Reactor Control Engineering	30	4
2	FRE16	Nuclear Instrumentation	25	2
3	FRE4	Reliability Engineering	20	2
4	FRE5	Process Design and Control	30	4
5	FRE17	Embedded System Design & Human Machine Interface	45	6
6	FRE18	Process Instrumentation	45	6
7	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**215**	**26**

MODULE III- OPERATIONS

S. No	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE9	Plant Control	25	3
2	FRE10	Turbine Generator Fundamentals	25	3
3	FRE11	Mechanical and Electrical Equipments	25	3
4	FRE12	Maintenance Engineering	25	3
5	FRE13	Regulatory Framework for NPPs	25	3
6	FRE14	Practical's	6 Weeks	12
		Total	125	27
		Total	515	74
1	**Viva-Voce**			**2**
		Grand Total		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP) (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II A- CORE ENGINEERING (ELECTRICAL AND ELECTRONICS)

1. Reactor Control Engineering (FRE15) (30 Hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (FRE16) (25 Hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (FRE4) (20 Hours)

S.No **Course content**

1. **Introduction: Reliability Engineering Applied to C&I Systems**
   Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
   Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
   Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
2. **Reliability Maths/Statistics:**
   - Mathematical and statistical expressions required for reliability study
   - Types of failures in electrical, electronic and computer components
   - Failure probability concept, statistical distribution models
   - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
   - Chi-square distribution and its use in confidence and risk factors
   - Baye's theorem
   - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
   - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions
   - Derivation of exponential reliability expression

- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

3. **Fault Tolerance and Systems Reliability:**
   - Fault tolerance concept for electronic and Computer based C&I systems.
   - Circuit hardware redundancy concept to enhance system reliability, types of redundancy
   - Series, parallel, active, passive, and voting redundancy
   - Redundancy and other fault tolerance methods for software
   - FMEA, FMECA concepts for C&I and Examples to solve
   - Concepts for the analysis of System Reliability, availability, and maintainability.
   - System reliability and availability analysis methods
   - Boolean logic
   - Digraph, cutest-tie set method
   - Fault tree model, and consideration of CCF, CMF, software errors
   - Markov Model

   Example from C&I system in the NPPs
4. **QA/QC Concepts in Brief:**
   - QA/QC Concepts in the components, systems procurement, manufacture and Site installation for C&I systems in the NPPs.
5. **Environmental Qualification and Reliability Testing:**
   - Environmental qualification, testing of the C&I systems
   - Effects of various environments on the electrical/ electronic components
   - Climatic Qualification tests: Temperature, Humidity
   - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
   - Reliability Testing of the electronic components, equipment and C&I systems
   - Reliability screening tests for electronic components
   - Accelerated environmental tests
   - Failure terminated and time terminated tests
   - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
   - Few examples to solve
6. **PSA/PRA Concepts in NPPs:**
   - Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs
   - Explain Event Tree
   - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency
   - Level-1, Level-2, Level-3 PSA studies (Brief introduction only)

7. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier
Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ.
(1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill
Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants
(2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment
(1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier
Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher
(2001),
(‘Formal Methods’ has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

5. Embedded System Design and Human Machine Interface(FRE17) (45 Hours)

S.No. **Course content**

Embedded System Design

A. Microprocessor Based Hardware Design:

1. Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16-bit Micro-controllers (e.g. 80196), Overview of 8-bit Atmel Micro-controller (AT89C51), Real Time Clock, DSPs (e.g. TMS320, SHARC family) and ARM processor.
2. Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3. Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play
4. Design Case Study: Single board computer architectures, Remote Terminal Unit, Circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.

B. Computer Communication and Networks

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.);Concept of Fieldbus, fieldbus standards, Industrial networks and Protocols.

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Programmable Logic Controller Design

Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, Relevant communication protocol and standards, PLCs for package systems.

Human Machine Interface

E. Human Machine Interface (HMI)

1. Overview of plant automation, Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
2. Design of HMI, Soft Console versus Conventional control panels, Virtual Control Panel.
3. PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.
4. Guidelines for design of HMI displays.
5. Case study of a commercially available Professional HMI package.
6. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons

7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek& R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.
17. IntellutionIfix documentation
18. NPC Guidelines for development of soft consoles

6. Process Instrumentation (FRE18) (45 Hours)

S.No.	Course content
1.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.
2.	Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors - performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques. Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
3.	Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and

differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

4. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
5. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position
6. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

   Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.
7. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

   Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
8. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

   Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
9. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

   Note:Course Work -35 Hours and Practicals -10 Hours

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication

3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrument Engineer's Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Field bus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

7. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.
- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.

- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal

pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.

- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings,

Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.
- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.

- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evoluation of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extention of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Indepence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.
- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
-

6. Practicals (FRE 14) (6 Weeks)

12. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

3. Class room Training

a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

4. Field training

a. Reactor Operation

b. Maintenance Activities

c. Technical Service Activities

d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

BACK TO MAIN

Homi Bhabha National Institute, RRCAT, Indore

Syllabus for
M.Tech. in Engineering Physics courses
(PROGRAM CODE: ENGG01)

Raja Ramanna Centre for Advanced Technology, Indore

Courses offered at HBNI, RRCAT for
Ph. D. in Physics
M.Tech. in Engineering Physics
(Specialization in Accelerators and Lasers)

- Total credit requirement for Ph. D. (Physics) : 60

Core courses	28 credits
Elective courses	20 credits
Laboratory experiments	04 credits
Two reading courses	08 credits

- Total credit requirement for M.Tech. (Engineering Physics) : 60*

Core courses	38 credits
Elective courses	12 credits
Laboratory experiments	04 credits
Short term project	06 credits

* An additional course (Foundation course) of 5 credits is offered to M.Tech. students as a bridge course.

Contents

Syllabus for M.Tech. (Engineering Physics) courses

A : Core Courses

03ENGG01-001-C Engineering Mathematics Credit (3)

Complex Analysis: Analytic functions, Cauchy-Reimann conditions, Cauchy integral theorem, Laurent expansion, conformal mapping, singularities, calculus of residues, evaluation of definite integrals.

Vector Calculus: Gradient, divergence and curl operations and their physical interpretations, vector integrations, Gauss theorem, Stokes theorem.

Matrix: Basic concept of matrix algebra, symmetric, skew-symmetric and orthogonal matrices, eigenvalues and eigenvectors of a matrix, hermitian, skew-hermitian and unitary matrices, illustration of symplectic matrices in particle transporting accelerator.

Integral Transform: Fourier integral, Fourier transform and inversion theorem, Fourier transform of derivative, convolution theorem, transfer function, Laplace transform, Laplace transform of derivatives, convolution theorem, inverse Laplace theorem.

Ordinary and Partial Differential Equations: Review of ordinary differential equations, introductions to partial differential equations, classification of partial differential equations, boundary and types of partial differential equations, solutions of one dimensional diffusion equation, two-dimensional Laplace equation, use of integral transform in solving partial differential equations. Introduction to difference equations.

Probability and Statistics: Bayes' formula, random variables, expected value and variance, discrete and continuous distributions, location parameters, joint distributions, conditional distributions and independence, covariance and correlation, bivariate normal distribution, Poisson process, the central limit theorem, statistical inference (with an aim to better understand and analyze experimental data), point estimators, estimating variance, confidence intervals, comparing two samples, estimation methods, hypothesis testing, goodness of a fit.

References:

1. "Mathematical Methods for Physicist", G. Arfken
2. "Mathematical Methods for Scientists and Engineers", Donald A. McQuarrie
3. "An Introduction to Probability: Theory and its Applications- Vol.1 and Vol 2", William Feller
4. "Ordinary Differential Equations" V.I. Arnold
5. "Advance Engineering Mathematics", Erwin Kreyszig

03ENGG01-002-C Magnet Physics and Technology: Credit (4)

Origin of Magnetism: Classical and quantum concepts, magnetic moments, angular momentum and quantization of angular momentum.

Classification of Magnetism: Diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetism.

Role of Magnets in Accelerators: Dipole, quadrupole, sextupole, and combined function magnets, DC and fast cyclic magnets, septum magnets, and kicker magnets.

Fundamentals of Magnet Design: Magnetic circuit, dipole, quadrupole, sextupole and higher order multipole magnets and coil design, B-H curve.

Application of Magnetic Materials in Accelerators: Materials for DC magnets: low field magnets, high field magnets, permanent magnets, and shielding.

Materials for AC Magnets: Silicon steels, laminated Ni-Fe alloys, and Ferrites. Numerical methods for magnet simulation: computer code and related mathematical formalism, methods of optimization, multipole expansion, Fourier representation of magnetic field.

Magnet Technology: Fabrication procedures, tolerances, and economic issues.
Methods of magnetic field measurements: magnetic induction, search Coil, Hall probe, and nuclear magnetic resonance.

Superconducting Magnets: Basic concept of superconducting magnets, magnet geometries for dipole magnets, superconducting materials, need for twisted composite conductors, hot spot temperature, current densities, quench, training of magnets and persistent switch.

Geodesy and Alignment of Accelerators: Introduction, survey and alignment as applicable to accelerators and its requirement. Position sensitive elements and their typical tolerances for alignment, fiducial references and adjustment system, fiducial posts and targets, and techniques of fiducialsation. Features of support elements and their adjustments during alignment.

Network and Alignment Procedure: Defining coordinate systems, control networks-types, survey procedure, data adjustment and error analysis.

Survey and Alignment Instruments and Toolings: Electronic theodolite, optical level, laser Interferometer, distinvar, inclinometer, offsetmeter etc. Different types of targets and sensors.

References:

1. "Iron Dominated Magnets", Jack T. Tanabe
2. "Synchrotron Radiation Sources - A Primer," Herman Winick
3. "Iron Dominated Electromagnets, Design, Fabrication, Assembly Measurements", Jack T. Tanabe
4. "Conventional Magnets,Proceedings of CAT- CERN Accelerator School, Nov. 1993, Page 23," Neil Marks
5. "Classical Electrodynamics," J. D. Jackson
6. "Superconducting Magnet Systems," H. Brechna
7. "Physics of Magnetism," S. Chikazumi
8. "Soft Ferrite its Applications", E.C Snelling
9. "Permanent Magnet Materials Their Applications," Peter
10. "Modern Ferrite Technology", Alex Goldman

03ENGG01-003-C Laser Physics and Technology: Credit (4)

Basic Formalism: Spontaneous and induced transitions, Einstein's approach, A and B coefficients, conditions for light amplification and oscillations, and characteristics of laser light. Homogeneous and inhomogeneous broadening of the transitions, spectral narrowing in a laser, gain saturation, spatial and spectral hole burning and their consequences, Lamb dip spectroscopy and its applications.

Propagation of optical beams in free space and in dielectric slab waveguides, Hermite-Gaussian beam modes, and ABCD law for Gaussian beam propagation.

Optical resonators, concept of cavity modes, resonators with spherical mirrors, resonance frequencies of optical resonators, losses in optical resonators, stable/ unstable resonators, Kirchoff's diffraction treatment for transverse modes.

Methods For Obtaining Population Inversion: Optical pumping, coherent and incoherent pumping, one- and two-photon processes, pumping geometries, pump sources, electrical pumping by discharge in gases, excitation mechanisms, self sustained and e-beam sustained operation, chemical pumping, and gas dynamic pumping.

Laser Dynamics: Laser oscillation, three and four level lasers, rate equation modeling, power in laser oscillators, optimum output coupling low- and high-loss regimes, multimode laser oscillation and mode locking. Different techniques of mode locking. Relaxation oscillations, cavity dumping and Q-switching. Techniques of Q-switching. Pulse compression techniques for ultrashort pulse generation. Spectral control of laser output, tunability of output frequency, single frequency operation, and frequency stabilization.

Physics and Technology of Specific Laser Systems: Solid state lasers, vibronic lasers, semiconductor diode lasers, diode pumped solid state lasers, fiber lasers, dye lasers, atomic and molecular gas lasers, chemical lasers, excimer lasers, free electron lasers. Measurement of parameters of a laser system.

Nonlinear Optics: Crystal optics, electro-optic effect, wave propagation in nonlinear media, phase matched second harmonic generation, optical parametric oscillator, two-photon absorption, stimulated Raman scattering, frequency mixing in gases and vapours, self-focusing, optical bistability and optical phase conjugation. Quantum optics: second quantization, non-classical effects.

References:

1. "Laser Fundamentals", W. T. Silfvast
2. "Laser Electronics", J. T. Verdeyen
3. "Lasers", A. E. Siegman
4. "Quantum Electronics", A. Yariv
5. "Laser Physics and Technology, Proc. of the school on Laser Physics and Tech." Eds. P. K Gupta, R. Khare
6. "Nonlinear Optics", R. W. Boyd
7. "Elements of Nonlinear optics", P. N Butcher and D Cotter

03ENGG01-004-C Electromagnetic Theory: Credit (3)

Electrostatics: Laplace equation and the uniqueness theorems, variational approach to solutions of the Laplace and Poisson equations. Formal solutions of electrostatic boundary value problems with Green function. Method of relaxation for 2D electrostatic problems, method of images, separation of variables and special functions, finite element method, and multipole expansions. Electrostatic field in matter.

Magnetostatics: Maxwell equations of magnetostatic, macroscopic Maxwell equations in magnetic material and boundary conditions on B and H, and solution of boundary value problems in magnetostatics.

Electromagnetic Wave: Wave equation, solutions in free space, plane waves, Gaussian beams, equations in material media, dispersion relations, Fresnel's laws of reflection and refraction, total internal reflection and evanescent waves. Lorentz transformation of electromagnetic fields.

Wave-guides, Resonant Cavities and Optical Fibers: Hollow metallic waveguides, dielectric waveguides, optical fibers, resonant cavities, and elements of microwave transport line.

Radiation by Moving Charges: Lienard-Wiechert potentials and fields, power radiated by an accelerated charge, Larmor's formula, and angular distribution of emitted radiation.

References:

1. "Electromagnetic Theory", D. J. Griffith
2. "Classical Electrodynamics", J. D. Jackson
3. "Electrodynamics: An introduction including quantum effects", H. J. W. Muller-Kirsten
4. "Microwave Devices and Circuits", S. Y. Liao.

03ENGG01-005-C Accelerator Physics and Beam Diagnostics: Credit (4)

Introduction: Motion under electric and magnetic fields. DC and RF acceleration. Relativistic kinematics, Brief history and review of particle accelerators.

Synchrotron/Storage Rings: Accelerator magnets - dipole, quadrupole and sextupole magnets. Multipole expansion method. Equation of motion, betatron oscillations, weak and strong focusing, transfer matrices, beam stability, twiss parameters, motion of particles with momentum deviation, momentum compaction, and chromaticity. Magnetic field errors, closed orbit distortion and its correction, resonances - integer and half integer, beam acceleration, synchrotron oscillations, phase stability, transition energy, beam emittance, Liouville's theorem, single turn injection, H-injection, and fast extraction.

Beam Transfer Lines: FODO cells, quadrupole triplet, phase space matching, emittance dilution.

Synchrotron Radiation Sources: Synchrotron radiation, Radiation damping, quantum excitations, equilibrium beam emittance, and beam lifetime.

Linear Accelerators: DC accelerators, various types of RF accelerators, EM mode in a simple structure, Q-factor, shunt impedance, transit time factor, filling time, energy gain, dispersion curve, TW and SW accelerators, and beam dynamics in LINACS.

Cyclotrons: Basic principle of cyclotron, resonance condition, orbit stability, limitations of classical cyclotrons, AVF cyclotrons, injection, central region, extraction, time structure, energy resolution, and beam emittance.

Microtrons: Classical microtrons, basic equations, and Racetrack microtrons.

Beam Diagnostics: Physical principles, charge collection, secondary emission, Ionization, fluorescence, scintillation, capacitive pick up, magnetic pick up, wall current, synchrotron radiation detection, and optical transition radiation.

Instrumentation: Faraday cup, secondary emission wire monitor, beam loss monitor, beam profile monitor, beam position monitor, DC beam current transformer, fast current transformer, wall current monitor, photomultiplier, photo diode, image dissector, and streak camera.

References:

1. "Particle Accelerator Physics", Helmut Wiedemann, Springer
2. "Introduction to Accelerator Physics", Arvind Jain, Macmillan India
3. "CERN Accelerator School Proceedings, Fifth General Accelerator Physics Course, 1992 (Available online)"
4. "The principles of circular accelerators and storage rings", P. J. Bryant and K. Johnsen, Cambridge University Press
5. "Principles of RF linear accelerators", T. Wangler, John Wiley and Sons
6. "Collective phenomenon in synchrotron radiation sources", S. Khan, springer
7. "Physics of collective beam instabilities in high energy accelerators", A. Chao, John Wiley and Sons

03ENGG01-006-C Reactor Physics, Radiation Physics, and Safety Issues of Accelerators and Lasers: Credit (3)

Health Physics: Radiation sources - radioisotopes, natural and manmade sources, radioactive series, reactors, accelerators, radiation facilities, solid, liquid and gaseous activity. Control measures - time, distance, decay, shielding, administrative control, radioactive discharge, waste disposal, and exposure control.

Interaction of Radiation with Matter: Interaction of light and heavy charged particles, photons, and neutrons. Interaction of high energy charged particles, electromagnetic cascade, and Hardronic cascade.

Radiation Quantities, Units, and Regulatory Recommendations: Dosimetric quantities, exposure, absorbed dose, equivalent and effective dose, committed dose, ALI, DAC, ICRP, AERB, and dose limits.

Biological Effects of Radiation: Somatic and genetic effects, stochastic and deterministic effects, and LD30/50.

Detection of Radiation: Ionisation chamber, proportional counters, GM tubes, scintillation detectors, semiconductor detectors, thermoluminiscent dosimeters, direct reading dosimeters neutron detectors, BF3 and He3 tubes, Rem-meters, CR-39-foils, pulsed radiation detection. Low and high energy radiation detection.

Reactor Physics: Introduction to nuclear energy - fission and fusion, interaction of neutrons with matter; fission process and energy release, fission cross-section, fissile and fertile materials. Chain reaction, neutron cycle and lifetime, criticality and classical four-factor formula. Thermal and fast systems, slowing down of neutrons, conversion and breeding of fissile materials, concept of neutron flux and current, neutron diffusion theory, critical size and mass, reflected systems and reflector saving, heterogeneous systems. Reactor kinetics, reactivity and importance of delayed neutrons, reactivity changes and coefficients, fission product poisoning, control devices, uranium and thorium fuel cycles and enrichment processes.

Accelerator Safety: Types of accelerators, prompt and residual radiation, source terms, radiation hazards, radiation safety systems, shielding, radiation monitoring, non-ionizing radiation safety, RF and MW safety, magnetic field safety; ozone safety, safety at synchrotron radiation beam lines, spallation neutron sources, and accelerator driven sub-critical systems.

References:

1. "Nuclear Reactor Engineering Vol-1", Samuel Glasstone and Sesonske
2. "Health Physics", Herman Cember
3. "Radiation Detection & Measurement", G. F. Knoll
4. "Atoms, Radiation & Radiation Protection", James Turner
5. "Physics for Radiation Protection", James Martin
6. "Radiological Safety Aspects of the Operation of Electron Accelerators, IAEA Technical Report Series. 188", W. P. Swanson
7. "Radiation Protection for Particle Accelerator Facilities NCRP Report No.144"
8. "Radiological Safety Aspects of the Operation of Proton Accelerators. IAEA Technical Report Series. 283", R. H.Thomas.
9. "A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators Nuclear Technology", A. Sullivan

03ENGG01-007-C Numerical and Mathematical Techniques and Scientific Programming and Computing Methodologies:

Credit (5)

Numerical Methods

System of Linear Algebraic Equations: Direct methods - Gauss elimination and Gauss Jordan methods. Iterative methods - Jacobi, Gauss-Seidel and Successive over relaxation (SOR) methods. Eigenvalue problem .

System of Nonlinear Equations: Newton-Raphson and Secant methods. Roots of polynomials, synthetic division of polynomials, and Baristow method.

Interpolation, Extrapolation, Error and Regression Analysis: Types of errors their analysis.

Numerical Integration: Newton-Cotes, Gauss quadratures, trapezoidal, Simpson's 1/3 and 3/8 rule. Numerical differentiation - forward, backward and central difference quotient.

Differential Equation: Solution of ordinary differential equations. Solution of partial differential equations. Fast Fourier transformation.

Statistical Distributions: Poisson and Gaussian distributions. Monte Carlo simulation, pseudo random numbers, and central limit theorem.

Finite Element Method (FEM)

Introduction: Basic concepts of finite element method, application of finite element method, finite element method versus classical methods, finite element method versus finite difference method, and advantage of finite element method.

Integral Formulations for Numerical Solutions: Variational method, collocation method; subdomain method, weighted residual methods, Rayleigh-Ritz method, Galarkin's method, and least square method

Elements, Nodes, and Co-ordinate Systems: Introduction, element shapes, nodes, nodal unknowns, and coordinate systems

Shape Functions: Introduction, polynomial shape functions, convergence requirement of shape function, and derivation of shape functions.

Introduction to Stiffness (Displacement) Method: Definition of the stiffness matrix, derivation of the stiffness, matrix, assembly of the total stiffness matrix, properties of the global stiffness matrix.

Application of Finite Element Method in Heat Transfer Problem: Fundamentals, one dimensional finite element formulation, and problems.

Fundamentals of Computers: Computer architecture, application of computers, input and output devices, latest processors, desktop PC and servers.

Networking Basic: TCP/IP, DNS, Internet, and Intranet.

Operating System Basic: Linux, windows, shell programming, and CLI, vi, multithreading, multiuser, multitasking, hyper threading, file permissions, and ssh.

Fundamentals of programming: Algorithm, flow charts, high-level languages like Fortran and C, and steps for creating a simple program.

Introduction to C Programming Language: Program structure, header files, basic data types, variables, and declarations.

Operators and Declarations in C: Relational, logical, increment, and decrement operators. Expressions and precedence of operators. Input and output operations, control statements, iterative loops, arrays, and pointer;

Overview of Scientific Computing: Languages and compilers and scientific libraries.

Overview of Trends and Techniques: Sequential, parallel computing, cluster and grid computing.

Architecture Taxonomy: Traditional architecture, Flynn's classical taxonomy, SISD, SIMD, MISD, and MIMD Models.

Steps for Creating a Parallel Program: Decomposition of the program, communication, computations, and composing the results. Parallel example-array processing.

References:

1. "Numerical Methods for Engineers with Personal Computer", S.C Chapra and R. P. Canale
2. "Numerical Analysis", R. L. Burden and J. Douglas Faires
3. "An Introduction to Numerical Analysis", K.E. Atkinson
4. "Numerical Method", E. Balagurusamy
5. "Numerical Methods for Engineers", D. V. Griffiths and I. M. Smith
6. "Data Reduction and Error Analysis for the Physical Sciences", P. R. Bevington and D. K. Robinson
7. "Finite Element Analysis", S. Krishnamurthy
8. "Introduction to the Finite Element Method", Desai and Abel
9. "An Introduction to the Finite Element Method", J. N. Reddy
10. "Concepts and Applications of Finite Element Analysis", R. D. Cook
11. "Finite Element Modeling for Stress Analysis", R. D. Cook
12. "Finite Elements and Approximation", O. C. Zienkiewicz and K. Morgan

03ENGG01-008-C Materials Science and Technology- I: Credit (4)

The structure of materials (metals and alloys, ceramics and glasses, polymers, composites, low dimensional materials, smart materials). Defects in materials, transport properties of materials, mechanical and thermal properties of materials, electrical, magnetic, galvanometric properties, superconductivity. Optical, nonlinear properties of optical materials, quantum size effects. Electronic materials (like spintronics, and other functional materials). Introduction to symmetry and ferroelectric materials.

References:

1. "Solid State Physics", N. W. Ashcroft N. D. Mermin

2. "Principles of the Theory of Solids", J. M. Ziman
3. "Introduction to the Physics of Electrons in Solids", B. K. Tanner
4. "Introduction to the Electron Theory of Metals", U. Mizutani
5. "Introduction to Superconductivity", A. C. Rose-innes E. H. Rhoderick
6. "Physics of Superconductors: Introduction to Fundamentals Applications", V. V. Schmidt; edited by P. Mueller A. V. Ustinov
7. "Superconductivity", Charles P. Poole, Horacio A. Farach Richard J. Creswic
8. "Shape Memory Materials", Ed. K. Otsuka C.M. Wayman.
9. "Phase Transformations in Materials", Ed. Gernot Kostorz.
10. "Magnetocaloric Effect its Applications", A. M. Tishin Y. I. Spichkin.
11. "Callister's Materials Science Engineering", R. Balasubramaniam.
12. "Engineering Materials 1: An Introduction to Properties, Applications Design", Michael F. Ashby David R. H. Jones.
13. "The Physics of Solids", R. Turton
14. "Dielectric Phenomena in Solids", Kwan Chi Kao.

03ENGG01-009-C Applications of Lasers in Nuclear Science, Industry, and Medicine: Credit (3)

Laser Applications: High resolution spectroscopy, ultra-fast spectroscopy, laser cooling, laser metrology, holography and its applications in NDT, optical data storage information processing, and optical communication. Laser photochemistry, laser application in biology and medicine

Laser Isotope Separation: Principles of selective photonic action, selective photonic action on atoms or molecules, atomic and molecular schemes for laser isotope separation, lasers for isotope separation, and uranium isotope separation technology employing lasers.

Laser Material Processing: Laser material interaction, Laser cutting, welding, surface hardening, laser surface re-solidification, laser surface alloying, and cladding, laser shock-hardening, laser rapid manufacturing, laser application in decontamination and decommissioning of nuclear installations.

03ENGG01-010-C. Applications of Accelerators in Nuclear Science, Industry, and Medicine: Credit (3)

Synchrotron Radiation and its Applications: Properties of synchrotron radiation, various types of sources like BM, wavelength shifter, wiggler, and undulators. Beamline design and

synchrotron optics. Applications of synchrotron radiation to condense matter physics, surface physics, biology and Industries

Industrial and Medical Applications of Accelerators: Accelerators for industrial and medical applications. Beam characteristics for medical and industrial applications.

Radiation Processing Using Accelerators: Radiation cross-linking, radiation curing, polymerization, de-polymerization, and radiation grafting. Dose distribution in the irradiated products.

Typical applications: Treatment of wire and cables, viscose rayon sheets, rubber products, heat shrinkable tubes, and sheets. Flue-gas treatment, waste water treatment, electron beam applications in food irradiation and sterilization.

Accelerator Based Radiotherapy: Clinical requirements of an accelerator for radiotherapy. Various components of radiotherapy machine. Photon beam therapy and electron beam therapy. Quality assurance in radiotherapy accelerator.

Applications of Accelerators in Nuclear and Particle Physics: Evolution of nuclear physics with energy of the incident beam. Nuclear physics and related phenomena at incident beam energy less than 10 MeV/nucleon, between 10 and 100 MeV/nucleon, and more than 100 MeV/nucleon. Nuclear physics with radioactive ion beams (RIB).

Spallation Source: General introduction, applications to condense matter, and nuclear physics.

03ENGG01-011-C. Vacuum Physics and Technology: Credit (2)

Vacuum Theory: Definitions - throughput, conductance, pumping speed etc. Pressure equations, mean free path, monolayer formation time. Units of vacuum, pressure regions in vacuum.

Vacuum Systems and Components: Vacuum pumps - rotary pumps, dry pumps, turbomolecular pump, titanium sublimation pump, non-evaporable getters, and sputter ion pump. Vacuum gauges - capacitance gauge, Pirani, thermocouple gauges, BA gauge, penning gauge, partial pressure gauge. flanges and seals, vacuum valves and leed throughs.

Vacuum System Design and Development: Design considerations, sources of gas load (vaporization, thermal desorption, diffusion, permeation, electron and ion stimulated desorption etc). Materials, fabrication techniques and leak detection. Processing to achieve ultra high vacuum.

References:

1. "Handbook of Vacuum Science and Technology", Ed. Dorothy M. Hoffman, Bawa Singh, John H. Thomas III and John H. Thomas III
2. "Vacuum Technology -3rd edition", A. Roth
3. "A User's Guide to Vacuum Technology - July 4, 2003", John F. O'Hanlon
4. "Vacuum Engineering Calculations, Formulas", Armand Berman
5. "Vacuum Technology-CERN Accelerator School", CERN

03ENGG01-012-C. Quantum Mechanics: Credit (6)

For Ph. D. (Physics) only

Mathematical Background and Postulates: Illustrations and application of postulates by using simple two-level systems and two-slit interference experiment.

Quantum Mechanics of Composite Systems: N-particle system, identical particles, symmetrization and antisymmetrization postulates, concept of density matrix, properties of density matrix, pure and mixed states.

Symmetry: Symmetries in quantum mechanics, space and time translation, time reversal symmetry and parity invariance. Rotational invariance, angular momentum, spin, and addition of angular momenta.

Approximate Methods: Variational methods, Wentzel-Kramers-Brillouin (WKB) method, time-independent perturbation theory, time dependent perturbation theory, adiabatic and sudden approximations, Fermi-Golden rule.

Scattering Theory: Born approximation, partial wave analysis, two particle scattering.

Relativistic Quantum Mechanics: Klein-Gordon equation, Dirac equation, electron spin, and positron.

Advanced Topics: Quantization of electromagnetic field, coherent, and squeezed states, interaction of radiation with matter, spontaneous emission and Lamb shift, entangled state, EPR paradox and Bell's inequality.

References:

1. "Principle of Quantum mechanics", Ramamurthy Shankar
2. "Quantum Mechanics, Vol. I and II", C. Cohen-Tannoudji, B. Liu, F. Laloe
3. "Modern Quantum Mechanics", J. J. Sakurai

03ENGG01-013-C: Research Methodology: Credit (0)

(Lecture: 20, Credit: 0)

Research Methodology: Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

Documentation: Preparing scientific papers/reports, scientific presentations.

Laboratory safety: Safe practices in laboratory.

Research ethics: Ethical conduct in science, ethical issues in scientific publication, awareness of plagiarism and other scientific misconducts.

Probability and Statistics: Bayes formula, random variable, expected value and variance, discrete and continuous distributions, joint distributions, conditional distributions, covariance and correlation, normal distribution, Poisson process, central limit theorem and its applications,
definition of precision, accuracy, systematic and random errors**,** propagation of errors in experimental data and their estimation, estimation of variance and confidence intervals.

Mathematical modeling: Measurement of functional relationships, order of magnitude analysis, dimensional analysis, goodness of a fit, linear regression and data fitting.

Data Security: Introduction to Data Security, Data security requirements, Different Cyber threats to Data & possible Solutions, Basic concepts of Cryptography & Data encryption algorithms, Research opportunities in Data Security.

Data management: Data planning, handling, modelling, analysis, visualization, Different Data Models, Data Management Software, Data Backup & Storage

References:

1) Research Methods for Science, M. P. Marder (Cambridge University Press
2) The Ethics of Science, An Introduction, David Resnick (Taylor and Francis, 2005)
3) Avoiding plagiarism, self-plagiarism, and other questionable writing practices: A guide to ethical writing, Miguel Roig
4) Advance Engineering Mathematics, E. Kreyzwig (Wiley, 2006)
5) An Introduction to Probability: Theory and Applications Vol. 1 and 2, W. Feller (Wiley)

C : Engineering Based Elective Courses

for M.Tech (Engineering Physics) only

03ENGG01-001-E. Power Supplies: Credit (4)

AC-DC Converters: Single phase and three phase diode and controlled rectifiers, effect of source inductance, ripple and harmonic analysis, 12-pulse rectifier, firing angle control schemes, THD and power factor, filters - passive and active, passive and active damping of filters.

Power factor Correction: Effects and limiting standards for line current harmonics, Passive PFC techniques, Active PFC.

DC-DC Converters: Principle of operation, steady-state analysis of buck, boost, buck-boost converters, Isolated dc-dc converters- forward, flyback and bridge converters, pulse width modulator and control of dc-dc converters.

Principles of Feedback Control System: Negative feedback, Stability criteria- gain and phase margin, steady state errors, transient response, current loop and voltage loop acting together.

Magnet power supplies in Accelerators: Requirements, Load characterisation, DC and ramping type power supplies, Pulsed power supplies.

High current magnet power supplies: Stability requirements, current cycling, Field stabilization.

Power supplies for superconducting magnets : Load requirements, quench detection, protection and training.

Laser and Plasma power supplies: Load characterisation, Gas discharge, Ballast requirements, CW/Pulsed operation, Current stabilisation, Power coupling schemes to gas discharges.

Thermal Management: Heat transfer, Heat sink design, Water- cooled heat sinks.

03ENGG01-002-E. Power Electronics: Credit (4)

Power Semiconductor Devices: Diode, SCR, MOSFET, IGBT, Static and switching characteristics, Safe operating areas, Drive requirements and circuits, Introduction to the properties of emerging materials and devices, High voltage switches, Turn-on and turn-off snubbers.

Modelling and Analysis : Introduction to modelling and analysis techniques for dc-dc converters, Averaged equivalent circuit modelling and analysis, small-signal analysis with an illustrative converter, Feedback control of power converters: Feedback controller design, voltage- mode control and current- mode control.

Soft-switching Converters: Concept of soft-switching, Load resonant converters: concept and

definition, ac analysis of converters and modes of operation, Full bridge zero voltage switching converter: Phase shifted PWM, Operation and analysis of converter in steady state.

High frequency Magnetics: Ferrites- characteristics and types, skin effect, proximity effect, parasitic components- origin, minimisation and characterisation, design of high frequency magnetic components, introduction to planar magnetics.

Electromagnetic Interference: Measurement techniques, LISN, separation of common mode and differential mode noise, limiting standards and mitigation techniques, design of high frequency filters.

03ENGG01-003-E. Advanced Course on RF and Microwaves: Credit (4)

Microwave Networks: S-parameters, Matrix representation of Microwave networks and its properties, cascade networks, periodic network system and application, mixed mode S parameters and their applications.

Generation of RF power for accelerators: Design requirements, RF power amplifiers using tetrode & triodes and solid state devices, klystrons, IOT, Gyrotron, Cooling and protection, Grounding and shielding.

High Power RF transmission: design aspect of high power RF transmission, directional couplers, dividers, combiners, high power waveguide and coaxial transmission lines, circulators, bends, magic-T, microwave windows, dummy loads, RF couplers.

Accelerator cavities: Characterizing RF cavity, determination of important cavity parameters, Fundamentals of beam-cavity interactions. RF power coupling to cavity.

Low level RF components and systems: Planar circuits, microstrips, substrate materials, lumped and distributed circuits, mixer circuits, phase shifters, filters, switches, couplers, dividers/combiners, Low level RF signal processing and RF feedback systems.

RF systems for accelerators: Design and configuration of typical RF system, Safety interlocks and operation of RF system.

RF/Microwave measurements: Specialty of high frequency measurements, Measurement of RF power, impedance, VSWR, frequency and phase. Measuring instruments used in RF/microwaves, passive and active detectors, spectrum analyzer, VNA calibration systems, Vector measurement with VNA, peak and average power meters, impedance analyzer, frequency counter.

03ENGG01-004-E. Advanced Data Acquisition and Control Systems: Credit (4)

Components of data acquisition system and their selection, signal conditioning modules, polling, hand-shaking, interrupt and event driven, DMA, data sampling methods.

Embedded system software concepts and development tools assembly and HLL, assembler,

compilers, linker, librarian, resident monitors, source level debuggers, in-circuit & in application programming (ICP/IAP) and logic analyzer. In circuit emulator (ICE), object code and HEX file formats, FPGA & CPLD architectures, logic cell structures, programmable interconnect and I/O ports, programming technologies and VHDL, implementation of combinational and sequential circuits, timing issues in FPGA synchronous circuits.

Centralized v/s distributed control system, PAC and PLCs, PC software issues and virtual instrumentation, VISA, image acquisition, data logging, online and offline data processing, data presentation and reporting, BUSES for digital data communication.

PC buses: PCI & PCI Express specifications mechanical, electrical functional.

Back plane buses: VME, CPCI, PXI, VXI mechanical electrical functional specification.

Buses for instrument network: Asynchronous & synchronous communication standards, bus, ring, net topologies, RS-232, RS-485, USB, LAN-Hub, GPIB, Ethernet, field bus serial port expansion cards on PCI, Converters: USB-GPIB, USB-Serial.

Real-time system concepts, timeliness vs speed, hard vs soft real time, scheduling method, concurrency, process & thread concepts, inter process communication and synchronization.

Software reliability: Software implemented fault tolerance, reliability and availability, safety issues. Software reliability standards and practice.

Process control elements, Set point, disturbance, servo system, regulatory system, analog vs digital control systems, Z - transform for digital control systems, feedback control system, continuous time domain PID controllers. Feed forward and cascade controls, digital controllers, digital form of PID controller, Z-transform based dead beat and Dahlin's algorithms, programmable logic controllers and applications, compensator design and stability criterion.

References:

1. "Process Control Systems: Application Design and Tuning", F.G. Shinskey.
2. "Modern Control Systems", K. Ogata, Prentice Hall (India)
3. "Chemical Process Control", G. Stephanopoulos.
4. "Digital System Design with VHDL and Synthesis: An Integrated Approach", K C. Chang.
5. "Digital System Design and Prototyping Using Field Programmable Logic and Hardware Description Language", Zoran Salcic.
6. "VHDL Made Easy", David Pallerin.

03ENGG01-005-E. Reliability Engineering: Credit (4)

Basic engineering statistics: Basic probability, random variables, probability density and cumulative distribution functions of engineering importance such as the binomial, poisson, normal, exponential, weibull, etc. Random sampling and sampling statistics and distribution of sampling statistics, such as the Chi-Square and Students test, point and interval parameter estimation, test of hypothesis, examples to solve on continuous and discrete distributions, mathematical equations relating to hazard rate, reliability, cumulative failure probability and

failure probability (density) function, Bath-tub curve - explanation of different parts of the life characteristic curve and corresponding failure distributions.

Quality and reliability, QA/QC concepts - Acceptance sampling plans, quality measurement, quality improvement and control methods with applications in design, development, and manufacturing, modern quality management philosophies, engineering/statistical methods including process control, control charts, process capability studies, loss functions, design of experiments, and total quality management (TQM) topics.

Reliability, availability and maintainability concepts and principles, reliability statistical analysis concept overview and application, accelerated life testing concepts, principles and application, qualitative and quantitative accelerated life testing principles, life-stress relationships and application to electronic components and semiconductor devices, software reliability issues, reliability prediction for electronic systems, system reliability concepts and case studies, role of redundancy in system reliability, design for reliability concepts and case studies, degradation analysis and case studies, reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software, hardware reliability analysis of electronic and computer based C&I systems based on MIL-STD-217, methods of measuring the reliability effectiveness of complex engineering systems, optimization theory, preventive maintenance models, and statistical analysis.

03ENGG01-006-E . Advanced Course in High Voltage Engineering: Credit (4)

High Voltage Technology: Introduction, classification of voltage levels, high voltage in electric supply network, major components of a high voltage network.

Electrostatic Fields and their Control: Electric field intensity, electric strength, classification of electric fields, degree of uniformity of electric fields, control of electric field intensity.

Dielectric Materials and their Behavior in Electric Fields:

a. Insulating Behavior of Air and other Gaseous Dielectrics: Generation of charge carriers: impact ionization, thermal ionization and photo-ionization, Negative ion formation, Breakdown by avalanche discharge (Townsend Mechanism); Breakdown voltage characteristics in uniform fields (Paschen's Law) Practical factors affecting the breakdown voltage: Corona, Fields non-uniform, high pressure and vacuum.
b. Liquid Dielectrics in High Voltage applications: Mineral insulating oils, Dielectric properties of insulating liquids, Dielectric power losses in insulating materials, Breakdown in liquid dielectrics, Aging of mineral insulating oils.
c. Solid Dielectrics and their Behavior in Electric Fields: Classification of solid insulating materials, Breakdown and pre-breakdown phenomena in solid dielectrics, Partial discharge and its effects on dielectrics.

Generation of High Voltages:

a. Alternating voltages: single step-up transformer, Transformers in cascade, Voltage control

of testing transformers, Series resonant circuits.

b. Direct Voltages: Half wave and full wave rectification, Voltage doublers and cascade circuits.

c. Impulse Voltages: Single stage impulse generator, Multistage Marx generator, Practical Impulse Generators.

High Voltage Test & Measurement: Types of tests, Power frequency tests, DC voltage test and Impulse withstand test, Peak voltage measurements by spark gaps, Sphere gaps and uniform field gaps, Voltage measurement using ammeter in series with high impedance, Voltage measurement using potential dividers, Generating voltmeter, Voltage and current transformers.

High Voltage Design and Applications: Design considerations of high voltage bushings, power cables, transformers and switchgears; high voltage applications and electrostatic hazards.

High Voltage Safety and Protection.

References:

1. "High Voltage Engineering", E. Kuffel and W S Zaengl.
2. "High Voltage Measurement, Testing and Design", T J Gallagher and A J Pearmain
3. "High Voltage Insulation Engineering", Prof. Ravindra Arora and Prof. Wolfgang Mosch
4. "High Voltage Technology", L. L. Alston

03ENGG01-007-E. Digital Signal, Image Processing and Applications: Credit (4)

Introduction: Digital image, steps of digital image processing systems, elements of visual perception, connectivity and relations between pixels. Image acquisition: Frame grabber, optics and illumination Simple Operations - Arithmetic, Logical, geometric operations.

Mathematical Preliminaries: 2D LTI systems, 2D convolution, correlation, 2D random sequence, 2D spectrum.

Image Transforms: 2D orthogonal and unitary transforms- properties and examples. 2D DFT, histogram, image smoothening, image filtering, Sharpening, thresholding.

Image Segmentation and Analysis: Edge detection, line detection, curve detection, Edge linking and boundary extraction, boundary representation, region representation and segmentation, morphology-dilation, erosion, opening and closing.

Image understanding and recognition: Matching by templates, classifiers models, statistical, matching shapes by contour and texture.

Review of LTI systems: Fourier transform for discrete-time signals and its properties, comparison with continuous-time Fourier transform. Discrete time signals, sequences, representation of signals on orthogonal basis, sampling and reconstruction of signals.

Signal analysis using the Fourier transform, impulse function and complex exponential signal, modulation and frequency translation, duality, Fourier transform of periodic signals,

correlation, energy and power spectral density, Hilbert transform, Fourier transform of finite-duration discrete - time sequences.

Z-transform, Discrete Fourier Transform (DFT), Fast Fourier Transform algorithm and applications. Design of FIR & IIR digital filters, effect of finite register length in FIR filter design. Overview of DSP processors, FPGAs.

Typical applications in Lasers and Accelerators.

Reference:

1. "Digital Image Processing", Rafel C Gonzalez, and Richard E Woods.
2. "Fundamental of Digital image processing", A K Jain.
3. "Fundamentals of Electronic Image Processing", A R Weeks Jr.
4. "Practical Image Processing in C; Wiley professional Computing", Dr. Craig A Lindsey.
5. "Digital image processing: concepts, algorithms, and scientific applications", Jaehne, Bernd.
6. "Digital Imaging: Theory and applications", Burdick Howard E.
7. "Two dimensional signal and Image processing", Lim Jae S, V Oppenheim Allan.
8. "Discrete-Time Signal Processing", A. Oppenheim, R. Schafer and J. Buck.
9. "Signals and Systems", Oppenheim, Willsky and Nawab.
10. "Discrete Time Signal Processing", A.V. Oppenheim and Schafer.
11. "Digital Signal Processing: Principle, Algorithms and Applications", John G. Proakis and D.G. Manolakis.
12. "Theory and Application of Digital Signal Processing", L.R. Rabiner and B. Gold.
13. "Introduction to Digital Signal Processing", J.R. Johnson.
14. "Digital Signal Processing", D. J. DeFatta, J. G. Lucas and W. S. Hodgkiss.

D : Laboratory Experiments (Credit :4)

Experiments relating to lasers, accelerators and general electronics techniques will be offered. A student needs to carry out twelve experiments (4 each from laser, accelerator and electronics related areas) in two phases with a total working time of 72 hours which will carry 4 credits.

03ENGG01-001-L: Lasers and Applications

1. Measurement of spectrum and spectral width of diode laser and their dependence on current.
2. Study of characteristics of a Q- switched Nd:YAG laser.
3. Second harmonic generation: phase matching and maker fringes.
4. Saturated absorption in atomic vapour: Doppler broadening, natural line width, power broadening.

5. Study of light propagation through fiber: coupling efficiency, bending losses, splicing and connecting fiber.
6. Studies on Nitrogen laser pumped dye laser.
7. Parametric study of a XeCl Excimer laser.
8. Output power characteristics of a diffusion-cooled CO2 laser.
9. Determination of severance energy for cutting mild steel with CO2 laser.
10. Determination of laser power coupling efficiency in Nd-YAG/CO2 laser welding of stainless steel.

03ENGG01-002-L: Accelerators Related Areas

1. Electrical resistivity measurement on metallic samples at low temperature.
2. Parametric studies of magnetic materials and operating point of magnets.
3. Outgassing of materials, discharge cleaning and ESD studies.
4. Estimation of radioactivity and shielding attenuation coefficient measurements.
5. Determination of cooling power of a cryocooler.
6. Electron gun: Operation and experimental studies.
7. Proton ion source: Operation and experimental studies.
8. X-ray fluorescence studies using radioactive source.
9. Calibration of cryogenic sensors.

03ENGG01-003-L: Electronics

1. Study of stepper motor, dc motor drive and position feed-back.
2. Study of different transducers and their interfacing.
3. Communication buses and protocols, buses for distributed embedded processing.
4. G.U.I. software familiarization and applications.
5. Digital image processing and their applications.
6. Current and voltage regulated power supplies and change from one another.
7. Study of flash lamp and measurement of flash lamp current and K0 factor.
8. Characterization of RF components.
9. Fast current transformers: Study and measurement of response.

E : Reading Courses (Credit : 8)

Ph. D. scholars will work on two reading courses each of four credit worth. For each reading course, a Ph. D. scholar is expected to do self reading (under the guidance of his/her Ph. D. supervisor) of a review paper or book(s)/monograph(s) of specialized subjects related to the

area of his/her proposed area of research. Alternatively he/she may also work out and comprehend a research paper or a part of research paper relevant to his/her Ph. D. work. The topic and the structure/contents of the two reading courses should be decided by the guide in consultation with the respective doctoral committee and the Ph. D. scholar. The two reading courses should be approved by the respective doctoral committee.

The two reading courses will be evaluated on the basis of the detailed reports that will be prepared by the scholar and presentations, which will be held at the end of first year (in the month of August). The total marks for each reading course is 150 with 100 and 50 for report and presentation respectively.

F : Foundation Courses

for M.Tech (Engineering Physics) only

03ENGG01-001-F. Physics Courses for Engineering Graduates Credit (5)

Quantum Physics: Wave-particle dualism. Wave function, operators, expectation values, Schrodinger equation, Some applications: particle in a box, harmonic oscillator and hydrogen atom.

Atomic and Molecular Physics: Hydrogen spectrum, selection rules. Fine and hyperfine structure. Many electron atoms, energy levels structure, angular momentum coupling like LS & JJ; molecular structure, chemical bonding; electronic, vibration and rotational levels of molecules, Frank-Condon principle, radiative and non-radiative processes in atoms and molecules e.g. fluorescence, phosphorescence, energy transfer, and Raman effect.

Special Theory of Relativity: Galilean transformation, Lorentz transformation, relativistic dynamics - length contraction and time dilation, mass-energy relation.

Solid-state physics: Bonding in solids. Bloch theorem, band structure in periodic systems. Fermi levels, semiconductors, metals and insulators. Normal modes of vibrations and phonons. Specific heat of solids.

Nuclear Physics: Binding energy, nuclear structure and models. Alpha, beta and gamma decay. Fission and fusion processes

Optics: Concepts of wave front amplitude, phase and coherence, Basic ideas of interference, diffraction and polarization. Michelson interferometer.

03ENGG01-002-F. Engineering courses for Physics Post-graduates Credit (5)

Engineering Drawing: Basics, dimensional management and tolerance analysis. Surface texture; standard machine elements, their specifications and usage.

Evolution of product, process of design, parameter determination based on numerical calculations; Material properties and selection; Introduction to material joining & machining processes.

Semiconductor and magnetic devices: Rectifier diode, Zener diode ,Bipolar junction transistor, MOSFET, IGBT, SCR, Triac & GTO: Principle of operation, characteristics, Specifications, Ratings, Protections, Series/Parallel operation, Thermal considerations.
Transformers, Inductors, Saturable reactors: Principle of operation, Parameters, Different types, Specifications, Ratings.

Circuit theory and applications and High voltage Switches: Thyratron, Spark gap: Principle of operation, Characteristics, Specifications, Ratings, Protections
Switching circuit analysis: R-L, R-C, R-L-C circuits.

Power amplifiers: Types, Biasing, Load line, Circuit configuration, preliminary design aspects. Basics of operational amplifiers, linear and nonlinear circuits based on opamps; Principles and types of ADC and DAC, specifications; Digital circuits- combinational and sequential; Logic families; Introduction to microprocessors and PCs, interfacing with PC with serial and parallel modes; Transducers: Temperature, pressure etc;

Electronic instruments: Oscilloscope, logic analyzer, multimeter etc.

RF and Microwave systems: Basic concepts: frequency band designations, units of RF power measurements

Transmission lines: EM waves, transmission modes TEM, TE, TM, co-axial lines, microstriplines, waveguides, VSWR, insertion loss, reflection coefficients

RF cavities: Physics of RF cavities, shunt impedance, quality factor, coupling: modes, HOs, multipactoring, transit time factor; superconducting cavities

Passive devices: Microwave diodes, isolators, circulators, directional couplers, power dividers/combiners, RF Load.

Active devices: RF transistors, FETS, klystrons, magnetrons, tetrodes, triodes, solid- state amplifier.

Measurements: Fundamentals of RF and microwave measurements, S-parameters, measuring RF instruments, VNA, spectrum Analyzers, RF power meter.

Typical RF & Microwave systems for accelerators: Pulsed microwave systems, CW RF systems for SRS and proton accelerators.

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MTech in Fusion Science and Technology

(PROGRAM CODE: ENGG01)

INSTITUTE for PLASMA RESEARCH
BHAT, Gandhinagar

Submitted to
HOMI BHABHA NATIONAL INSTITUTE
Anushaktinagar, Mumbai

Contributors

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Dr S Mukherjee
Dr S Sengupta
Dr SS Khirwadkar
Dr SK Gupta
Dr RP Bhattacharya
Mr AK Chakraborty
Mr AK Bhardwaj
Mr AK Srivastava

IPR Science and Engineering Faculties

Dr M Bandyopadhyay
Dr R Srinivasan
Dr D Raju
Dr R Ganesh
Dr G Ravi
Dr J Ghosh
Dr Vinay Kumar
Dr S Kulkarni
Dr CVS Rao
Dr A Sircar
Dr S Khirwadkar
Dr S Pradhan
Dr PM Raole
Dr P Sharma
Mr H Pujara
Mr Paritosh Chaudhary
Mr Anil Bhardwaj
Mr NP Singh
Mr Manoj Gupta
Mr Ziauddin Khan
Mr PK Atrey

MTech in Fusion Science and Technology (for BTech, BE, AMIE, MSc Physics)

Course CI – IPR, Gandhinagar: Degree to be awarded by HBNI, Mumbai

Starting time – 01 August 2015

Course pattern
1st year – 2 trimester courses, 1 trimester Mini Project
2nd year – Project thesis/Dissertation

IMPORTANT:
After 1st year, people who qualify will be given a job in IPR as per Scientist / Engineer SC – details to be mentioned in the Technical Training Programme (TTP) 2015 advt. IPR employees who have BTech/BE/AMIE/MSc degree can also take this course as per HBNI guidelines for employees.

Only BTech/ BE / AMIE in following disciplines are considered: Mechanical, Electrical/Electronics/Instrumentation. MSc – Physics is also considered.

Trimester 1:
All courses are common to all: 1 class (lecture) – 60 minutes, 3 classes a day; 2 classes a week / faculty per subject; total number of classes/subject ~ 30 (including assignment, presentation, etc.)

Subject	Credits	Marks
Basic Plasma Physics (FC1)	3	100
Experimental Plasma Physics (FC2)	3	100
Tokamaks (FC3)	3	100
Fusion Plasma Diagnostics (FC4)	3	100
Measurement Techniques (FC5)	3	100
Numerical Methods (FC6)	3	100
Mathematical Methods (FC7)	3	100
Vacuum, Cryogenics and Magnets (FC8)	3	100
TOTAL	**24**	**800**

Trimester 2:
All courses in part (A) are common to all: 1 class – 60 minutes, 3 classes a day; 2 classes a week / faculty per subject; total number of classes/subject ~ 30 (including assignment, presentation, etc.). Courses in part (B) are subject/discipline specific.

Part (A): Advanced Subjects

Subject	Credit	Marks
Fusion Neutronics (AS1)	3	100
Plasma Facing Components: First Wall, Divertors, Blankets (AS2)	3	100
Fusion Materials (AS3)	3	100
RF, Current Drive and Neutral Beam Heating (AS4)	3	100
TOTAL	**12**	**400**

Part (B): All courses in part (B) consist of 4 classes a week; 1 class – 60 minutes, 2 classes a week / faculty per subject; total number of classes/subject ~ 60 (including assignment, presentation, etc.)
Subject Credit: 30 hours – 3 Credits
60 hours – 6 Credits

Subject	Hours	Total Credits	Marks	Remarks
Magneto Hydro Dynamics (PH1)	60	21	700	For Physics
Kinetic Theory and Statistical Mechanics (PH2)	60			
Advanced Heat Transfer and Cryogenics (PH3/ME5)	60			
Tokamak Related Code (PH4)	30			
Code Design for Internal and External Pressure Vessel (ME1)	30	21	700	Mechanical Engineering
Finite Element and Volume Methods (ME2)	60			
Mechanics of Solid/Vibration/Remote Handling (ME3)	30			
Advanced Manufacturing Technologies (ME4)	30			
Advanced Heat Transfer and Cryogenics (ME5)	60			
Advanced Data Acquisition System (EE1)	30	21	700	Electrical/Electronics/ Instrumentation Engineering
Advanced Tokamak controls (EE2)	30			
High Voltage, DC& AC/ Power Supplies (EE3)	60			
Signal Conditioning and EMI/EMC Aspects (EE4)	30			
Computer Based System Design (EE5)	30			
Digital Signal Processing and Image Processing (EE6)	30			

Trimester 3: Subject/Discipline specific project work

	Credit	Marks
Mini Project	**9**	**300**

TOTAL CREDITS IN 1ST YEAR: 24 + 12 + 21 + 9 = 66
TOTAL MARKS IN 1ST YEAR - 2200

2nd YEAR: M.Tech Thesis work

	Credit	Marks
1-year project/dissertation	**30**	**1000**

TOTAL CREDITS FOR 2 YEARS: 66 + 30 = 96
TOTAL MARKS for 2 YEARS – 3200

TRIMESTER 1

FC1 - Basic Plasma Physics (30 Lectures)

- **Introduction**

Definition of plasma, description of collective behaviour in contrast to single particle behaviour, derivation of plasma frequency (slab model), Debye length (description of Boltzmann distribution), conditions for collective behaviour (Physical basis for these conditions), binary collisions (derivation of Rutherford scattering), derivation of collision frequency ν_{ei} (large angle collisions, cumulative effect of many small angle collisions, Coulomb logarithm), discussion of collective behaviour revisited with relationship between various conditions (discussion of $k\lambda_D << 1$, plasma parameter).

- **Single Particle Motion**

Lorentz force equation, Nonrelativistic motion of a charged particle in constant electric and magnetic field: motion in constant **E** field, constant **B** field (derivation of cyclotron frequency, Larmor radius), motion in crossed **E** and **B** field, general solution for arbitrary angle between **E** and **B** field (Gantmakher formula), drift in a combined magnetic field and a general force field (non-magnetic), Motion in non-uniform **B** field (guiding centre approximation): Grad B drift ($\nabla \mathbf{B} \perp \mathbf{B}$), curvature drift, $\nabla \mathbf{B} \| \mathbf{B}$ (magnetic mirrors, invariance of μ, concept of adiabatic invariance), Uniform **B** and spatially varying **E** field (Finite Larmor radius effects), Time and space varying **E** field (Ponderomotive force), Time varying magnetic field (adiabatic compression), Time varying **E** field (polarization drift)

- **Fluid Description of Plasma**

Fluid equations, Equation of state, Complete set of two fluid equations, Fluid drifts parallel and perpendicular to **B** (diamagnetic drift), Plasma Equilibrium, Transport and Stability

- **Waves in Plasma**

Notion of phase and group speeds, High frequency electrostatic waves in an unmagnetized plasma (Langmuir waves, Bohm-Gross waves), High frequency electrostatic waves in a magnetized plasma (upper hybrid oscillation), High frequency electromagnetic modes in an unmagnetized and magnetized plasma, Low frequency electrostatic waves in unmagnetized and magnetized plasma: ion-acoustic wave, ion cyclotron wave, lower hybrid oscillation, low frequency electromagnetic modes: Alfven wave, magnetosonic wave.

- **MHD Description**

Derivation of single fluid equations from two fluid equations, complete set of equations of Magneto Hydro Dynamics (MHD), MHD waves, MHD energy.

FC2 - Experimental Plasma Physics (30 Lectures)

- **Fundamental Gas Processes**

Maxwell-Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization, Thermal Ionization, De-ionization, Diffusion, Different Mechanisms of Electron-Ion Recombination, Electron Attachment and Detachment Processes, Ion-Ion Recombination Processes, Formation of Negative Ions, Electronic Properties of Solids, Surface Emission Processes, Thermionic Emission, Field Emission, Photoemission, Particle Interaction with Solids, Interaction of Electrons with Surfaces, Interaction of Ions with Surfaces, Interaction of Neutrals with Surfaces, Sputtering Phenomena.

- **Charged Particles in a Gas in Electric Field of Low and High E/p**

Diffusion and Drift in an Electric Field, Redistribution of Particles through Diffusion and Drift, Ion Mobility, Ambipolar Diffusion, Electron Drift Velocity, Concept of High E/p, Primary Ionization Processes, Electron Avalanche, First Ionization Coefficient.

- **Self-sustaining Discharge**

Over-exponential Carrier Multiplication, Ionization by Positive Ion Collision, Cathode Processes, Processes in the Gas, Secondary Ionization Processes, Second Townsend ionization Coefficient, Paschen's Law, Breakdown Criterion, Limitations of Townsend Mechanism.

- **Glow Discharge**

Structure of Glow Discharge, Current-Voltage Characteristics of Glow Discharges, Physical Interpretation and Theoretical Analysis of Cathode Zone, Negative and Faraday Dark Space, Positive Column and Anode Layer, Striations, Specific Glow Discharge Plasma Sources.

- **Breakdown under Special Conditions**

Breakdown under Alternating Fields, Microwave Controlled Breakdown, Mobility Controlled Breakdown, Inductively Coupled Discharge, Capacitive Coupled Discharge.

- **Arc Discharge**

Glow to Arc Transition, Current-Voltage Characteristics of Arc Discharges, Classification of Arc Discharges, Cathode and Anode Layers, Different Models of Positive Column, Different Configurations of Arc Discharges, Bennet Pinch and Electrode Jet Formation.

- **Plasma Sheath and Diagnostics**

Basic Concepts, Bohm Sheath Criterion, High Voltage Sheath, Generalized Criteria for Sheath Formation, Electrostatic Probe Diagnostics, Single Langmuir Probe, Double Probe and Emissive Probe.

- **Experimental Plasma Devices**

Large Volume Plasma Device, BETA machine, SMARTEX, Helicon Plasma Expt., Q-machine, SYMPLE, Linear Magnetized Plasma Beam Expt., Plasma Wakefield Expt., Plasma Torch.

FC3 - Tokamaks (30 Lectures)

- **Introduction to tokamaks**

Thermonuclear Fusion reactions, Power Balance and Lawson Criteria, Tokamak as Fusion reactor, Tokamak Research, Major constituents of Tokamaks, Indian Tokamaks, Tokamak Confinement, Confinement times, Ohmic Confinement, L-mode and H-mode Confinement, Confinement scaling, Radiation loses.

- **Equilibrium and Transport**

Tokamak Equilibrium, Grad-Shafranov Equation, Safety Factor, q and Plasma Beta, Shafranov Shift and Plasma position control, Classical Transport, Neoclassical Transport.

- **Heating**

Ohmic Heating, Neutral Beam Heating, Wave Heating, Lower Hybrid Heating and Current Drive
Ion Cyclotron Resonance Heating, Electron Cyclotron Resonance Heating.

- **MHD Stability**

Ideal Kink modes, Ideal internal modes, Resistive tearing modes, Mirnov Oscillations, Saw-tooth oscillations, ELMs, Disruption scenarios.

- **Tokamak Devices and Other Fusion Devices**

Operating Regimes, Tokamak Magnetic Systems, Power systems, Plasma Production, Measurements of major operational parameters, Plasma wall interaction, Runaway electrons, Impurities, Operational experience in Aditya and SST-1, Other Fusion Devices.

FC4 - Fusion Plasma Diagnostics (30Lectures)

- **Introduction to Tokomak diagnostics**

  Introduction to all the tokomak diagnostics and related measurements.

- **Electrical diagnostics**

Langmuir probe: Single probe characterisation, explanation and other issues, Probe configurations, Double and Triple probes, Emissive probes.

- **Magnetic diagnostics**

Rogowski, flux and diamagnetic loops, Configuration and other details, plasma position and shape measurements, Introduction to MHD instabilities and Mirnov oscillations.

- **Measurements of plasma density and electron temperature**

Thomson scattering diagnostics: General concepts of Thomson scattering. Principles of Thomson scattering diagnostics. Types of Thomson scattering diagnostics used in tokamaks, Description of a typical diagnostics set up, technical features of the diagnostics set-up. Advantages and limitations of the technique.

Reflectometery: General concepts of Reflectometery. Physics principles of diagnostics. Different types of Reflectometry techniques, description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis. Advantages and limitations of the techniques.

Interferometry: General concepts of Interferometry. Physics principles of diagnostics. Description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis. Advantages and limitations of the techniques.

ECE diagnostics: Concepts of Electron Cyclotron Emission. Physics principles of the diagnostics. Description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis, Advantages and limitations of the techniques.

- **Measurement of impurities**

Introduction to spectroscopy, basics of passive and active spectroscopy and introduction to Visible, VUV and X-ray spectroscopy. Measurements of impurities by Visible spectroscopy and VUV/X-ray spectroscopy Data analysis by using actual spectra.

- **Measurement of ion temperatures**

Charge exchange recombination spectroscopy (CXRS) : Physics principles of CXRS , typical diagnostic set up, technical features of set up and brief on analysis techniques. Estimation of ion temperature using actual data.

X –ray crystal spectroscopy : Physics principles of X-ray crystal spectroscopy diagnostics , typical diagnostic set up, technical features of set up and brief on analysis techniques.

Neutral particle analyser: Concept of charge exchange (CX) neutral flux escaping from the tokamak plasmas, introduction to the different techniques for measurement of CX flux and energy distribution, description of the diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of the techniques, presentation of data analysis and estimation of core-ion temperature, analysis of actual plasma discharge data and estimation of ion-temperature.

- **Measurements of Radiated power**

Bolometers: Concept of Bolometry, requirement of bolometric measurements for tokamak plasmas, introduction to the different Bolometry techniques available for measurement of total radiated power loss from toakamak plasma, description of the different bolometers namely: Metal foil, AXUV and Imaging Video Bolometers, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each Bolomters, presentation of data analysis and estimation of total radiated power loss, analysis of actual plasma discharge data and estimation of total radiated power loss from the plasma.

- **Measurements of operational parameters**

Soft X-ray diagnostics: Introduction to the Soft X-ray diagnostics, physics principles and measurement technique, description of the diagnostics set up, description of the technical features of the diagnostics set up, advantages and limitation of the SXR diagnostic for electron temperature measurements.

Imaging Diagnostics: Requirement of imaging diagnostics for tokamak plasma, concept of different imaging diagnostics namely: Infrared Imaging Diagnostics, Visible Imaging Diagnostics etc., physics principles involved, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each imaging diagnostics, presentation of data analysis and analysis of actual plasma discharge data available for the imaging diagnostics.

Hard X-ray monitors: Concept of runaway electrons production in tokamaks, different measurement techniques available for the runaway detections, requirements of HXR measurements on tokamaks, principles of Hard X-Ray (HXR) generation due to runaways, introduction to HXR monitors for confined and de-confined runaways, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of HXR monitors.

Motional Stark Effect diagnostics and Beam emission spectroscopy: Introduction to beam based diagnostics, description of various beam based techniques for different types of operational parameters (q profile, ne(edge),Te(edge) and neutral beam density). Description of the diagnostics setup and technical features of the diagnostics setup and data analysis techniques.

Dust and Erosion monitors and Tritium monitors : Introduction to the concept of the Dust, erosion in tokomaks. Importance of the measurement of Dust, Erosion and Tritium. Challenges involved in the measurements. Example schemes of the measurement techniques.

- **Measurement of fusion products**

Introduction to fusion product measurements and importance of the measurement and control of fusion product generation. Various techniques available for measuring fusion products.

Confined and Lost alphas: Requirements of lost alpha particle diagnostics on future fusion devices, different diagnostics techniques available for the lost alpha diagnostics, principle of detection techniques, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each techniques and future applicability to fusion devices.

Gamma ray spectroscopy: Requirements of gamma ray spectroscopy on future fusion devices, principle of detection technique, diagnostics set up, description of the technical features of the diagnostics set-up.

Neutron flux and neutron profiles: Introduction to neutron flux and neutron profile measurements, measurement principles, measurement schemes and typical diagnostics set ups and discussion on challenges involved.

- **Overview and summary of ITER Diagnostics**

Discussion on the challenges involved in diagnosing fusion grade plasmas, over view of ITER diagnostics.

FC5 - Measurement Techniques (30Lectures)

- **Measurement System**

Introduction, Measurement system architecture, Computer based measurement systems, Errors in measurements, Measurement Units, Standard used in measurements, Types of Measurement Systems: Differential Measurement System, Referenced and Non-Referenced Single-Ended Measurement Systems.

- **Specifications parameters of Measurement Systems**

Sensitivity, Resolution, Nonlinearity, Saturation, Dynamic Range, Offset, Drift, Electromagnetic Compatibility, Reliability.

- **Electrical Measurements and Disturbances in Measuring System**

Measurement of Electrical Parameters: Voltage, Current, Resistance, Capacitance, Impedance, Frequency, Phase shift, Power.
Disturbances in Measuring System, Leakage Current, Parasitic Capacitive Coupling, Parasitic Inductive Coupling, Disturbances caused by: Electromagnetic Field, Feeding Cables, Improper Grounding.

- **Sensors/Transducers and Their Applications to Physical Measurements**

Sensors and Transducers – Performance Parameters, Selection of Sensors/Transducers, Temperature measurements, Pressure measurements, Flow measurements, Measurement of Linear/Angular acceleration, Velocity and Displacement, Measurement of Force and Torque, Measurement of radiant energy/light with Photosensitive Devices, Physical parameters sensing with Plasma diagnostics.

- **Analog Electronics**

  Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Pre-amplifiers, Pulse Amplifier, Signal isolation, Filters, Attenuators.

- **Introduction to Data Acquisition**

  Data Acquisition (DAQ) overview, Major components in development of Data Acquisition System (DAS), PC based data acquisition system, Data plotting and analysis. DAQ Software: Overview of Graphical/command based programming for the acquisition, Data processing and presentation of data: MATLAB, LabVIEW Application development environment, Concept and importance of Data Storage System, Microprocessors/Microcontrollers based measurement system.

- **Noise in Measurement System**

  Introduction to EMI/EMC, Methods of Noise Coupling, Methods of eliminating interference, Grounding, Cabling, Shielding, Intrinsic Noise source, Digital Circuit Noise, Sensor – DAS interface, Grounded Signal Sources, Floating Signal Sources, Grounding Issues: Various Grounding schemes for measurement.

FC6 - Numerical Methods (30 Lectures)

- **Modeling, computation and error analysis:**

Mathematical modeling, numerical methods and problem solving, Introduction to MATLAB programming, Error analysis methods, Case study.

- **Solutions of Linear Algebraic equations:**

Matrix algebra, Eigen value problems, Gauss elimination and LU factorization, Matrix inverse and conditions, Singular value decomposition, Iterative methods, Case study.

- **Numerical Differentiation and Integration**

Numerical differentiation, Numerical Integration, Case study.

- **Roots, optimization and nonlinear sets of Equations**

Bracketing methods, Open methods Optimization - Case study.

- **Application of Ordinary Differential equations**

Initial Value problems, Adaptive methods and stiff systems, Boundary value problems, Case study.

•**Application of Partial Differential equations**
Methods to solve PDEs, Case study.

•**Application of Curve fitting methods**
Linear Regression analysis, Fast Fourier Transform, Power spectral analysis, Bispectral analysis, Polynomial interpolation and extrapolation, Cubic spline interpolation, Nonlinear Least **Square** methods Case study.

FC7 - Mathematical Methods (30 Lectures)

- Vector analysis: vector identities, Use of Levi Civita and Kronecker delta functions for the derivation of vector identities, Notion of gradient, divergence and curl. Gauss, Green's And Stokes Theorems. Laplacian Operator in Different Coordinate Systems.
- Matrix Algebra: Classification of matrices; Elementary operations; Determinant, rank and inverse of a matrix; Solution of linear equations; Eigenvalues and eigenvectors; Similarity transformation and diagonalisation of a matrix.
- Complex analysis: Complex variables, function of a complex variable, continuity and differentiability, Cauchy-Riemann conditions, Analytic functions, Taylor and Laurent Series, singularities(poles and essential singularity) , Residues, Cauchy Residue theorem, Contour integration, Conformal Mapping and its application to the solution of Laplace equation.
- Differential equations: First and second order differential equations with constant and variable coefficients; Linear differential equations: Approximate method for solving ODE's (Series method of solution; Legendre and Bessel's differential equations and their solutions); Orthogonal polynomials and Special functions - Bessel functions, Gamma functions and Beta functions.
- Partial differential equations: First order partial differential equations, complete integral and general solution, methods of solution of a first order partial differential equation, second order partial differential equations, Laplace's equation, wave equation, diffusion equations. Method of charateristics, Separation of variables.
- Integral Transforms: Fourier, Laplace Transforms and the inverse transforms, connection to physical problems. Applications for obtaining solution of ordinary/partial differential equations.

FC8 - Vacuum, Cryogenics and Magnets (30 Lectures)

- **Fundamental of vacuum**
- The vacuum and its applications, Gas laws, Pressure and mean free path, Flow regimes, Conductance, Throughput and pumping speed, Ultimate pressure and pumpdown time, Outgassing and permeation. Exposure to pumps and gauges.

- **Design of a vacuum system**

Selection of materials, Pumps, Gauges, Valves, Rules for operating vacuum system. Permanent seals, Demountable seals, Vacuum components, Cleaning techniques.

- **Fundamental of cryogenics**

Cryogens properties, Heat loads in Cryogenic systems, Basic Thermodynamics and Cryogenic Processes, Material properties at low temperatures.

- **Design of cryogenics system**

Design aspects of Cryostat, Dewars and Cryolines. Fundamentals of Thermo-hydraulics and distribution network, Economics of Cryogens, Recovery of Helium and Thermal insulation.
Basics of Cryogenic valves, sizing, leaks and heat load estimation, Instrumentation at cryogenic temperatures. Safety aspects in handling cryogens.

- **Applications of Cryogenics Engineering in Fusion machines**

SST-1 Magnets, Cryo pumps, pellet injectors.

- **Fundamentals of Magnet system**

Resistive and Superconducting Magnet Systems,LTS and HTS based conductors, Flux Jumps, Filament twisting, AC losses, Cryo-stability, Monolithic & Cable-in-conduit-conductor (CICC) concepts.

- **Design and fabrication of magnet system**

Magnetic field calculations (analytical & computational tools), Magnetic force calculations, Structural design for magnets, Conductor design & Magnet winding pack design. Magnet winding pack fabrication & engineering issues, Insulation systems in magnets manufacturing, Magnets winding pack consolidation, QA/QC in magnets manufacturing.

- **Magnet operation**

Sensors and Instrumentations in Superconducting Magnets, Superconducting Magnet Quench and Protection aspects, Superconducting Magnet Tests & auxiliary test facilities, SST-1 Magnet System.

TRIMESTER 2 – PART A

(Part A is common to all)

AS1 - Fusion Neutronics (30 Lectures)

- **Neutronics Basics**

Fusion Neutronics Principles, neutron production & detection techniques, nuclear interaction processes, nuclear reactions, cross section, and thermalisation, scattering & absorption processes.

- **Particle transport phenomena in matter**

Neutron & photon transport, mathematical transport problem-Boltzmann transport equation, -probabilistic particle transport simulation - MCNP Monte Carlo code, tools: MCNP, Attila, Validation of computational tools and data.

- **Basics of fusion neutronics & blanket neutronics**

Neutronics design optimization, nuclear design of reactor components (blankets, divertor, first wall, heating systems, diagnostics etc.), Nuclear design analysis – optimization, source modelling, nuclearresponsecalculations,neutronandgammafluxes,nuclearheating,tritiumproductionrates,gasproductionanddpa.Amountoftritiumrequiredforafusionreactor,TritiumBreedingRatio, activation products & decay heat assessments, radiation damage & transmutation

- **Principles of Neutron & Fusion product diagnostics**

Processes in the plasma leading to non-maxwellian fuel ion distribution, experimental neutron, gamma-ray & alpha particle detection techniques, computational techniques to extract relevant information about the velocity functions of fusing ions out of measured neutron signals. Concepts of integrated modelling to assess and analyze the neutron emission features.

- **Radiation and licensing**

Radiation units, Radiation protection standards, Biological & genetic effects of radiations, Radiation shielding principles, composite shielding materials. Concepts of licensing & decommissioning of nuclear installations.

- **Radiation damage & transmutation**

Activation & after-heat, tools for calculations EASY-2010, concept of direct one step (D1S) method and Rigorous 2 step (RS2) process (MCNP-FISPACT) in estimating the dose rate on components of a fusion reactor after reactor shut down. Generation & management of radioactivewastefromatypicalfusionreactor.Quantification&Categorizationofradioactivewaste

- **Nuclear Safety aspects**

Basic concepts in safety, reliability and RAMI analysis, loss of coolant accidents, conceptual design of safety systems, risk and reliability analysis of systems, operational safety procedures, regulatory process, introduction to safety related instrumentation, remote handling of irradiated components

- **Fusion Neutronic Activities Worldwide**

Overview &Latest neutron facilities being built all over the world and recent trends. 4th generation nuclear reactors (high temp & compact reactors), Accelerator Driven Systems (ADS), IFMIF & CTF, Spallation Neutron Source (SNS), Fus-Fis hybrid systems (breeders), Transmutation of radiation wastes

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AS2 - Plasma Facing Components: First Wall, Divertors, Blankets (30 Lectures)

- **First Wall**
  - **Firstwall Concepts :** Basic Design of Firstwall.
  - **Loads on Firswtall: I**nertial loads, Kinetic Pressure Loads, Electromagnetic loads, Thermal & Particle loads, Neutronic Loads.
  - **Challenges for Firstwall:** Material Challenges, Fabrication Challenges, Operational Challenges.

- **Divertors**
  - **Divertor Concepts:** Basic Design of Diveror, Toroidal & Poloidal Divertor, Single-Null Divertor, Double-Null Divertor.
  - **Loads on Divertor:** Inertial loads, Kinetic Pressure Loads, Electromagnetic loads, Thermal & Particle loads, Neutronic Loads.
  - **Challenges for Divertor:** Material Challenges, Fabrication Challenges, Operational Challenges.
  - **Divertor Testing:** Destructive Testing, Non-Destructive Testing, Metrology.
  - **Novel Divertor Concepts:** Helium Cooled Divertor, Liquid Divertor.

- **Blankets**
  - **Blanket Concept**: Requirement and essential features of Shield Blanket (SB) and Breeding Blanket (BB) in a fusion reactor.
  - **Shield Blanket:** Types of SB and SB material, SB Design Concept, Thermal-hydraulic and thermo-mechanical analysis of SB.
  - **Breeding Blanket:** Types of BB and blanket materials (solid and liquid), concept of Indian BB, Indian Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) for ITER, concept of LLCB-TBM design, thermal-hydraulic and thermo-mechanical analysis of SB, LOCA and LOFA analysis of BB, Diagnostics of BB.
  - **Solid Ceramic Breeder (CB) Technology:** Development of Li CB, characterization of Li CB material, characterization of Li CB pebble bed, thermal and thermo-mechanical analysis of pebble bed.
  - **Liquid Metal (PbLi) Technology: C**omposition and developmental process of PbLi eutectic alloy, Study of basic (PbLi) loop and loop components, PbLi diagnostics. Liquid

metal MHD studies – basic analytical formulation (Velocity profile and Pressure drop studies), liquid metal MHD code development (Electric potential Method and Magnetic induction method), code benchmarking, Liquid Metal MHD experiments (Experimental set up, experimental results), liquid metal (Pb-Li) Corrosion studies (Corrosion experiments, experimental results, numerical formulation).

- **Fusion Fuel Cycle:** Requirement and essential features of fusion cycle of a fusion reactor, inner & outer fuel cycle of a fusion reactor, tritium handling technologies, tritium storage & delivery system, tritium extraction system, Tokamak exhaust processing system, tritium diagnostics.
- **Blanket Safety:** Gaseous and liquid releases during normal operation and maintenance, accidental conditions – Design Basis Accidents (DBA), Beyond Design Based Accidents (BDBA), Loss of Coolant Accidents (LOCA), Loss of Flow Accidents (LOFA), complete loss of active cooling.

AS3 - Fusion Materials (30 Lectures)

- **Fundamentals of Material Science**

  - Crystalline nature of matter - Structure and bonding of atoms, atomic arrangements in materials, Structural phase formation and transition, Types of materials (Metals, Alloys, ceramics, composites, glasses, polymers, Superconductors).
  - Defects in solids – Imperfections, Frenkel pairs, Dislocation theory, Grain-boundary, Stress Fields and Strain Energy
  - Metallurgical Aspects of materials – Solid solutions, solubility, Precipitation, Diffusion in solids (Diffusion Laws), ordering in alloys, Phase diagrams, strengthening and hardening Mechanisms, Annealing and heat treatment.
  - Physical Properties of materials – Electrical, Thermal, Magnetic, Dielectric, optical and other properties of materials
  - Mechanical Behaviour of materials – Elastic and Plastic deformation, metallic Creep and fatigue, Strengthening and toughening of steels and non-ferrous alloys, fracture and DBTT , toughness
  - Introduction & Survey of Computational Tools, Multi-scale Models

- **Fusion Materials Requirements & Issues**

  - High heat flux handling – HHF source types, parameters and effects.
  - Erosion & Corrosion – Sputtering, erosion due to heat and particle bombardment, erosion and corrosion due to liquid metals, Hydrogen embrittlement, Oxidation, Pitting and crevice corrosion

- **Material Development and Joining Technologies**

- Manufacturing Methods & Processes – Steels and alloys melting, Powder metallurgy route, Ceramics preparation methods, Composites developments, Superconducting materials manufacturing.
- Structural Materials – Austenite and Ferritic Martensitic (FM) steels, ODS alloys, Vanadium and Titanium alloys, Carbon and SiCf/SiC composites
- Functional Materials – Plasma facing Materials (Tungsten, graded and other materials), Tritium Breeding & Blanket materials, special ceramics, Superconducting materials, Heat sink Materials, shielding Materials, Diagnostics and window materials, coatings
- Joining Technologies – Methods and Issues (Welding, Brazing, Diffusion Bonding, Hiping)

- **Material Characterization & Qualification**

- Structural Characterization – Crystal and Microstructural Analysis, defect structure, Phase Transition (XRD, SEM, TEM, Neutron Diffraction, PAS)
- Compositional Characterization & Surface Techniques (EPMA, EDX, ICP-MS, XPS and AES, SIMS), Impurity limits
- Particle beam Techniques (ERDA, RBS, NRA, Synchrotron Source)
- Mechanical Property Testing- Hardness, Fatigue, Fracture, Tensile, Creep
- Thermal Property Testing – High Heat Flux test, Thermal conductivity, Thermal Expansion coefficient, Electrical Property Testing & NDT, codes and standards – Resistivity (AC &DC), Radiography, Ultrasonic techniques

AS4 - RF, Current Drive and Neutral Beam Heating (30Lectures)

- **Heating and current drive physics by neutral beam**

Basic process during beam-plasma interaction, Beam injection geometry and its implication, Energy transfer mechanism from energetic neutral beam particle to plasma, Energetic particles orbits in asymmetric field structure, Physics of current drive by NBI, Role of fast ions in Neutral Beam Current Drive efficiency.

- **Neutral beam injector system design and engineering**

Basic NBI configuration, Optimization procedure of beamline configuration, Pressure profile optimization, Beam transmission optimization.I on source design and engineering, Different Plasma production mechanism, Positive ion and negative ion production, Ion extractor and accelerator system, Beamline component design and engineering, Neutralizer, Residual Ion Dump (RID), Calorimeter or V – target, Vacuum system design and engineering, Vacuum vessel, NBI – tokamak interface duct, Cryopumps and cryogenic system, Auxiliary pumping system, Diagnostic system design and engineering, Ion source plasma diagnostics, Electrical Probe based, Spectroscopy based, Negative ion diagnostic, Laser photo-detachment, Cavity ring down method, Hairpin resonator based, Ion-acoustic wave based, Beam profile diagnostic, Doppler shift spectroscopy, Thermal imaging diagnostic, Calorimetric diagnostic, Power supply system design and engineering, RF Power supply, HV power supply for ion extraction and acceleration.

- **Introduction to RF heating**

Introduction to Fusion Reactor: Why RF and Microwave Power is required for Fusion? Interaction of electromagnetic waves with plasma.

- **Waves**

Theory of waves in unmagnetized plasma, EM waves, Longitudinal waves, Transverse wave, Ion acoustic waves. Theory of waves in magnetized plasma, EM waves, X-mode, O-mode, Hybrid waves. Classification of RF regimes. RF Requirements of Fusion Reactor, Different heating, pre-ionization and current drive mechanisms. Dispersion relations. Wave propagation in toroidal plasma geometry. Power absorption, Landau damping, Current drive mechanisms in different regime.

- **RF devices and Design tools**

Introduction to general type Waveguide, RF amplifier and Oscillators, Antennas, Engineering issues, RF design software.

- **ICRH**

Introduction to RF applications in ICRH, its design and issues. Introduction to RF transmitter, Power transmission, Antenna design, Auxiliary systems for ICRH. Diagnostic system, Impedance matching unit, Control system. Important results on different tokamaks about ICRH system. Introduction to Aditya and SST-1 ICRH Systems

- **ECRH**

Introduction to RF application in ECRH its design and issues. Introduction to Gyrotron source. Power transmission, Antenna design, Auxiliary systems for ECRH. Diagnostic system. Control system. Important results on different tokamaks about ECRH system. Introduction to Aditya and SST-1 ECRH Systems.

- **LHCD**

Introduction to LHCD system its design and issues. Introduction to Klystron source, Power transmission, Antenna design, Auxiliary systems for LHCD. Impedance matching unit, Diagnostic system, Control system. Important results on different tokamaks about LHCD system. Introduction to Aditya and SST-1 LHCD System.

- **Other types of wave heating**

Alfven wave heating, Bernstein wave heating, Design and its issues, Introduction to its sources, Power transmission, Antenna design, Impedance matching unit, Diagnostic system, Control system. Important results on different machines.

TRIMESTER II – PART B

Part –B contains the details of the core subjects.

PHYSICS

PH1 - Magnetohydrodynamics (60 Lectures)

- Physical description of electrically conducting fluids
- Derivation of basic MHD equations: Continuity, Equation of motion, Energy flow, Ohm's law, Validity of MHD equations
- The low frequency dynamics of the electromagnetic field
- Some properties of MHD: Ideal MHD equations, The Frozen Flux theorem, The effect of resistivity, Similarity scaling, The Wöltjer invariants and helicity
- Equilibrium: General considerations, The Virial Theorem, Examples of simple equilibria: -pinch, Z-pinch, screw pinch, Poloidal , paramagnetic and diamagnetic states, Force-free fields, Toroidal equilibrium: the Grad-Shafranov equation, nonlinearity, Definition of q, beta, plasm ashape, etc.
- Comparison of fusion confinement systems: Spheromak, FRC, RFP, Spherical Tokamak
- Tokamak Equilibrium: In large aspect ratio limit with arbitrary choice of profile, Solovev equilibrium with finite aspect ratio and linear profile in poloidal flux, Solution with arbitrary aspect ratio and arbitrary choice of profiles (numerical)

PH2 - Kinetic theory and Statistical mechanics (60 Lectures)

- Gas dynamic way of describing an uncharged fluid – heuristic
- Recollect derivation of basic MHD equations – one fluid only (Continuity, Eqn of motion, Energy equation [thermodynamic closure], Electron equation of motion [Ohm's Law])
- Introduce ideas of Phase Space (x,v) and distribution functions f(x,v,t)
- Using heuristic arguments in single particle phase space (x,v) to obtain "fluid equations" in phase space – namely – the Vlasov-Poisson Equations
- Introduce conservation of Energy and other physical quantities as constraints.
- Using constrained variation technique demonstrate how entropy extremization leads to Maxwell-Boltzmann distribution f_mb(x,v) and importance of Maxwell-Boltzmann distribution
- Langmuir Oscillations and Waves – Vlasov-Poisson dispersion
- Linear Landau Damping – why is this not seen in fluid equations?
- Two stream instability and Phase Space structure formation
- Many stream interpretation of an equilibrium distribution f_mb(x,v)

- Stability – Newcomb-Gardner Theorems and Penrose Stability Criteria
- Nonlinear Landau damping and Theory of BGK modes – revisit Two stream instability.
- Stability of BGK modes.
- Particle correlations and need for two-body and higher order distributions
- Equations governing two body distrution f_2(x,v,t) and its relationship to f(x,v,t) the one-body or Vlasov distribution studied earlier – Introduction of pair correlations
- Construction of a N-body distribution function f_N and BBGKY Hierarchy issues.
- Klimontovich-Dupree (KD) procedure – Obtaining a "statistical N-body" distrituion from KD equation.
- Green-Kubo formalism – Transport and Correlations
- Examples of GK formalism and obtained transport
- Very cursory introduction to Onsager relationships

PH3 - Advanced Heat Transfer and Cryogencis (60 Lectures)

(PLEASE SEE ME5 – these are common courses for Physics and Mechanical disciplines)

PH4 - Tokamak related Code (30 Lectures)

- **Plasma core modelling:**

— Plasma equilibrium IPREQ

— Plasma transport TSC

— Plasma stability ERATO, PEST2

— ICRH heating TORIC

— NBI heating NUBEAMS

— Plasma start up model

— Reactor system code

— Eddy current analysis

— TF modelling EFFI

— Vertical instability analysis

- **Edge-SOL studies**

— 2D blob transport

— Divertor study SOLPS (B2+ERINE)

— 3D plasma study ERINE-3D

- **First principle simulations**
  - Low frequency (w/wc <<1) transport – what is Gyrokinetic method?
  - What are the transport processes neglected by gyrokinetic formalism?
  - What are global and local simulations – examples (flux tube modes and global models)?
  - Under what conditions do results from these two simulations are expected to match?
  - Gyrokinetic equations derived from Vlasov-Poisson equations using Bessel function procedure
  - How does Gyrokinetic formation capture the physics of Finite Larmor Radius to all orders at low frequencies?
  - Numerical Advantages of Gyrokinetic formalism – examples
  - Simulating very large scale systems (100s of larmor radii) using very large parallel computers – Issues and Advantages
  - Modelling energetic particle transport using Gyrokinetic formalism

MECHANICAL

ME1- Code Design for internal and external pressure vessel (30 Lectures)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and tori spherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div – II equations for cylindrical / Spherical shell and conical, ellipsoidal and tori spherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3.
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive

Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1and Div.2.

- Difference between metallic pressure vessel and FRP pressure vessels.
- Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Failure modes of pressure vessels, Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and piping's.

ME2 - Finite element and volume methods (60 Lectures)

Finite Elements methods (30 Lectures):

- Introduction to FEM: Weighted residual method, Galerkin's methods, Weak form formulation, piecewise approximations. Basis of Finite Element Method, Variation principles, energy principles in structural mechanics, Element libraries
- Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements
- Bar element: Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss.
- Beam element: Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- 2D plane elements – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- 2D isoparametric formulation – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress.
- Introduction and Application to 3D elements: Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Shell element: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions.
- Introduction to Nonlinear problems: Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method.

- Finite element applications for design: Finite element modelling and discretization criterion,h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

Finite Volume Methods (30 Lectures):

Basics of Fluid Flow, Heat Transfer and Numerical Analysis

- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity',momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme

Laminar Boundary Layer and Forced Convective Heat

- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Convective heat transfer for internal and external flows.
- Low and high Prandtl number limits and different thermal boundary conditions.

Turbulent Flow and Heat Transfer

- Reynolds decomposition for turbulence.
- Prandtl's mixing length theory, Mixing length models.
- Structure of turbulent boundary layer over flat plate and through circular cylinder.
- Calculation of friction factor and drag coefficient.
- Analytical and semi-analytical correlations for calculating heat transfer coefficients.
- Reynolds analogy & Low Reynolds number models.
- Turbulence Modelling.
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model.
- Reynolds stress models: algebraic and differential models.

Natural Convection

- Basic Equations of natural convection.
- Derivation of Dimensionless groups from basic equations.
- Analytical approximations.
- Numerical solution of approximate equations.

Numerical Solution of Complete Fluid Flow and Energy Equation

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation.
- Primitive-Variable (P-V-T) formulation.
- Pressure velocity coupling for incompressible flow
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE, SIP and SIMPLEN family of Methods.
- Simple grid generation techniques for structured grid.
- Elliptic, parabolic and hyperbolic equation method.
- Domain decompositions in CFD and heat transfer.

ME3 - Mechanics of solid/vibration/ remote handling (30 Lectures)

Mechanics of solids

- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of stress

- Description / Notations of Forces & Stress.
- Component of stress.
- Reciprocity of shear stress in 3D.
- Stresses Transformation using direction cosines.
- Stress Traction Vectors or Traction Vectors.
- Stress component on an arbitrary plane.
- Principal stresses & Mohr’s Diagram for 3D state of stress.
- Stress Invariants.
- Hydrostatic and Deviator components of stress.
- Principle planes and their orthogonally.
- Octahedral plane, Octahedral stresses.
- State of pure shear.

Analysis of strain

- Description / Notation of Strain in 3D.
- Components of strain.
- Strain Transformation using direction cosines.
- Principle Strains, Strain Invariants.
- Strain Deviator Tensor.

Principles and fundamental Equations of Elasticity

- Strain and displacement relations (Cauchy's equations).
- Compatibility equations (Saint-Venant's Equations).
- Generalized Hook's Law.
- Anisotropy and Isotropy of elastic behaviour.
- Stress and strain relationship.
- Equations of equilibrium (Navier's Equations, Lame's equations).
- Strain Energy.
- Uniqueness theorem.
- Bounds on elastic constants.
- Superposition Principles.
- Saint-Venant's Principle.
- General Solution Procedures for an elasticity problem.

Vibrations

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations underdamped, overdamped and critically damped systems; Response to harmonic loading -complementary solution and particular solution; Response to periodic loadings using Fourier Series
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems;Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration).

Remote handling

- Automation and introduction to remote handling.
- Industrial manipulators.
- Kinematics of manipulators specifying position and orientation of rigid bodies, Euler angles, homogeneous coordinate transformations, D-H representations of kinematic linkage, velocity analysis of manipulators.

ME4 - Advanced Manufacturing Technology (30 Lectures)

ADVANCE MANUFACTURING PROCESSES

- INTRODUCTION: Unconventional Machining Process, Need – clarification – Brief overview of all techniques.
- MECHANICAL ENERGY BASED PROCESSES: Abrasive Water Jet Machining, Water Jet Machining, Ultrasonic Machining (AJM / WJM/ USM). Working principles – equipments used – process parameters – MRR – Variation in techniques used – Applications.
- ELECTRICAL ENERGY BASED PROCESSES: Electro Discharge Machining, Working principles – Equipments – Process parameters – MRR – electrodes/ tools / power circuits – tool wear – Dielectric- flushing- Wire cut EDM – Applications.
- CHEMICAL AND ELECTRO-CHEMICAL ENERGY BASED PROCESSES: Chemical Machining, Electro- Chemical Machining – Etchants- maskant-Techniques of applying maskants – Process parameters – MRR –Applications. Principles of ECM-MRR-Electrical circuit – process parameters – ECG and ECH applications.
- THERMAL ENERGY BASED PROCESSES: Laser Beam Machining, Plasma Arc Machining and Electron Beam Machining. Principles – equipments – types – beam control techniques applications.

ADVANCED MATERIALS JOINING AND TESTING

- INTRODUCTION: Classification – heat sources – metallurgical effect of weld – residual stresses: formation and relieving – capillary and welding action – temperature range – filler material and fluxes – types of joints and welding positions – weldability: design, process and metallurgical consideration – testing and improvement.
- JOINING TECHNIQUES: Bolting – riveting – soldering – blazing – adhesive bonding – diffusion bonding – mechanical joining. Fusion welding: Oxyacetylene welding – SMAW – GTAW – GMAW – FCAW – SAW – ESW – High energy beam welding: EBW, LBW, PAW – friction stir welding. Output parameter variation – advantages and disadvantages – applications.
- RESPONSES OF MATERIALS TO WELDING: Microstructural changes – distortion – defects: undercuts –overlaps – grain growth – blowholes – inclusions – segregation – lamellar tearing – porosity. Remedies: Edge preparation – alignment – control of heat input – preheating – peening – heat treatment – jigs and fixtures – number of passes.
- DESTRUCTIVE AND NON-DESTRUCTIVE TESTS FOR WELDS: Introduction – need – principles – applications –destructive tests: tensile, bend, impact, hardness, fatigue, cracking,

etching. Non-destructive tests: Visual, dye penetrants, magnetic particle, acoustics, pressure, radiographic, ultrasonic, eddy current.

ME5 - Advanced Heat Transfer and Cryogenics (60 Lectures)

Computational Fluid Dynamics

- Basics of fluid flow and heat transfer, Mathematical description of fluid flow, conservation equations for mass and momentum, Classification of partial differential equations, discretization techniques using finite difference and Finite volume methods, Taylor's series and control volume formulations, stability, consistency and Convergence of numerical schemes, application of numerical methods to model equations.
- Natural convention and Forced convection heat transfer and calculation heat transfer coefficient for different geometrical configurations and analytical approximations relations
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and adiabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio.

Heat Transfer

Conduction:

- Derivation of energy equation for conduction in three dimensions – Initial and boundary conditions. Solution of simple problems in steady state conduction with analytical solutions – Concept of electrical analogy – fin heat transfer and concept of fin efficiency and fin effectiveness.
- Concept of Biot number – Lumped capacitance formulation – simple problems – unsteady conduction from a semi-infinite solid- solution by similarity transformation method. Solutionof the general 1D unsteady problem by separation of variables and charts- example problems.
- Laplace equation – solution by variable separable method – concept of superposition and homogeneous boundary conditions. Phase change problems – The Stefan and Neumannproblems – analytical solutions.

Convection:

- Natural Convection heat transfer: Governing equations for natural convection, Bossiness approximation, Dimensional Analysis, Similarity solutions for Laminar flow past a vertical plate with constant wall temperature and heat flux conditions, Integral method for natural convection flow past vertical plate, effects of inclination, Natural convection in enclosures, mixed convection heat transfer past vertical plate and in enclosures.
- Laminar External flow and heat transfer:
  Similarity solutions for flat plate (Blasius solution), flows with pressure gradient(Falkner-Skan and Eckert solutions), and flow with transpiration,

Integral method solutions for flow over an isothermal flat plate, flat plate with constant heat flux and with varying surface temperature (Duhamel's method), flows with pressure gradient (von Karman-Pohlhausen method).

- Laminar internal flow and heat transfer:

  Exact solutions to N-S equations for flow through channels and circular pipe, Fully developed forced convection in pipes with different wall boundary conditions, Forced convection in the thermal entrance region of ducts and channels (Graetz solution), heat transfer in the combined entrance region,

  Integral method for internal flows with different wall boundary conditions.

Radiation:

- Fundamental of thermal radiation and electromagnetic wave theory
- View factors.
- Radiative exchange between grey and diffuse surfaces.
- Radiation between non-ideal surfaces.
- Surface radiative exchange in the presence of conduction and convection.
- The equations of radiative transfer in participating media.
- Radiative properties of molecular gases.
- Introduction to monte Carlo method for thermal radiation.
- Governing Equations: Continuity, Momentum and Energy Equations and their derivations indifferent coordinate systems, Boundary layer Approximations to momentum and energy.

Cryogenics

- **Basic Principles of Cryogenics:**

Thermodynamics, Heat Transfer, Heat Leak, Pressure drop, Cool down, Applications of cryogenics, Properties of cryogenic fluids, Properties of materials (Structural & thermal) at cryogenic temperature, Material selection criteria

Gas-Liquefaction and Refrigeration Systems:
Refrigeration and Liquefaction, Recuperative cycles, Liquefaction of gases, Inversion temperature, Expansion processes, Refrigerator efficiency, Refrigeration and Liquefaction Methods, Regenerative cycles, Ultra low temperature refrigerators, Cryo-coolers.

Cryogenic Insulations:
Types of insulations, Vacuum Insulation, Evacuated Porous Insulation, Gas-filled Powders and fibrous materials, Solid foams, Multilayer Insulations, Liquid and vapor shields, Composite insulations, Placement of insulation systems, Comparison of insulations

Instrumentation in Cryogenics:
Measurement: Strain, Displacement and position, Pressure, Temperature, Flow, Liquid level, Density

Cryogenic Equipment and Cryogenic System Analysis:
Introduction, Compressors, Pumps, Expansion Engines, Valves, Heat Exchangers, Storage, Transfer of liquefied gas

Safety with Cryogenic Systems:
Physiological Hazards, Suitability of materials and construction techniques, Explosions and Flammability, Excessive pressure gas, Special considerations for Hydrogen and Oxygen, General Safety Principles, Safety Checklist

Electrical/Electronics/Instrumentation

EE1 - Advanced Data Acquisition System (30 Lectures)

- **Theory of Quantization**
  Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, antialiasing filters.

- **Advanced Data Acquisition Systems**

  Modular Data Acquisition Systems in Nuclear Instrumentation: CAMAC, VME, PXI, PXIe. DAQ system architecture and major components. Data Archival and Retrieval. DAQ Data server architecture and interface, Data plotting and analysis tools

- **Data Acquisition Interface**

  Sensor – DAQ interface: Grounded Signal Sources, Floating Signal Sources, Grounding Issues: Various Grounding schemes for accurate measurements, Types of Measurement Systems: Differential Measurement System, Referenced and Non-Referenced Single-Ended Measurement Systems, Graphical/command based programming for the acquisition, processing, and presentation of data: MATLAB, LabVIEW Application development environment.

- **Analog Input/output**
  Analog Input Circuitry, Anti-aliasing Filters, sampling and DAQ device architecture, Analog Output Architecture, Analog Output Circuitry, Update rate and output interface.

- **DAQ Clock and Trigger**
  Theory and concepts of analog and digital triggering, Continuous and event-based acquisition, Clock and trigger input and output to DAQ device for timing and synchronization, Counter I/O: Edge Counting, Pulse Generation, Pulse Measurement, Frequency Measurements.

- **Synchronization**
  Single Device Synchronization: Simultaneous sampling, Multiple Device Synchronization: Clock and trigger synchronization, Introduction to Timing system.

- **SST-1 Data Acquisition System**

  Architecture of SST-1 Data Acquisition System: overview and major components, System requirements, Various DAQ interfaces: CAMAC, PXI, PXIe, digitization requirements, Signal-conditioning system: Channel requirements, various stages in signal conditioning system, CAN bus interface, DAQ Software: LabVIEW based GUI for remote operation, Networking requirements and TCP/IP based communication with subsystems, distributed system, DAQ NAS server, Central Data storage server, server management, data plotting utilities.

EE2 - Advanced Tokamak Controls (30 Lectures)

- **Fundamentals of Control System**

  Systems and their representation: Terminology and basic structure of control system, Open loop and Closed loop systems, servomechanism, regulatory system, analogous systems, electrical analogy of physical systems, Physical Systems and their models, transfer function, Block diagram representation of physical systems, Block diagram algebra, Signal Flow graph. Systems in state space: Concept of states and state model, State equation from transfer function, modelling of dynamical systems, State space representation of multivariable systems, Building blocks of state space models. Advanced control system: Cascade control, ratio control, feed forward control. Over-ride, split range and selective control. Multivariable process control, interaction of control loops Process Control System: Terms and objectives, piping and Instrumentation diagram, instrument terms and symbols. Regulator and servo control, classification of variables. Process characteristics: Process equation, degrees of freedom, modelling of simple systems – thermal, gas, liquid systems. Process lag, load disturbance and their effect on processes. Self-regulating processes, interacting and non-interacting processes.

- **Different types of Control Systems**

  Feedback control system, Real-time control system, Nonlinear and Adaptive Control, Robust control system, Embedded Systems: Hardware and software architecture, Neural Networks, Fuzzy Logic Systems

- **Introduction to Plasma Control**

  Plasma Position Control, Shape Control, Density Control, modelling aspect, simulations, Plasma Control case studies: D-III-D, JT-60, JET, SST-1, EAST, ITER.

- **ITER Instrumentation & Control**

  CODAC (Control, Data Access and Communication) System, Central Interlock System (CIS), Central Safety Systems (CSS), Plant Control System, Plant Interlock System, Plant Safety System, CODAC Core Systems, EPICS, SNL, CSS, MDS Plus, LabVIEW, Matlab Simulink, Python, Grid Computing, Parallel Processing, Diagnostic Data Analysis Tools and Codes, Real-Time OS.

- **SST-1 Operation &Control**

Architecture of SST-1 Operation &Control System, System requirements, system overview and major components. Signal-conditioning system: Channel requirements, various stages in signal conditioning system, CAN bus interface, GUI based remote operation, TCP/IP based communication with subsystems, distributed system. Data Acquisition System: System overview, various interfaces, CAMAC, PXI, PXIe based technology; LabVIEW based GUI, digitization requirements, system architecture, technical requirements, network storage server, server management, data plotting utilities. Operation and Control System: Timing system, Central Data storage server, Interlock system, Tokamak operation and subsystem control, VME based control system

- **Monitoring and Control of Auxiliary Systems**

Monitoring& Control for ICRH, ECRH, NBI. Vacuum System, RHVPS and Switching scheme, Cryogenic Cooling Plant, CWS, BMS, Access Control, Super conducting Magnet Quench detection and protection.

EE3 - High Voltage DC & AC/ Power Supplies (60 Lectures)

- **Overview of Electrical systems in Fusion machines**

Basic introduction to electrical systems in Tokamak, Stellarator and Z-machine; Tokamak as a transformer, Electrical systems for plasma formation – Ohmic discharge, Arc discharge, RF discharge, MW discharge; Electrical systems for plasma confinement – Magnet power supplies, Electrical systems for plasma acceleration – Accelerator power supplies for charged particles. Use of other HV equipment in Fusion Technology: Capacitor bank, Van-de-graf generator, Pulse forming lines, Marx generator, Power supply systems applications in fusion machines.

- **High Voltage DC & AC**

High Voltage Generation, High AC, DC and Impulse Voltages, High Voltage Components, Basic design features of High Voltage Power Transformer: Basic design of HV Transformer, Transformer insulation requirements, dielectric strength and voltage conditions, winding arrangements, surge behavior, behavior of liquid dielectric, electrode surface phenomena, gas evolution, processing techniques, construction of EHV transformer, short circuit behavior. High Voltage Circuit Breakers: Air break, SF6 and vacuum circuit breakers. Gas Insulated Substation (GIS): Advantages of GIS, comparison of GIS and air insulated substations, design and layout of GIS, description of various components of GIS. High Voltage Measurement: CVT, Peak voltmeters, sphere gaps, impulse recording, Over-voltage and protection, Insulation coordination, High voltage testing methods using Partial discharge (PD), Causes and effects of PD, PD diagnostic techniques. HV and UHV systems: Fusion Technology Applications. Basic Overview of Pulse Power Technology.

- **Power Supplies**

- DC Power Supplies: Linear and switching power supplies, DC to DC converters and their operating characteristics, Selection of Power Semiconductor Devices, Magnetic component behavior and

selection. Control pulse generation and control techniques, Feedback isolation techniques, Auxiliary power supply generation, Parallel operation.

- AC Power Supplies: Linear mode AC power supplies. Switching mode Inverters, Sine wave inverters, Parallel operation, AC voltage regulators, UPS systems.
- Special Power Supplies: Power supplies for pulsed gas discharge tubes, High current power supplies. Power supplies for heating and current drive: Power Supply for Neutral beams, Power Supply for Ion cyclotron & Electron Cyclotron heating.
- Power supplies required for RF amplifiers or Oscillators. HV supplies, their interconnections for RF applications. Specific requirements of power supply protections etc., General topologies with emphasis on conventional and modular topologies, Performance requirements, Critical protections, Remote control and Monitoring requirements.
- Requirement for arc fault protection, Protection by crowbar, Deices used for crowbar applications, Importance of fault energy and techniques to limit the fault energy, wire-burn test.
- Auxiliary supplies: Screen grid, Control Grid, Filament and ion pump power supplies, General topologies for each of the supply. Performance requirements, important performance requirements, Critical protections, monitoring and remote control requirements.
- Safety and System Grounding: Power supplies inter connection at load end. Issues related to system grounding, choices available for system grounding. Safety of system and personnel for RF system.
- Integrated operation, Protection and Monitoring: HV isolation for input power of auxiliary supplies. Monitoring power supplies' status and performance. Remote and local control of power supplies. Fast and slow interlocks.

- **Power Electronics and design through modelling & simulation**

Junction Transistors (BJT, HBT), Field Effect Transistors (JEFT, MESFET, MOSFET, HEMT), Power semiconductor devices, IGBT, GTO and MCT: AC-DC Converters; Forced commutation; synchronous link converters, DC-AC converters, buck, boost, buck-boost, cuk, flyback configuration, resonant converters, PWM inverters; active filters. Machine modelling, DC machines, induction motor and synchronous machines; simulation of transients; Simulation tools: SABER, PSPICE, and MATLAB-SIMULINK; Simulations of converters, inverters and cyclo-converters etc.

EE4 - Analog Signal Conditioning and EMI/EMC Aspects (30 Lectures)

- **Analog Signal Conditioning**

Principles of Analog Signal Conditioning, Signal Conditioning Configuration, Signal Conditioning Functions, Amplification, Transducer Excitation, Filtering, Isolation, Signal Conditioning for Plasma Diagnostics, Operational Amplifiers, Op-amps/ integrated circuits in instrumentation, Phase-sensitive rectifiers, Industrial Electronics.

- **Signal Processing and Applications**

Review of signals and systems: Introduction, advantages and limitations of Analog and Digital Signal Processing, Advantages and Disadvantages of Digital Filters over Analog Filters, Introduction to Infinite Impulse Response Filters and Finite Impulse Response Filters, Applications of digital signal processing in measurement and control systems.

- **EMI/EMC**

Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Fusion Devices, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards, Testing Standards for Emissivity & Susceptance.

- **EMI Modelling**

Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling &Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EE5 - Computer Based System Design (30 Lectures)

- **Computer Fundamentals**

Personal computer architecture, memory organization, industrial PC, Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications, Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL).

- **Communication**

Asynchronous and synchronous communication, Standards like RS232, RS422, RS485, USB, Encoding schemes.

- **Networking**

Local Area Networks, OSI 7 layer model and TCP/IP reference model, Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth, Networking hardware – cables, hub, switch, router etc. Role of fibre optics in communication, Fieldbus standards, Deterministic communication techniques, Case study: various techniques used in Tokamak/Fusion devices for communication and networking.

- **Real-time systems**

Real-time Systems, their characteristics and applications, Real-time Operating Systems, Concepts of Process and threads, Concurrency, Latency, context switching, Scheduling policies, Inter process communication, Semaphores, Priority inversion, Shared memory, Common systems calls, Communication features in RTOS, Comparative study of various RTOS, Integrated software development environment

EE6 - Digital Signal Processing & Image Processing (30 Lectures)

Digital Signal Processing

- **Introduction**
  Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**
  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT

- **Fast Fourier Transform**
  Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- **Digital filters**
  FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- **DSP Applications**
  Applications of digital signal processing in fusion and other fields.

Image Processing

- **Introduction**
  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format.

- **Image Enhancement**
  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing.

- **Image Segmentation and Analysis**
  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation, Boundary extraction and representation.

- **Morphological operations**
  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy based Methods, Image Compression Models, Error free compression, Lossy compression, Standards.

BACK TO MAIN

Revised Syllabi after approval of:

BARC Training School Chemistry Committee
(Date of meeting: 28-05-2018)

HBNI BoS (Chemical Sciences)
(Date of meeting: 1-06-2018)

HBNI Academic Council
(Date of meeting: 30-06-2018)

Submitted to BARC Training School on 3-07-2018

SYLLABUS FOR

M.Phil. in CHEMICAL SCIENCES under BARC (Program Code: CHEM02)

SYLLABUS - 2018

CHEMICAL SCIENCES

COURSE STRUCTURE-CHEMISTRY

FOUNDATION COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Mathematics, Quantum Chemistry & Computational Methods	CY501	40+10	4	150
2	Analytical Chemistry	CY502	40+8	4	150
3	Material Science	CY503	20+5	2	75
4	Radiation Detection and Measurements	CY504	20	2	75
5	Nuclear and Radiochemistry	CY505	40+8	4	150
6	Thermodynamics	CY506	20+4	2	75
	FOUNDATION TOTAL		**180+35**	**18**	**675**

CORE COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Lasers	CY601	10	1	50
2	Electronics & Chemical Instrumentation	CY602	20+4	2	75
3	Production and Applications of Radioisotopes	CY603	20+4	2	75
4	Reactor Physics and Reactor Chemistry	CY604	20	2	75
5	Molecular Structure & Spectroscopy	CY605	30+6	3	125
6	Radiation and Photochemistry	CY606	30+8	3	125
7	Chemistry in Nuclear Fuel Cycles	CY607	40	4	150
8	Advanced Chemical Kinetics & Dynamics	CY608	20+4	2	75
9	Health Physics and Radiation Biology	CY609	20	2	75
10	Research Methodology	CY610	20	3	100
11	Safety in Chemical and Radiochemical labs	CY 611	10	1	50
	CORE TOTAL		**240+26**	**25**	**975**

***Tutorials**

ELECTIVES (Any Two) 4 Credits

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Nanomaterials, Chemical Sensors	CY701	20	2	75
2	Soft Condensed Matters	CY702	20	2	75
3	Nuclear Probes for Material Characterization	CY703	20	2	75
4	Molecular Bioorganics	CY704	20	2	75
5	Laser Spectroscopy	CY705	20	2	75
6	Actinide Chemistry	CY706	20	2	75
7	Computational Chemistry	CY707	20	2	75
8	Advanced NMR Spectroscopy	CY708	20	2	75
9	Atmospheric Chemistry	CY709	20	2	75
10	Statistical Analysis	CY710	20	2	75
	ELECTIVES TOTAL		**40**	**4**	**150**

	THEORY TOTAL	**460+61**	**47**	**1800**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code		Credits	Marks
1	Viva Voce	CY591	-	6	200
2	Mini Project	CY592	-	9	300
3	Seminar	CY593	-	2	100
		TOTAL		**17**	**600**

Total Contact Hrs: 460+61 (Tutorials); Total Credits: 64; Total Marks: 2400

Note: Credit Requirement for PhD: 60

Marks are calculated using the formula (As per BOS decision)

2*Hours+20*Credits (Nearest multiple of 25)

Summary Table and Index- Chemical Sciences

S.No.	Course Code	Course Title		Lectures	Marks	Credits	Sem	Page No.
FOUNDATION COURSES								
1	**CY501**	Mathematics, Quantum Chemistry & Computational Methods		40	150	4	1	
2	**CY502**	Analytical Chemistry		40	150	4	1	
3	**CY503**	Material Science		20	75	2	1	
4	**CY504**	Radiation Detection and Measurements		20	75	2	1	
5	**CY505**	Nuclear and Radiochemistry		40	150	4	1	
6	**CY506**	Thermodynamics		20	75	2	1	
CORE COURSES								
11	**CY601**	Lasers		10	50	1	2	
12	**CY602**	Electronics & Chemical Instrumentation		20	75	2	1	
13	**CY603**	Production and Applications of Radioisotopes		20	75	2	2	
14	**CY604**	Reactor Physics and Reactor Chemistry		20	75	2	2	
15	**CY605**	Molecular Structure & Spectroscopy		30	125	3	2	
16	**CY606**	Radiation and Photochemistry		30	125	3	2	
17	**CY607**	Chemistry in Nuclear Fuel Cycles		40	150	4	2	
18	**CY608**	Advanced Chemical Kinetics & Dynamics		20	75	2	2	
19	**CY609**	Health Physics and Radiation Biology		20	75	2	2	
21	**CY 610**	Research Methodology		20	100	3	2	
20	**CY 611**	Safety in Chemical and Radiochemical labs		10	50	1	2	

ELECTIVE COURSES								
S.No.	Course Code	Course Title	Course Coordinator	Lectures	Marks	Credits	Sem	Page No.
20	**CY701**	Nanomaterials and Chemical Sensors		20	75	75	SS	
21	**CY 702**	Soft Condensed Matters		20	75	75	SS	
22	**CY703**	Nuclear Probes for Material Characterization		20	75	75	SS	
23	**CY704**	Molecular Bioorganics		20	75	75	SS	
24	**CY705**	Laser Spectroscopy		20	75	75	SS	
25	**CY706**	Actinide Chemistry		20	75	2	SS	
26	**CY707**	Computational Chemistry		20	75	2	SS	
27	**CY708**	Advanced NMR Spectroscopy		20	75	2	SS	
28	**CY709**	Atmospheric Chemistry		20	75	2	SS	
29	**CY710**	Statistical Analysis		20	75	2	SS	
NON-SUBJECTASSIGNMENTS								
22	**CY591**	Viva Voce		NA	200	6	SS	
23	**CY592**	Mini Project		11 Weeks	300	9	SS	
24	**CY593**	Seminar		NA	100	2	SS	

FOUNDATION COURSES

CY 501: Mathematics, Quantum Chemistry and Computational Methods (40/10/10)

Differential Equations & Integral Transforms

Introduction to differential equations: order and degree; Different methods of solution; Overview of Legendre, Lagurre and Hermite differential equations;
Introduction to Fourier series, Fourier transform and Laplace transform.

Vector Calculus

Vector differentiation and integration: Concepts of gradient, divergence and curl; Laplacian operator.

Matrix Algebra
Elementary operations and elementary matrices. Solution of linear equations; Similarity transformations; Eigenvalues and eigenvectors; Diagonalization and inversion of matrices.

Group Theory and Symmetry in Chemistry
Concepts of groups, sub groups and classes; Symmetry elements, and symmetry operations; Point groups and matrix representations; Great orthogonality theorem and its importance in chemistry, Reducible and irreducible representations; Character Tables and their applications to spectroscopy, molecular geometry and chemical reactions.

Quantum Chemistry

Postulates of quantum mechanics, Classes of operator: Linear and Hermitian, Physical significance of eigen value in quantum mechanics; Boundary value problem in quantum mechanics; Exactly solvable problems: Particle in a box and ring; simple harmonic oscillator; rigid rotor and hydrogen atom; Approximation methods: Variation method; perturbation theory for time-independent and time dependent systems; Many-electron systems: Hartree-Fock theory and beyond; Chemical binding in simple molecular systems: Valence bond and molecular orbital theories; Concept of LCAO and introduction to ab-initio and semi-empirical molecular orbital calculations of molecules; Extended systems: From bonds to bands; Applications to few simple molecules.

Computer Programing and Numerical Methods
Computers and modeling in chemistry; Basics of computer programming: Variables, constants, input/output and control statements, arrays, functions, and subroutines. Computer oriented numerical methods: Newton-Raphson method for finding roots, differentiation, integrations by quadrature techniques, solutions of differential equations, diagonalisation and inversion of matrices. Curve fitting. Basics of computer simulation: Monte Carlo and molecular dynamics simulations.

References
[1] M.R. Spiegel. Advanced Mathematics for Engineers and Scientists, Schaum's Outline Series (1983).
[2] K.F. Riley, M.P. Hobson and S.J. Bence. Mathematical Methods for Physics Engineering, Cambridge University Press (1998).
[3] M.R. Spiegel. Theory and Problems of Vector Analysis, Schaum's Outline Series (1981).
[4] F.A. Cotton. Chemical Applications of Group Theory, Wiley (1971).
[5] S.F.A. Kettle. Symmetry and Structure: Readable Group theory for Chemists, John Wiley (1995).
[6] A. K. Mukherjee and B. C. Ghosh. Group Theory and Chemistry: Bonding and Molecular Spectroscopy, University Press, 2017.
[7] I.N. Levine. Quantum Chemistry, Prentice-Hall (1994).
[8] A.K. Chandra. Introductory Quantum Chemistry, Tata McGraw Hill (1979).
[9] V. RajaRaman. Computer Oriented Numerical Analysis, Prentice Halls India, 3rd ed. (1999)
[10] William E. Mayo. Programming with Fortran 77, Schaum Outlines Series, McGraw Hill, International ed. (1995).

CY 502: Analytical Chemistry (40/8/5)

Introduction
Relevance of Analytical Chemistry in Atomic Energy Programme, Terminologies in Analytical Chemistry, Quality Assurance in Analytical Chemistry, Accreditation and its importance

Separation Technique
Solvent extraction: Principles and Applications, Conventional solvent extraction, Liquid membranes, Bulk membranes, Supported and Emulsified liquid membrane, Super critical fluid extraction (SFE).
Ion Exchange: Principles and Applications, Conventional ion exchange, Solid Phase Extraction (SPE)
Chromatography: Principles and Applications, Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion chromatography (IC), Supercritical fluid Chromatography(SFC),Capillary electrophoresis.

Electrochemical Techniques
Introduction to the oxidation and reduction process, equilibrium electrochemistry, Activity, Nernst equation, Butler-Volmer equation, Tafel treatment. Potentiometry/potentiometric titration and ion Selective Electrodes (ISE), Modified electrodes.
Electrochemical double layer, Mass transfer processes, Fick's law of diffusion, Polarisation, Voltammetry & Polarography, working electrode, reference electrode and counter electrodes, Votammetric techniques like; Linear sweep voltammetry, Cyclic voltammetry, Pulse and Stripping Voltammetry, Coulometry and Amperometry, Hydrodynamic voltammetry.
Electrochemical Impedance spectroscopy and modelling of the electrochemical interface. Electrochemistry at ultramicro electrode, Scanning Electrochemical Microscopy, electrochemistry at confined geometry and detection at single molecule level, Hyphenated in-situ spectro-electrochemical techniques.

Spectrochemical Techniques
An introduction to spectrometric methods, Performance Characteristics of instruments, Calibration of instrumental methods, Quantitative aspects of spectrochemical measurements.
Atomic Absorption spectrometry(AAS), Sources of radiation(Hollow Cathode lamp, Continuum Source), Atom cell, Flame Atomic Absorption Spectrometry (FAAS), Electrothermal Atomic Absorption Spectrometry (ETAAS), Cold vapor Atomic Absorption Spectrometry (CVAAS), Hydride generation Atomic Absorption Spectrometry (HGAAS), Types of Interferences in AAS and Background correction methods.
Optical Emission Spectrometry, Emission sources: Flame, Inductively Coupled plasma, Glow Discharge, DC-Arc, Inductively Coupled Plasma Optical Emission Spectrometry(ICP-OES), Types of interference in ICP-OES and background correction methods, Laser Induced Fluorescence(LIF).

Mass Spectrometry
Basic principle, Ion sources: Thermal Ionisation (TI), Electron Impact(EI), Inductively Coupled Plasma(ICP), Glow Discharge(GD), Laser Ablation (LA), Secondary Ionisation (SI), Resonance Ionisation (RI), Matrix Assisted Laser Desorption and Ionisation (MALDI), mass analysers: Magnetic Sector, Quadrupole, Time of Flight (TOF), Ion Cyclotron Resonance(ICR),detectors: Faraday Cup, Channeltron and Daly detector, resolution, abundance sensitivity, Laser Induced Breakdown Spectroscopy (LIBS), Resonance Ionization Mass Spectroscopy (RIMS) Hyphenated Technique - IC-MS, HPLC-MS, GC-MS.

Thermal Methods
Principle and applications, Thermogravimetric Analysis (TGA), Derivative Thermogravimetric Analysis (DTG), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Evolved Gas Analysis (EGA)

Nuclear Methods
Principle of Activation Analysis – Neutron Activation Analysis (NAA), Charged Particle Activation Analysis (CPAA), X-ray fluorescence (XRF) spectrometry: Principles, methodology and matrix effect.

Statistics in Chemical Analysis
Accuracy, Precision, Errors in quantitative analysis, Classification of errors, Propagation of errors, treatment of errors, Normal distribution, Tests of Significance and Confidence Limits, Reporting of analytical results

Laboratory Experiments (Any Five)
1. Determination of trace impurities in high purity materials by AAS.
2. Application of electroanalytical methods to trace analysis.
3. Anion analysis by ion selective electrode.
4. TGA and DTA study of inorganic compounds
5. Neutron Activation Analysis of trace constituents in a complex matrix
6. Analysis of an alloy sample by EDXRF
7. Chromatographic separation and measurement of the components in a mixture
8. Isotopic Analysis by Mass Spectrometry

References

[1]. Encyclopaedia of Analytical Chemistry: Applications, Theory and Instrumentation, Editor R. A. Meyers, John Wiley & Sons Ltd. (2000).
[2]. Fundamentals of Analytical Chemistry, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
[3] Principles of Instrumental Analysis, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
[4]. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).
[5] Solvent Extraction of Metals, A. K. De, S. M. Khopkar and R. A. Chalmers, Van Nostrand, Reinhold (1970).
[6] Ion Exchangers, F. Helfferich, McGraw Hill (1962).
[7] Introduction to Modern Liquid Chromatography, L. R. Snyder and J. J. Kirkland, 2nd Edition, Wiley (1979).
[8] High Performance Liquid Chromatography : Principles and Methods in Biotechnology, Editor E. D. Katz, John Wiley and Sons, Chichester (1996)
[9] Atomic Absorption and Emission Spectroscopy, A. Metcalfe, Wiley (1987).
[10] Introduction to Mass Spectrometry: Instrumentation and Techniques, John Roboz, Interscience (1968).
[11] Inductively Coupled Plasma Spectrometry and its Application, Editor Steve J. Hill, Sheffield Academic Press (1998).
[12] Thermal Analysis, T. Daniels, Kogan Page (1973).
[13] Electrochemical Methods, A. J. Bard and L. R. Faulkner, 2nd Edition, Wiley (2001).
[14] Principles of Activation Analysis, P. Kruger, Wiley Interscience (1971).
[15] Principles and Practices of X-Ray Spectrometric Analysis, E. P. Bertin, Plenum Press New York, Fourth Edition (1984).
[16] Statistics and Chemometrics for Analytical Chemistry, J. N. Miller and J. C. Miller, Sixth Edition, Pearson Education Limited (2010).

CY 503: Material Science (20/5/2)

Crystal Structure
Different types of unit cells, Space lattices, Miller indices, atomic packings, radius ratio, structures of NaCl, CsCl. ZnS, diamond, CaF_2, perovskite, double pervoskites, pyrochlores, spinels, garnet structure and framework solids, aperiodic systems, symmetry, relevance of crystal structures to nuclear materials (glass, ceramics, intermetallics and alloys).

Powder X-ray Diffraction Technique for Phase Identification
Concept of X-ray diffraction, reciprocal space, Ewald construction, structural and scattering factors, grain/particle size effects, different techniques of recording diffraction patterns, indexing of diffraction patterns, Diffraction data files and their utility, Neutron diffraction, electron diffraction.

Types of Bonding in Solids
Van der Waals interactions, Lennard-Jones potential, crystals of inert gases, ionic bonding, Madelung energy and its calculation in the case of NaCl/CsCl, covalent bonding, hydrogen bonding.

Defects in Solids
Defects and defect concentration, dependence on temperature, 0- D, 1- D, 2-D defects, Experimental methods for their characterisation, color centres, phase transitions, classification with examples, dependence of phase transition on T and P, thermodynamic classification of phase transitions, order- disorder phase transitions, austenite- martensite phase transitions in alloys. Solid solutions, their significance, simple and complex solid solutions, methods to characterize solid solutions.

Transport Properties of Solids
Ionic conductivity, electronic conductivity, dielectric, ferro, piezo and pyro electric materials. structural basis and applications, superconductivity, thermal conductivity with examples.

Basic techniques for characterization
Concept of various characterization techniques based on X-rays and electrons: XRF, EPMA, XPS, AES, EELS and their application with examples

Methods of material preparation and processing
Solid state reactions and soft chemical routes, concepts of annealing, sintering and calcination, processing techniques like spin coating, powder coating, screen printing etc.

Laboratory Experiments: (Any two)
1. XRD characterization, indexing and cell parameter determination
2. Micro structure of metal/alloy by metallography and SEM
3. Electrical resistivity and its temperature dependence

References
[1]. Introduction to solid state physics – Charles Kittle
[2] Solid-state chemistry and physics, Vol. 1 & 2 – (Ed) P. F. Weller
[3] A first course in materials science – V. Raghavan
[4] Modern aspects of solid-state chemistry – C.N.R. Rao
[5] New Directions in solid-state chemistry – C.N.R. Rao and J. Gopalakrishnan
[6] Solid-state chemistry and its applications – Anthony R. West
[7] The powder method in X-ray crystallography – Leonid V. Azaroff and M. J. Buerger
[8] Solid-state chemistry techniques (Ed) – A. K. Cheetam and Peter Da
[9] Advanced Techniques for Materials Characterization" Eds. A. K. Tyagi, M. Roy, S. K. Kulshreshtha, S. Banerjee, Trans Tech Publications Ltd, Switzerland (2009)
[10] Functional Materials: Preparation, Processing and Applications, Eds. S. Banerjee and A. K. Tyagi, Elsevier Publishers (2011)
[11] Solid State Chemistry: An Introduction, by Lesley E. Smart, Elaine A. Moore
[12] Principles of the Solid State by H. V. Keer

CY 504: Radiation Detection and Measurement (20)

Interaction of Radiation with Matter
Interaction of Heavy Charged Particle with matter
Ionization in gaseous medium, Bragg's curve, stopping power, Bethe Equation for stopping power, Range of heavy charged particle and straggling, Range energy relationship.

Interaction of Fast Electrons with Matter
Comparison with heavy charged particle, LET for electron, Bremsstrahlung radiation, Cerenkov radiation, Bethe Equation, path length and range of electrons, Attenuation and absorption of β particles, Backscattering of β- and Positron annihilation.

Interaction of Electromagnetic Radiations (γ, X-Rays) with Matter
Photoelectric Effect, Compton Scattering, Pair Production, .Variation of cross section for different process with γ energy and Z of the medium, Attenuation and Absorption of gamma rays

Interaction of neutrons with matter
Elastic and Inelastic Scattering of neutrons and slowing down, nuclear reactions

Radiation Detectors
Principle of Radiation Detectors: Pulse height spectrum, Counting Characteristics, plateaus, Detection efficiency, Energy resolution, Dead time, Counting Statistics

Gas filled Detectors
Ionization Chamber, Proportional counter, GM counter

Scintillation Detectors
Organic and Inorganic scintillators, Liquid scintillation counter, Pulse shape discriminator, Solid state scintillation detectors: NaI(TI), CsI and $LaBr_3$ detectors

Semiconductor Detectors
p-n junction, HPGe detector for gamma ray spectroscopy, Clover detectors, Si(Li) for x-ray spectroscopy, Silicon detectors for charged particle spectroscopy

Neutron Detectors
BF3, 3He gas filled counters.

Solid State Nuclear Track Detectors (SSNTD)
Basic principle and applications

Application of Radiation Detectors in Nuclear Probes

References
[1] Radiation detection and measurement, G.F. Knoll, John Wiley & Sons

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CY 505: Nuclear and Radiochemistry (40/8/5)

Radioactivity
Radioactivity, Radioactive decay laws, Half-life and radioactive equilibria.

Nuclear Stability
Concept of nucleus, Nuclear mass and Binding energy, Nuclear force.

Nuclear Models
Liquid drop model, Shell model, Concept of spin, Parity electric and magnetic moments, Isomerism.

Modes of Decay
α decay, β decay, Electron captures, γ de-excitation, Internal conversion.

Nuclear reaction and fission

Q value equation, Reaction threshold, Centre of mass system, Cross-section for neutron and charged particle induced reactions , Nuclear Temperature, Compound nucleus mechanism, Nuclear fission: observables and models, Synthesis and separation of heavy and trans-actinides, Accelerators, Application of accelerators in ion beam analysis

Techniques in Nuclear Chemistry
Target preparation and target chemistry, Radiochemical separations, Concept of tracer and carrier, Chemical yield, Radiochemical purity, Application of radiotracers in chemical sciences, Determination of half-life.

Laboratory Experiments (Any Five)
1. GM Counter: plateau, statistics and dead time
2. Gamma-ray spectrometry using NaI(Tl) and HPGe detector: Energy Calibration, Resolution, Efficiency
3. Separation of actinides using solvent extraction technique
4. Alpha spectrometry

5. Determination of half-life of a radioisotope
6. Solid State Nuclear Track Detector
7. Separation of fission products / Transient equilibrium

References

[1] Nuclear and Radiochemistry (1981) – G. Friedlander, J. Kennedy, J. M. Miller and J. W. Macias
[2] Atomic Nucleus (1955) - R. D. Evans
[3] Source book of Atomic Energy (1969) - S. Glasstone
[4] Man made elements (1963) - G. T. Seaborg
[5] Essentials of Nuclear Chemistry (1982) - H. J. Arnikar
[6] The Chemistry of Transuranium Elements (1971) - C. Keller
[7] Fundamentals of Radiochemistry, IANCAS Publication, 2007

CY 506: Thermodynamics (20/4)

Introduction to Chemical and Statistical Thermodynamics

Laws of thermodynamics, Fundamental equations and thermodynamic potentials, Introduction to statistical thermodynamics, Einstein and Debye theories of specific heats of solids, Phase transitions, Thermodynamics of solutions, ideal and regular solution models.

Chemical Equilibrium

Solid-gas equilibrium, Ellingham diagram.

Relation between Thermodynamics and Phase Diagrams

Binary and ternary phase diagrams, CALPHAD definition of phases, Degree of freedom rule and lever-rule, Calculation of simple binary phase diagrams from thermodynamic properties, Chemical potential variations across phase diagrams

Phase Diagram and Thermodynamics of Nuclear Fuels

Relevant phases for nuclear fuel applications, Change in chemical potentials with compositions of virgin fuels, Change in chemical potentials with burn-up, Thermodynamics of Fuel-Clad and Coolant-Clad interactions, Thermodynamics of molten fluorides, Concepts of metastable materials.

Experimental Thermodynamics

Calorimetric measurements, Vapor pressure measurements, Estimation of thermodynamic quantities

References

[1] Introduction to Thermodynamics of Materials (Fourth Edition) by D. R. Gaskell (2003) Taylor & Francis Books, Inc., New York
[2] The Principles of Chemical Equilibrium by K. Denbigh (Fourth Edition) (1981) Cambridge University Press, Cambridge
[3] Materials Thermodynamics by Y.A. Chang and W.A. Oates (2010), John Wiley & Sons, Hoboken, New Jersey.
[4] Fundamentals of Classical and Statistical Thermodynamics by B.N. Roy (2002) John Wiley & Sons, Hoboken, New Jersey, England
[5] Comprehensive Nuclear Materials, R.J.M. Konings, T.R. Allen, R.E. Stoller, S. Yamanaka, Elsevier 2012.

CORE COURSES

CY 601: Lasers (10/0/1)

Basic principles - Spontaneous & stimulated emission, population inversion, laser components, Einstein coefficients, optical amplification, optical & electrical pumping, rate equations (two, three and four level laser systems)

Properties of laser beams - coherence (spatial and temporal), monochromaticity, intensity, polarization

Optical resonators – Types, properties, spatial field distribution in resonators, stable & unstable resonators, gain and losses in the cavity, Q-factor, threshold condition, laser modes (longitudinal and transverse),
Types & some laser systems - Solid state lasers, gas lasers, dye lasers, diode lasers, fiber lasers, free electron laser and quantum cascade lasers, tunable lasers

Generation of short and ultrashort pulses - Q-switching and mode locking, chirp pulse amplification

Non-linear optical techniques – Phase matching, harmonic generation, optical parametric oscillator & amplifier

Modulation in laser pulses-amplitude, wavelength, temporal

Characterization of laser pulses - Measurement of the pulse temporal profile (electronic & optical), spectral measurements (interferometric), amplitude - phase measurements (FROG)

Laser applications & laser safety.

References
[1] Laser Spectroscopy: Basic Concepts and Instrumentation- W. Demtroder
[2] Laser Fundamentals-William Silfvast
[3] Laser and Non-linear Optics- B. B. Laud
[4] Principles of Lasers- O. Svelto and D. C. Hanna
[5] Laser Safety- Roy Henderson and Karl Schulmeister

Laboratory experiment: Time-frequency bandwidth relationship for laser pulses-Checking the Heisenberg uncertainty principle

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CY 602: Electronics and Chemical Instrumentation (20/4/5)

Electronics
DC & AC Fundamentals: Concept of charge, current, voltage, power, Ohms law, AC –Sinusoidal, Peak & RMS values, Frequency.
Electronic components: Resistors, capacitors, diodes, transformer
Power Supply, Rectification, Filter, Line/Load Regulation, Regulator Chips, Low Voltage & High Voltage power supplies, SMPS.

Analogue Electronics
Operational Amplifiers, Ideal Characteristics, Inverting, Non-invertingAmplifier, Integrator, Comparator, Summer, Pulse Amplifier and Instrumentation Amplifier.

Digital Electronics
Number system and Logic gates - Decimal, Binary and Hexadecimal number systems, Logic gates, Flip Flop, Counter, Decoder, Display Device.
Analog to Digital Converters and Digital to Analog Converters

Instrumentation
Concept of Instrumentation, Order of instruments, concept of broad specifications (accuracy, precision etc), Voltmeter and Current meter, concept of Multimeter & concept of loading.
Signal & Noise: Concept of Noise & Signal, dB, S/N ratio and improvement techniques.
Transducers: Transducers and their applications (temperature sensors, PMT, photo diode and vacuum gauges)
Signal analysis & Processing: Selective signal amplification, filter, Lock-in-amplification, Boxcar Averager, Fast Fourier Transform.

Computer in Labs
PCs & interfacing concepts, RS232, USB ports, Embedded systems, Lab View programming.

References:
[1] Basic electronics for Scientists- McGraw Hill International (1977) - J. J. Brophy
[2] Basic Electronics - Bernard Grob McGraw Hill Book Co.
[3] Electronic Principles – Tata McGraw Hill Pub. Malvino
[4] Operational Amplifiers and linear integrated circuits –Prentice Hall of India Ltd.-Robert Conghlin, Fredrick Driscoll
[5] Art of Electronics, Cambridge University Press, London - Paul Horonitz and Winfield Hill
[6] Digital Principles and applications Tata McGraw Hill - Malvino& Leach
[7] Instrumental methods of chemical analysis, McGraw Hill - Ewing
[8] Introduction to instrumental analysis, McGraw Hill Book Co. - Robert D. Bramn.
[9] Principles of instrumental analysis by Skoog , Holler and Neiman (Fifth Edition)
[10] Electronic Instrumentation & Measurement technique - W D Cooper & A. D. Helfrick
[11] Optimisation of Electronic Measurement - Enke, Croach, &Florlicks
[12] Myer. Kuts, Temperature Control- Wiley (1968)
[13] S. Dushman and J.M. Lafferty- Scientific foundations of vacuum techniques, Wiley (1962)

CY 603: Production and Applications of Radioisotopes (20/4)

Introduction to the course
Relevance and contribution of the isotope program in DAE.

Production of Radioisotopes
Need for radioisotope production, Basic principles and different routes of radioisotope production using nuclear reactors and charged particle accelerators. Szilard-Chalmers effect and its utility in radioisotope production. Derivation of equation to calculate production yields in nuclear reactors and charged particle accelerators, Calculations of production yields; Bateman's equation and its utility in production yield calculations.

Production of some important radioisotopes in nuclear reactor and in cyclotron, Selection of target material, Methods of target preparation, Methods of processing of irradiated targets, Methods of production of some important radioisotopes (such as, $^{32/33}P$, ^{60}Co, ^{82}Br, ^{99}Mo, ^{99m}Tc, ^{125}I, ^{131}I, ^{137}Cs, ^{153}Sm, ^{166}Ho, ^{177}Lu, $^{186/188}Re$, ^{192}Ir, and ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{44}Sc, ^{64}Cu, ^{67}Ga, ^{68}Ge, ^{89}Zr, $^{123/124}I$, ^{201}Tl etc.).

Concept of radionuclide generators; Growth and decay of activity in a radionuclide generator; Different types radionuclide generators with special emphasis to ^{99}Mo-^{99m}Tc generators along with their relative advantages and disadvantages; Few other important generator systems such as, ^{68}Ge-^{68}Ga, ^{90}Sr-^{90}Y, ^{188}W-^{188}Re etc.

Applications of Radioisotopes in Medicine
Concept of nuclear medicine and radiopharmaceuticals, Classification of radiopharmaceuticals, Characteristics of diagnostic (SPECT and PET) and therapeutic radiopharmaceuticals. Basis of designing radiopharmaceuticals, Preparation of radiopharmaceuticals and Methods of radiolabeling.

New approaches in radiopharmaceuticals chemistry - ^{99m}Tc-tricarbonyl method, ^{99m}Tc-nitrido method, ^{99m}Tc-HYNIC method etc., Advantages of new approaches.

Some important organ-specific diagnostic radiopharmaceuticals (myocardial imaging, brain imaging, renal imaging, tumor and inflammation imaging, receptor-specific imaging agents etc.). Radioimmunoscintigraphy (RIS), PET radiopharmaceuticals - Principle and applications.

Concepts of brachytherapy and teletherapy.

Therapeutic radiopharmaceuticals for some specific applications [Metastatic Bone Pain Palliation (MBPP), Radiation Synovectomy (RSV), Peptide Receptor Radionuclide Therapy (PRRT), Radioimmunotherapy (RIT) etc.]

Quality control of radiopharmaceuticals - physicochemical and biological quality control tests.

Industrial Applications of Radiation Technology
Fundamental aspects of radiation processing and radiation technology, Radiation sources and effects of ionizing radiation on materials, Comparison of different radiation sources for different applications, Radiation dosimetry for industrial radiation sources.

Radiation polymerization vis-à-vis conventional polymerization, Polymerization kinetics and polymer characterization, Radiation effects on Polymers under different conditions, Theories of radiation crosslinking.

Radiation induced modification of polymers for industrial and environmental applications, wire and cable crosslinking, surface curing and grafting, heat-shrinkable materials, radiation cured polymer coatings and radiation grafted functional polymers for various applications, radiation degradation of polymers and applications, etc..

Radiation processed polymers for healthcare applications, Introduction to radiation sterilization of medical products (process, D_{10} value, SAL, inactivation factor and safety factor), hydrogels and their property standardization using radiation for wound dressings, radiation processed drug delivery devices.

Radiation processing of food, Objectives and dose limits for different food items

Radiation chemistry aspects of radiation hygienization of sewage sludge process and process control

Radiation processing of flue gases and radiolysis of flue gas components

Radiation induced enhancement in the functional attribute of blends and composites, Introduction to rheology of polymers, crosslinking and degradation behavior of multi-phase system, microscopic and mechanical characterization of blends and composites.

Application of radioisotopes as tracers in process optimization, trouble shooting in industries and sediment transport in harbours.

Application of Radioisotopes as Tracers
Principle and industrial applications of radiotracers, Process optimization and trouble shooting in industries-blockage location in buried pipelines, Leak detection in buried pipelines & industrial systems, Wear rate of anti-fungal paints, Flow rate determination in industrial processes.
Environmental isotopes and artificial radioisotopes in hydrology. Application of environmental isotopes in studying ground water salinity, pollution, recharge etc., Artificial radioisotopes in studying dam seepage, effluent dispersion etc.

References
[1] Manual for Reactor Produced Isotopes. IAEA-TECDOC-1340, IAEA, 1999.
[2] Fundamentals of Radiochemistry. D.D. Sood, A.V.R. Reddy, N. Ramamoorthy. Indian Association of Nuclear Chemists and Allied Scientists, 2004.
[3] Radiopharmaceuticals: Chemistry and Pharmacology, Adrian D. Nunn. Marcel Dekker, 1992.
[4] Fundamentals of Nuclear Pharmacy, G.B. Saha, Springer-Verlag, 1984.
[5] Radionuclides in Therapy, R.P. Spencer, R.H. Sievers, A.M. Friedman. CRC Press, Boca Raton, 1987.
[6] PET in Oncology: Basics and Clinical Applications, J. Ruhlmann, P. Oehr, H.J. Biersack. Springer-Verlag, 1998.
[7] ICRU Report (1980) Radiation Quantities and Units, ICRU Publications, 33
[8] An Introduction to Radiation Chemistry. J.W.T. Spinks and R.J. Woods, John-Wiley, New York-London-

Sydney, 1990.
[9] Radiation Processing of Polymer Materials and its Industrial Applications K. Makuuchi, S. Cheng, Wiley, 2012.
[10] Dynamic Mechanical Analysis: A Practical Introduction. K.P. Menars, CRC Press, Boca Raton, 1999.
[11] Industrial application of radioisotopes. G. Foldiak.
[12] Guide Book on Radioisotope Tracers in Industry - Tech. Rep. Series 316, IAEA, Vienna, 1990.
[13] Environmental Isotopes in Hydrogeology. Ian Clarke and Peter Fritz, Lewis Publishers, NY, 1997.

CY 604: Reactor Physics and Reactor Chemistry (20)

Fission, Energy from fission, Burn-up, Spontaneous and induced fission, Chain reaction, Fissile-Fissionable-fertile materials, Prompt and delayed neutrons, Four factor formula, Neutron interaction with matter, Fission products, Critical mass, Neutron Diffusion Theory, Multiplication factor, Reactor kinetics and control.

Different types of homogeneous and heterogeneous reactors, Components of reactors.

Introduction to the types of water cooled power reactors & their process systems. Schemes of preparation of dimineralized water, Variation in properties of water and heavy water as a function of temperature and pressure. An overview of types of corrosion, methods of evaluation of corrosion and its prevention. An overview of materials of construction for the different components of reactor systems. Hot Conditioning of PHT circuit in PHWR. An overview of water chemistry regimes in BWR, PWR & PHWR.

Principles and processes relevant to chemistry control in primary heat transport systems. Radioactivities in reactor waters & their control. CRUD generation and activity transport in the primary heat transport system of reactors its control. Radiolysis of water, related hazard, and its control, Reactivity control through chemistry: Use of soluble neutron poisons- for chemical shim and for emergency shutdown. Purification of reactor cover gas by Catalytic recombination and adsorption techniques.

Chemistry control in secondary heat transport system, pH control methodologies of secondary system, Scaling and methodology of its control in secondary system.

Chemistry control in the tertiary heat transport system, Bio-fouling and its control methodologies.

References
[1] R.A. Knief: Nuclear Energy Technology (1981).
[2] S. Glasstone and M.C. Edlund: The elements of Nuclear Reactor Theory (1952).
[3] P. Cohen: Water Coolant Technology in Power Reactors, American Nuclear Society, U.S.A (1980).
[4] Proc. Int. Conf. on water chemistry in Nuclear Reactor Systems organized by British Nuclear Energy Society, U.K.(1977,1980,1983,1986,1989,1992).
[5] H. H. Uhlig: Corrosion and Corrosion Control, John-Wiley & Sons, N.Y., (1985)
[6] International Atomic Energy Agency, Coolant Technology of Water Cooled Reactors, IAEA-TECDOC-667, Vols. 1-4,Vienna
[7] M. Benedict, T.H. Pigford and Levi: Nuclear Chemical Engineering.
[8] S. Glasstone & A. Sesonske: Nuclear Reactor Engineering, Vol I & II, CBS Publications, Delhi (1977)

CY 605: Molecular Structure and Spectroscopy (30/6/4)

Coordination Chemistry
Werner's Coordination theory, Valence Bond Theory, Crystal Field Theory, splitting of "d" orbital in different geometry, Jahn Teller effect, Thermodynamic effects of crystal field, Coordination chemistry of lanthanide and actinide ions, Brief introduction to group theory, Application of group theory for d-d transition, Racah parameters, electronic spectra of complex ions, Tanabe Sugano diagram, nephelauxetic effect, ligand metal orbital overlaps, magnetic properties and susceptibility measurements of complex ions, drawbacks of CFT, f-f transitions in lanthanides.

Molecular orbital theory and construction of molecular orbital diagram from concepts of group theory, MO's for Sigma bonding in AB_6 molecules, tetrahedral AB_4 case, MO's for pi bonding in AB_6 molecules, Metal organic framework materials. Dissociative & associative reaction mechanism of ligand replacement in octahedral and square planar complexes, trans effect and its implications.

Characterization Techniques of Complexes

NMR: Basic Principles of NMR Spectroscopy, Chemical Shift, Spin-Spin Coupling, Decoupling Experiments, Pulse NMR, Relaxation Effects, Two-Pulse Experiment, T1-Measurment, T-2 measurement, solid state NMR, ESR: Basic Principles of ESR Spectroscopy, The g-value, Hyperfine Coupling, Electron Nuclear Double Resonance (ENDOR), Mossbauer spectroscopy

Electronic, Vibrational and Rotational Spectroscopy

Classification of molecules, their characteristic spectral features and selection rules, pure microwave, Rotational Raman, Vibrational and rotational vibrational spectroscopy, IR and Raman spectroscopy.
Basic principles of Fourier transform spectroscopy (FTIR, FT-RAMAN).
Surface enhanced Raman spectroscopy (SERS), Terahertz spectroscopy, Nonlinear optical methods, sum & difference frequency generation (SFG & DFG).
Synchrotron radiation and its application in spectroscopy, X ray absorption based techniques (XANES, EXAFS)
X ray Photoelectron Spectroscopy.
Doppler-free high-resolution spectroscopy

Laboratory Experiments

[1] Electronic spectra of a transition metal complex .d-d transitions.
[2] NMR
[3] FT-IR
[4] Raman

References

[1] Advance Inorganic Chemistry - F.A.Cotton and G.Wilkinson
[2] Physical Methods in Inorganic Chemistry - R.S. Drago
[3] Modern Coordination Chemistry – Lewis and Wilkins
[4] Introduction to ligand fields - B.N. Figgis
[5] Ligand field theory - C.J. Ballhausen
[6] Comprehensive Inorganic Chemistry - Huchey
[7] Molecular Spectroscopy - C.N. Banwell
[8] Infra red spectra of Inorganic and coordination compounds - K. Nakamoto
[9] Laser spectroscopy: Basic concepts and instrumentation - W. Demtroder

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CY 606: Radiation and PhotoChemistry (30/6/4)

Radiation Chemistry

Interaction of High-energy Radiation with Matter

Chemical consequences, absorption coefficients, G-values, track entities and LET effects, radiation sources.
Diffusion kinetics and homogeneous reaction stages, time scales of events in radiation chemistry, ion-pairs, ion-molecule reactions

Radiation Chemistry of Water and Nonpolar Liquids

Radiolysis of water & heavy water, radical and molecular yields, material balance, chemical dosimetry
Radiolysis of non-polar solvents, geminate recombination, electron salvation
Radiation chemistry of micro heterogeneous systems and ionic liquids
Comparative aspects of radiolysis of liquids, solids and gases

Experimental Techniques

Detection of primary species and free radicals using pulse radiolysis coupled with optical absorption

spectroscopy, ESR, conductivity, resonance Raman spectroscopy
Evaluation of absolute rate constants, pK values of transient species, one-electron redox potentials, picoseconds pulse radiolysis

Application
Radiolytic synthesis of nanoparticles
Radiation chemistry of water at high temperature and high pressure
Radiation chemistry of antioxidants and radioprotectors.

Photochemistry
Photophysical Processes
Electronic transitions, oscillator strength, selection rules
Franck-Condon principle, absorption, emission and fluorescence excitation spectra, charge-transfer spectra.
Deexcitation processes - fluorescence, phosphorescence, delayed emission, triplet-triplet annihilation, heavy atom effect, kinetics of excited state processes, quantum yields of photo-processes
Fluorescence anisotropy
Photophysical processes in semiconductors, multiphoton processes
Environment effect- polarity, viscosity (anisotropy), temperature

Photochemical Processes
Excited state acid-base properties, redox potentials, geometry, dipole moments
Kinetics and mechanism of processes like photo-dissociation, photo-ionization, electron transfer, energy transfer, proton transfer, supra-molecular interactions

Experimental Techniques
Steady-state absorption and fluorescence techniques
Time-resolved absorption and fluorescence techniques like time-correlated single photon counting, fluorescence up-conversion, nanosecond laser flash photolysis and ultrafast pump-probe spectroscopy; single molecule spectroscopy, fluorescence correlation spectroscopy

Applications
Photosynthesis, vision, solar energy conversion, photocatalysis, fluorescence sensors.

Laboratory Experiments
Radiation Chemistry
[1] Fricke dosimetry and estimation of G-values.
[2] Study of free radical reactions using pulse radiolysis technique.
Photochemistry
[1] Fluorescence quenching studies: determination of quenching rate constant.
[2] Excited state properties: determination of acid dissociation constant using absorption & fluorescence techniques.

References
Radiation Chemistry
[1] An introduction to Radiation Chemistry. J. W. T. Spinks and R. J. Woods; Wiley Interscience, New York, 1990.
[2] Radiation Chemistry: An Introduction. A. J. Swallow; Longman, London, 1973.
[3] Radiation Chemistry. Belloni
[4] Charged particle. A. Mozumdar &Y. Hatano .
[5] Radiation Chemistry: Principles and Applications. Editors: Farhataziz and Michael A. J. Rodgers, VCH, New York, 1987.
[6] The Study of Fast Proccesses and Transient Species by Electron Pulse Radiolysis. Editors: J. H. Baxendale and F. Busi; Reidel, Dordrecht, Holland, 1982.
[7] A. J. Swallow, Reaction of free radicals produced from organic compounds in aqueous solution by means of radiolysis. Prog. React. Kin. 9, 1978, 195.
Photochemistry
[1] K. K. Rohatgi-Mukherjee, Fundamentals of Photochemistry; Wiley Eastern: New Delhi, 1978.
[2] J. B. Birks, Photophysics of Aromatic Molecules. Wiley Interscience, New York, 1970.
[3] J. R. Lakowicz, Principle of fluorescence spectroscopy, 3rd ed.; Springer: New York, 2006.
[4] J. Turro, Modern Molecular Photochemistry, Benzamin, Menlo Park, CA, 1978.

[5] R. P. Wynes, Principles and Applications of Photochemistry. Oxford Science Publications, 1988.
[6] A. Gilbert, J. Baggott, and P. J. Wagner, Essentials of molecular photochemistry, Blackwell Science Inc. Cambridge, USA, 1991.
[7] D. V. O'Connor and D. Phillips, Time Correlated Single Photon Counting. Academic Press, New York (1984).
[8] J. N. Demas, Excited State Life Time Measurements. Academic Press, New York, 1983.

CY 607: Chemistry in Nuclear Fuel Cycle (40)

Separation and purification of uranium and thorium from their ores, Principles of isotope separation, enrichment of uranium, systematics and processes.

Conversion processes for preparation of UO_2, $(U,Pu)O_2$, UC, (U,Pu)C, UN (U,Pu)N, metals and alloys.

Separation and purification of zirconium from its ore, Principle and process for heavy water production.

Fuel fabrication processes and chemical quality control

Behavior of nuclear fuels (thermal/fast) during irradiation

Post irradiation studies, fuel clad chemical interaction, Burn-up etc.

Thermo-physical and themo-chemical aspects of fuel, Properties of oxide, carbide, nitride and metallic fuel materials, Coated particle based fuels.

Cladding, moderator, coolant materials and their properties, Liquid metal coolants like sodium and lead-bismuth, Chemical aspects of corrosion, Monitoring and maintenance of the purity of coolant.

Reprocessing of thermal and fast reactor fuels, chemistry of various process PUREX, THOREX etc., Systematic and process of pilot plant CORAL, Challenges in reprocessing of fast reactor fuel.

Waste processing and management, classification of waste and treatment practices of gaseous, liquid and solid waste.

Vitrification of high level liquid waste, Partitioning of actinides from high level liquids waste, Decontamination process.

Nuclear safety, Management of H_2, Xe, Kr, I_2 and tritium in operating nuclear power plants

References

[1] D. R. Olander: Fundamental Aspects of Nuclear Reactor Fuel Elements: USERDA Report TID-26711 (1976)
[2] D. Wilson: The Nuclear Fuel Cycle, From Ore to Waste, Oxford University Press Inc. New York (1996)
[3] E. Glueckauf, Atomic Energy Waste: Its Nature, Treatment and Disposal, Interscience Publishers Inc. New York (9161)
[4] R. L. Murray and J. A. Powell: Understanding Radioactive Waste, 4th Edition, Columbus: Battelle Press (1994)

CY 608: Advanced Chemical Kinetics and Dynamics (20/4)

Intermolecular interaction potential, Collision theory, Potential energy surfaces, Activated complex theory, adiabatic and non-adiabatic reactions, Landau-Zener crossing, Lindemann's theory of unimolecular reactions, energy transfer, fall-off region and its limitations, Hinshelwood's Treatment. Rice-Ramsperger and Kassel (RRK) model, and Marcus refinement of RRK model (RRKM) for the calculation of rate constants of simple unimolecular reactions.

Molecular beam experiments, types & characteristics of molecular beams, scattering as a probe; differential cross-section; quantum mechanical approach to elastic scattering; conservation of angular momentum – Newton diagram, lab–to-centre of mass transformation, reaction cross section - reaction probability; opacity function – steric factor; reactive asymmetry – angular distribution in reactive collisions – direct reaction versus collision complex; forward, backward, and forward–backward scattering; potential energy contour diagram, reactions with early & late barrier. Different molecular energy transfer processes. Laser based spectroscopic techniques- LIF, REMPI, CRDS, detection and measurement of trace constituents and free radicals, rate coefficient measurement, chemical kinetics and dynamics studies, atmospheric chemistry.

IR laser chemistry, laser isotope separation, mode and bond selective chemistry, intramolecular vibrational energy redistribution (IVR), coherent control of chemical reaction,

References

[1] Chemical Kinetics - K. J. Laidler, Third Edition, Pearson Education, Singapore (2004).
[2] Molecular reaction dynamics and chemical reactivity - R. D. Levine and R. B. Bernstein, Oxford University Press, New York (1987).
[3] Chemical dynamics via molecular beam and laser techniques - R. B. Bernstein, Clarendon Press, Oxford (1982)
[4] Unimolecular reactions - P. J. Robinson, S.H. Robertson and K. A. Holbrook, Wiley, London (1996)
[5] Introduction to molecular dynamics and kinetics - G.D.Billing and K.V. Mikkelsen, Wiley, NY (1996)
[6] Chemical Kinetics and Dynamics - J F. Steinfeld, J.S. Francisco and W. L. Hase, Prentice Hall International, Inc. III, New Jersey (1999).
[7] Chemical Kinetics and Reaction Dynamics – P.L. Houston, McGraw-Hill Higher Education, (2001).
[8] Laser Spectroscopy: Basic Concepts and Instrumentation- W. DemtrÖder, Springer International (2004)

CY 609: Health Physics and Radiation Biology (20)

Health Physics
Fundamentals of Radiation Protection
Radioactivity, Ionizing radiation, Radiation quantities and units**,** Basis and structure of the system for radiation protection, System of radiological protection for human, natural radiation.

Basic Radiation Physics and Radiation Dosimetry Aspects
Interaction of radiation with matter, External and internal radiation hazards in nuclear and radiation facilities, Radiation dosimetery: basics, concepts and definitions, External radiation dosimetry and dosimetry of internally deposited radio nuclides, Radiation detection principles, Monitoring instruments and Personnel monitoring devices

Operational Monitoring and Safety Aspects of Facility Design
Exposure situations as per ICRP-103 recommendations, Control of external and internal radiation hazards, Radiation dose limits and its basis, General principles and techniques of radiation monitoring, air activity and area contamination, Assessment and control of radiation hazards in nuclear fuel cycle facilities with special reference to metallurgical, radiochemical and radioisotope facilities and fuel reprocessing plants, Criticality safety aspects, Environmental safety aspects during operation of nuclear and radiation facilities, Industrial hygiene and safety aspects during operation of nuclear and radiation facilities.

Radiological Safety Aspects in Design of Radio-Chemical Laboratories
Safety aspects of design of radiochemical laboratory, its types and operational aspects, Partial containment/confinement systems and ventilation system in a laboratory.

Emergency Preparedness and Response System at Nuclear and Radiation Facilities
Classification of radiation emergency, Emergency preparedness and response system, Reference levels and guidance values for emergency workers.

Basic Radiation Radiobiology
Water radiolysis, Free radicals and its reactions with biological systems, Oxygen effect.

Radiation damage at bio-molecular level, Damage to DNA and chromosomes (single and double structural breaks, chromosomal aberrations) and its biological consequences, Radiation damage to membrane and its biological consequences, Major health effects of radiation exposure.

Mode of interaction of different types of radiation with biological systems, Track structure, Concept of LET, Radiobiological effectiveness (RBE), Radiation dose units with reference to radiobiology, Direct and indirect effect of radiation.

Molecular and Cellular Effects of Radiation
Assay for radiation damage in human cells (survival curve), Physical and biological factors affecting the cellular radio-sensitivity, Dose and dose rate effect, Dose fractionation, Inverse dose rate effect, Oxygen enhancement ratio and Optimum LET, Radio-protectors and radio-sensitizers.
Cell cycle arrest and radiation damage repair, Cancer and its induction by radiation, Radiobiology of cancer radiotherapy approaches

References

[1] Introduction to Health Physics by Herman Camber
[2] International Commission on Radiological Protection (ICRP) Publication-103, 2007
[3] IAEA- BSS- GSR Part-7, 2015
[4] AERB Safety Guidelines NO. AERB/NRF/SG/EP-5 (Rev. 1), 2015
[5] Biological Effects of Radiation by J. E. Coggle
[6] Radiobiology for Radiologist by Eris J. Hall

CY 610: Research Methodology (20)

Objectives and types of research: Motivation and objectives - Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem - Literature review – Primary and secondary sources - reviews, treatise, monographs-patents - web as a source - searching the web - Critical literature review - Identifying gap areas from literature review - Development of working hypothesis.

Research design and methods - Research design – Basic Principles - Need of research design - Features of good design – Important concepts relating to research design - Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Value of Statistics; Errors and Statistics - Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results - students's t test; F-test; Chi Square test; propagation of errors.

Reporting and thesis writing – Structure and components of scientific reports - Types of report - Technical reports and thesis - Significance - Different steps in the preparation – Layout, structure and Language of typical reports - Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation - Planning - Preparation - Practice - Making presentation - Use of visual aids - Importance of effective communication - Computers in Chemistry, Usage of packages such as, Excel, AIM2000, ChemCraft, etc. Manuscript drafting based on 'Experimental data and Literature Survey'.

Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialisation - Copy right - Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights - Reproduction of published material - Plagiarism - Citation and acknowledgement - Reproducibility and accountability.

References

[1] Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction to Research Methodology, RBSA Publishers.
[2] Kothari, C.R., 2000, Research Methodology: Methods and Techniques. New Age International.
[3] Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Publications (2 volumes)
[4] R. Paneer Selvam - Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
[5] Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
[6] Day, R.A., 1992.How to Write and Publish a Scientific Paper, Cambridge University Press.
[7] Vogel's Text Book of Quantitative Inorganic Analysis, ELBS.

CY 611 Safety in Chemical and Radiochemical labs (10)

Chemical labs

Definition of chemical safety and its assessment, general chemical safety awareness, Classification of chemicals: Corrosive, Flammables, explosives, toxics, pyrophoric, carcinogen. Chemical which create lachrymation and smoke, Entry of such chemicals into human/biological system and its consequences, precautionary and safe methods for handling such chemicals, Compatibility issues with chemicals, Understanding the Safety Data Sheets (Material Safety Data Sheets) for different chemicals. Storing different chemicals, incompatible chemicals, making inventory of chemicals, labelling chemicals depending upon its nature, safe disposal of chemicals, precautions and safe operating procedures (SOP) to be taken into consideration for chemical spills, chemical protective clothing, chemical accidents and their classification and consequences, Emergency Procedures during chemical accidents, Personal Protective equipment from chemical exposure, precautions to be taken with chemical which need to be refrigerated. Safe practices while using vacuum lines and laser. Fire safety and different types of fire extinguishers.

Radiochemical labs

Classification of laboratories, classification of radioactive zones in the laboratory, ventilation, Shielding and dosimetry requirements for handling different types of radioactivity, Radioactivity handling in fume-hoods and glove boxes, Movement of radioactivity within the lab, Washing of radioactive glass wares, Disposal of radioactive aqueous and organic waste, Disposal of compressible and non-compressible radioactive waste, fire safety in radioactive labs, Personnel radiation monitors, Managing personnel and laboratory contamination, Precautions in a radioactive lab and emergency procedures.

ELECTIVE COURSES

CY 701: Nanomaterials and Chemical Sensors (20)

An overview of the course

Physics of nanomaterials
Finite size systems, cluster science, bulk versus nanomaterials, quantum confinement effects in nano-regime, evolution of electronic structure from atoms to bulk, density of states, dimensionality and its effect on electronic structure, surface effects, calculation of surface-to-volume ratio for different structural arrangements, size dependent physico-chemical properties, carbon based materials (0D, 1D, 2D and 3D).

Chemistry of nanomaterials
Top down and bottom up approaches for synthesis of nanomaterials, such as laser ablation, ball-milling, sputtering, combustion, metathesis, sol-gel etc.

Common characterization techniques for nanomaterials
Characterization techniques at different length scales, application of XRD, TEM, SEM, AFM and DLS for characterization of nanomaterials.

Properties of nanomaterials
Fundamentals of Semiconductors, direct and indirect band gaps, semicounductor in nano-dimesnions (quantum dots, core-shell nano-particles of semiconductors), metallic nanoparticles and surface plasmon, an overview of magnetic, optical and catalytic properties of nanomaterials.

Applications of nanomaterials
Nanomaterials in energy conversion (solar cell, rechargable batteries, supercapacitors and materials for hydrogen energy), nanomaterials for bio-applications (drug delivery), environmental applications (sorbents) and DAE application.

Chemical sensors and their applications
Threshold limit values (TLV) of common toxic species, selection of sensor materials mechanism of sensing action, features of sensors (selectivity, response time, reproducibility and regeneration), typical examples of nanomaterials based sensors for H_2S, NH_3, SO_2, and heavy metal ions, common bio-sensors, sensors for DAE applications.

References

[1] Advanced Techniques for Materials Characterization Eds. A. K. Tyagi, M. Roy, S. K. Kulshreshta, S. Banerjee, Trans Tech Publications Ltd, Switzerland (2009)
[2] Fundamental properties of Nanostructured Materials, Eds. D. Fiorani (World Scientific, Singapore, 1994)
[3] Nanostructured Magnetic Materials and their Applications, Eds. D. Shi et al. (Springer, Berlin, 2002)
[4] Mechanical Properties and Deformation Behavior of Materials having Ultrafine Microstructures, Eds. M. Nastasi et al. (Kluwer, Amsterdam, 2002)
[5] Functional Materials: Preparation, Processing and Applications, Eds. S. Banerjee and A. K. Tyagi, Elsevier Publishers (2012)

CY 702: Soft Condensed Matter (20)

Introduction to Soft Matter
Forces, energies, length and time scales in soft matter. Soft matter systems (colloids, surfactant / micellar systems, gels, polymer solutions, polymers, polyelectrolytes, microemulsions, membrances, biological macromolecules), Interactions (electrostatic, van der Walls, hydrophilic and hydrophobic interactions, depletion interaction). Viscous, elastic and viscoelastic behavior, Liquids and Glasses, Soft matter in nature:

Experimental techniques to investigate structure and dynamics in soft matter
Scattering techniques (Small-angle X-ray scattering (SAXS), Ultra-small-angle-X-ray scattering (USAXS), Small-angle (SANS) Static and Dynamic light scattering (SLS & DLS)

Colloids
Introduction, Brownian motion of colloidal particles. Sterically stabilized and Charge stabilized colloids, Colloidal interactions, Liquid phase synthesis of colloidal particles, Structural ordering, Dynamics, Phase Transitions [Gas-liquid, Melting /freezing, Glass Transition, Crystal-amorphous]

Surfactants
Types of surfactants, Micellization, Langmuir- Blodgett films, Monolayer, Bilayers and Vesicles, Lyotropic liquid crystalline phases, Micro emulsions.

Polymers and Polyelectrolytes
A single ideal chain, mean-squared end to-end distance, radius of gyration. Gaussian chain, Freely joined chain. Excluded volume, solvent quality, theta-temperature. Polymer solutions : Flory-Huggins theory, osmotic pressure, scaling laws for good solvents, Size of a polymer in semi-dilute solutions : osmotic pressure, light scattering, intrinsic viscosity, Classes of gels : physical gels, chemical gels and photo-polymerized gels, Sol-Gel transition, Swelling and shrinking of gels, theory of gelation. Polyelectrolytes : Debye-Huckle theory, Donnan equilibrium, manning condensation. Dynamics of polymeric liquids : Maxwell model. Rouse theory, Zimm theory, Reptation theory : tube model, reptation dynamics, self –assembly and order-disorder transitions of diblock copolymers

Applications of Soft Matter
Nanoparticle suspensions as heat transfer fluids. Colloidal assemblies in liquid-liquid extraction systems. Ionic liquids as extractants. Foams and Gels for decontamination. Foamability of surfactants. Dynamic interfacial tension and foamability. Defoamers, Soft matter in drug delivery and diagnostics.

References
[1] Soft Condensed Matter. R. A. L .Jones, Oxford university (2003)
[2] Soft Matter: Complex Materials on Mesoscopic scales. J.K.G Dhont, G. Gompper and D. Richter (Eds) (Forschungzentrum Jülich GmbH, Jülich-2002)
[3] Ordering and Phase Transitions in Charged Colloids. A.K. Arora and B.V.R. Tata (Eds) (VCH-1996)
[4] Colloidal Dispersions. W.B. Russel, D.A. Saville and W.R. Schowalter (Cambridge university press, Cambridge, 1989)
[5] Intermolecular and Surface Forces. (J.N. Israelachvili) (Academic press, London, 1992)
[6] Micelles. Membranes, Microemulsions and Monolayers. Edited by W.M. Gilbet, A. Ben-Shaul and D. Roux (Springer-Verlag, Berlin,1994)
[7] Principles of Condensed Matter Physics. P.M. Chaikin and T.C. Lubensky, (Cambridge university press, Cambridge, 1995)
[8] Polymer Solutions: An introduction to Physical Properties. Iwao Toraoka, (John Wiley & Sons, 2002)
[9] Polymer Physics. M. Rubinstein and R.C. Colby (Oxford University Press ,2003)
[10] Physical properties of polymeric gels. J.P.C. Added (John Wiley & Sons, 1996).
[11] Neutrons, X-rays and Light: Scattering Methods Applied to Soft condensed matter" P. Linder, T. Zebu Eds. (North Holland-Elsevier, 2002)
[12] Dynamic light scattering: Applications of Photon Correlation Spectroscopy. R. Pecora (Plenum, 1985).
[13] The colloidal domain: where physics, chemistry, biology and technology meet. D. F. Evans and H. Wennerstrom (Wiley-VCH)

CY 703: Nuclear Probes for Material Characterization (20)

Positron Annihilation Spectroscopy
Introduction to positron, positronium, formation and its systematic, Experimental techniques, applications in molecular solids, defect studies in metals, alloys and semiconductors, Slow positron accelerators and associated developments in materials characterization.

Ion beam analysis

Introduction to ion beam analysis, Rutherford backscattering spectrometry, elastic recoil detection analysis, nuclear reactions analysis, particle induced gamma ray emission, particle induced X-ray emission-Theory and applications.

Neutron Scattering Techniques
Neutron Sources, Properties of Neutron, Neutron Scattering Lengths and Cross-sections, Coherent and Incoherent Neutron Scattering

Small-Angle Neutron Scattering
Scattering from General Two Phase Systems, Scattering from Fractal Aggregates, Nuclear vs. Magnetic Scattering

Small-Angle Neutron Scattering Instrumentation
Experimental Aspects, Data Treatment

Analysis of Small-Angle Neutron Scattering Data
Model Independent Analysis, Model Dependent Analysis, Contrast Variation

Applications
Nanomaterials, Colloids, Biological Systems, Porous and Fractal Structures)

X-ray absorption Spectroscopy
Introduction of X-ray absorption spectroscopy including different processes of absorption of X-rays in materials, Theoretical formalism of EXAFS, Derivation of the EXAFS equation with physical interpretation, Experimental techniques with some introduction to Synchrotron radiation, Data analysis (EXAFS & XANES), Usefulness of the EXAFS technique in material characterization- with few case studies.

References
[1] Structure Analysis by Small-Angle X-Ray and Neutron Scattering, L.A. Feigin and D.I. Svergun (Plenum Press, New York, 1987)
[2] Neutron, X-Ray and Light Scattering, P. Lindner and T. Zemb (North-Holland, Amsterdam, 1991)
[3] Neutron Scattering from Polymers, J.S. Higgins and H. Benoit (Clarendon, Oxford, 1994)
[4] Analysis of Small-angle Scattering Data from Polymeric and Colloidal Systems: Modelling and Least-squares Fitting, J. S. Pedersen, Advances in Colloid and Interface Science **70**, 171-201 (1997).
[5] Small-angle Scattering Studies of Biological Macromolecules in Solution, D.I. Svergun and M.H.J. Koch, Reports on Progress in Physics 66, 1735–1782 (2003).
[6] Introduction to XAFS: A Practical Guide to X-ray Absorption Fine Structure Spectroscopy, G. Bunker, Cambridge University Press, 2010.
[7] X-ray Absorption: principles, applications and techniques of EXAFS, SEXAFS and XANES, D.C. Koeningsberger and R. Prins, Wiley (NY) 1988.
[8] Treatise on Heavy Ion Sciences, W.A. Landford, Edited by Allan Bromley, vol. 6, (1986), p363.

CY 704: Molecular Bioorganics (20)

New paradigm in synthesis
Rational synthetic design, convergent and divergent strategies, multi-component and domino reactions, sequential reactions, high-throughput synthesis, organocatalysis, substrate and reagent controlled asymmetric synthesis
New paradigm in synthetic approaches
Green strategies, atom economy, bio-catalysis and solvent engineering, microwave and sono-chemistry, non-conventional reaction media (room temperature ionic liquids, super critical fluids, florous phase, super-heated steam), template-driven synthesis.

New paradigm in functional targets
Design and synthesis of functional molecules/ molecular assemblies, non-covalent interactions, electro-magnetic radiation active organics, organic-inorganic hybrids, organics in nuclear fuel cycles.

References

[1] J. Zhu and H. Bienayme, Multicomponent Reactions, Wiley-VCHVerlaggmbH& Co. 2005.
[2] G. Jung, Combinatorial Chemistry: Synthesis, Analysis, Screening, Wiley, 1999.
[3] W. Bannworth and E. Felder, Combinatorial Chemistry: A Practical Approach, Wiley, 2000.
[4] G. R. Stephenson, Advanced Asymmetric Synthesis, Chapman & Hall, 1996.
[5] P. T. Anastas and T. C. Williamson, Green Chemistry, Oxford Univ. Press, 1998.
[6] C. H. Wong and G. M. Whiteside, Enzymes in Synthetic Organic Chemistry, Pergamon Press 1994.
[7] G. W. Gokel, Advances in Supramolecular Chemistry, 2000.
[8] J. W. Steed and J. L. Altwood, Supramolecular Chemistry, Wiley, 2004.

CY 705: Laser Spectroscopy (20)

Coherence properties of radiation fields
Temporal and spatial coherence, coherence volume, degree of coherence, coherence of atomic systems.

Widths and profiles of spectral lines
Natural line width, Doppler width, collisional broadening of spectral lines, transit time broadening, homogeneous and inhomogeneous line broadening, spectral line profiles in liquids and solids.

Nonlinear optical mixing techniques
Phase matching, second harmonic generation, sum frequency and higher harmonic generation, difference frequency generation, optical parametric oscillator and amplifier, tunable Raman laser, Gaussian beams.

Spectrometers, interferometers, wavemeters and detectors
Basic concepts of spectrometers and interferometers, different kinds of interferometers - Michelson interferometer, Mac-Zhender interferometer, Fabry - Perot interferometer, multilayer dielectric coatings, interference filters, tunable interferometers. Webmeters - Michelson, Sigmameter, Fabry - perot and Feazeu. Detectors – photoconductive and photovoltaic detectors, fast and avalanche photodiodes, photodiode arrays, photomultipliers, multichannel platesand image intensifiers.

Absorption and emission spectroscopic techniques
High sensitivity methods of absorption spectroscopy - cavity ring down spectroscopy. Laser induced fluorescence spectroscopy, photoacoustic spectroscopy, optothermal spectroscopy, ionization spectroscopy, optogalvanic spectroscopy.

Nonlinear spectroscopy
Nonlinear absorption, saturation of inhomogeneous line profiles, hole burning spectroscopy, lamb dip spectroscopy, saturation spectroscopy, polarization spectroscopy, multiphoton spectroscopy, Doppler free two photon spectroscopy, saturated interference spectroscopy.

Laser Raman spectroscopy
Stimulated Raman, coherent anti-Stokes Raman spectroscopy (CARS), Resonance Raman and surface enhanced Raman scattering.

Applications of laser spectroscopic techniques in physics, chemistry and biology

CY 706: Actinide Chemistry (20)

Position in Periodic Table: Electronic configuration, The Actinide Concept, Transuranium elements.

Actinide Spectroscopy: Electronic states, Atomic properties, UV-visible absorption and emission spectroscopy. Time resolved fluorescence spectroscopy (TRFS).
Electronic structure and bonding: Introduction to *'f'* orbitals and their splitting in the ligand field. Relativistic effect and its consequences. Modern techniques for understanding the bonding in actinide compounds.

Co-ordination Chemistry: Ionic radii, Coordination number, Hydration Energy.

Redox Behavior: Redox potentials, Eh-pH diagrams, Variable oxidation states, Ionic species, unusual oxidation states in actinides and their stabilization, Thermodynamic/ kinetics of redox reactions, Disproportionation.

Hydrolysis of Actinides: Hydrolysis, Polymerization / Depolymerization.

Auto-radiolysis: Auto-radiolytic effects in aqueous solutions, Auto-radiolysis effects in solid compounds of actinides.

Complexation behaviour with inorganic/organic ligands: Ion-exchange, Solvent extraction methods for actinides (inter and intra-group separations), Complexation reactions relevant in CQC of nuclear fuels, Analytical chemistry of transplutonium elements, Lanthanides-actinide separation, SANEX process.
Actinides in the Environment: Natural abundance of actinides, Oklo phenomenon, Actinide speciation in aquatic environment, Complexation with naturally occurring organics such as humic acid and fulvic acid, Sorption and Migration, Interaction with rock, clay, mica etc. Formation and migration of radiocolloids.

Biochemistry of Actinides: Actinide-microbe interaction, Actinide migration in the food chain, Fixation in human, Pu in blood, Intra-cellular uptake of Pu, Sequestering using chelation therapy, Bioremediation of nuclear wastes.

Transactinides: Production, Rapid separation techniques, Atom-at-a-time chemistry. Aqueous chemistry of elements 104, 105 and 106

References
[1] J.J. Kratz, G.T. Seaborg and L.R. Morss; The Chemistry of Actinide Elements, 2nd Edition, Vol. 1&2, Chapman & Hall, New York (1986).
[2] J.J. Katz, L.R. Morss, J.Fuger, and N.M. Edelstein; Chemistry of Actinide and Transactinide Elements, 3rd edition, Springer, Berlin Volume 1-5, (2006).
[3] J.C. Bailar, H.J. Emelius, R. Nyholm and A.F. Trotman-Dickenson; Comprehensive Inorganic Chemistry, Vol. 5, Pergamon Press, Oxford (1973).
[4] A.J. Freeman and C. Keller (Eds.); Handbook of Chemistry and Physics of the Actinides, Vol. 1-6, North Holland Publishers, Amsterdam (1986).
[5] G.R. Choppin and M.K. Khankhasayev; Chemical Separation Technologies and Related Methods of Nuclear Waste Management, Kluwer Academic Publishers, Netherlands (1999).
[6] G.R. Choppin and J. Rydberg; Nuclear Chemistry, Theory and Application, Pergamon Press, Great Britain (1980).

CY 707: Computational Chemistry (20)

Introduction: Revision to Classical Mechanics, Revision to Quantum Mechanics
Force Field Methods: Force Field Energy , Stretching, Bending, Out-of-plane bending, Torsion, van der Waals, Electrostatic, cross terms, Validation of Force Fields, Advantage & Limitations.
Optimization Techniques: Finding Minima-Steepest descent, Conjugate gradient methods, Newton–Raphson methods; Finding Saddle Points-linear and quadratic synchronous transit, gradient norm minimization, Newton–Raphson; Conformational Sampling and the Global Minimum Problem; Stochastic and Monte Carlo methods; Simulated annealing.
Electronic Structure Methods: Self Consistent Field Theory, Restricted & unrestricted HF, Semi-empirical Methods.
Electron Correlation Methods: Configuration Interaction Methods, Multi Configuration Self-Consistent Field, Many Body Perturbation Theory, Couple Cluster Method.
Basis Sets: Slater and Gaussian Type Orbitals, Pople style basis sets, Dunning–Huzinaga basis sets, Correlation consistent basis sets, Plane Wave Basis Functions, Basis Set Superposition Errors.
Density Functional Methods: Kohn–Sham Theory, Reduced Density Matrix Methods, Exchange–Correlation Functionals-Local Density Approximation, Hybrid or hyper-GGA methods, DFT Problems.
Wave Functional analysis: Population Analysis Based on Basis Functions, Population Analysis Based on the

Electrostatic Potential, Population Analysis Based on the Electron Density, Localized Orbitals, Natural Atomic Orbital and Natural Bond Orbital Analysis.
Molecular Properties: Perturbation Methods, Derivative Techniques, Electric Field Perturbation, Magnetic Field Perturbation.
Simulation Techniques: Monte Carlo Methods, Molecular dynamics methods.
Computer Laboratory Work: Ab initio electronic structure calculation of small systems-designing of input using a visualization program, running an electronic staructure calculation applying GAMESS program, analyzing output manually and using visualization program.

References
[1]. An Introduction to Computational Chemistry by Frank Jensen (Wiley)
[2]. Essentials of Computational Chemistry: Theories and Models by Christopher J. Cramer (Wiley)
[3]. Electronic Structure: Basic Theory and Practical Methods by Richard M. Martin. (Cambridge University Press)
[4]. Molecular Quantum mechanics by Atkins & Friedman
[5]. Computer Simulation of Liquids by Allen & Tildesley

CY 708: Advanced NMR Spectroscopy (20)

The basics of NMR experiment
Basics of NMR spectroscopy, Pulse NMR, The mechanisms of relaxation, The components of a modern NMR instrument, Basic data acquisition and processing

The NMR of Important Nuclei
Chemical shifts for ^{1}H, ^{13}C and ^{31}P nuclei, Homolnuclear and heteronuclear couplings (J), Factors that influence the sign and magnitude of J

Double Resonance Techniques and Complex pulse sequences
Decoupling experiments (homonuclear and heteronuclear), Nuclear Overhauser Effect (NOE), Distortionless Enhancement by Polarization Transfer (DEPT) Experiments

The study of dynamic processes by NMR
Reversible and irreversible dynamic processes, Reversible complexation and chemical shift reagents, Variable temperature NMR, Determination of activation parameters

Two-Dimensional NMR Spectroscopy
Basics of 2D NMR experiments, ^{1}H-^{1}H Correlation Spectroscopy, ^{1}H-^{13}CCorrelaion Spectroscopy,

Nuclear magnetic resonance in solids
Basic NMR interactions in the solid state and their relative magnitudes, Chemical shift tensors and their orientation, Dipolar and quadrupolar couplings, Electron Paramagnetic effects in solid state NMR, Differences in the solid state NMR spectra from spin ½ and quadruple nuclei, Detection of NMR signals in solids, Wide line and zero field NMR experiments

High resolution Solid State NMR experiments
Magic Angle Spinning (MAS) NMR experiments, Side band manipulations and line shape analysis in MAS NMR experiments, Evaluation of chemical shift anisotropy parameters form side band intensity analysis, Cross Polarization Magic Angle Spinning (CP MAS) NMR experiments with suitable examples, Probing the local environmentaround nuclei and measurement of inter-nuclear distances by different solid state NMR techniques, Variable temperature MAS NMR experiments, Multi Quantum (MQ) MAS NMR experiments, Application of solid state NMR techniquesfor characterization of glasses, porous and amorphous materials, polymers, biomaterials, nano-materials, hybrid-materials, catalysts etc.,

Principle of NMR imaging.

References:
[1] Understanding NMR Spectroscopy, 2nd Edition, James Keeler, Wiley, 2008

[2] Becker Edwin D., High Resolution NMR: Theory and Chemical Applications, 3rd Edition, Academic Press 1999.
[3] A complete introduction to modern NMR spectroscopy, R. S. Macomber, Wiley Interscience, 1998.
[4] Sanders, Jeremy K. M. and Brian K. Hunter. Modern NMR spectroscopy: a guide for chemists, Oxford; New York : Oxford University Press, 1987.
[5] Solid state NMR in Materials Science: Principles and Applications By Vladimir I. Bakhmutov, CRC Press, Boca Raton (2012)
[6] C. A. Fyfe, Solid State NMR for Chemists, CFC press, Guelph (1983)

CY 709: Atmospheric Chemistry (20)

Structure of Atmosphere
Physical characteristics, Chemical Composition, Carbon, Hydrogen and oxygen cycle.

Atmospheric Radiation
Terrestrial and solar radiation, Energy balance for Earth and Atmosphere, Radiative flux, Actinic flux; Spectroscopy, Absorption of radiation by atmospheric gases and aerosols, Absorption by O_2 and O_3, Radiative forcing, Photolysis rate as a function of altitude.

Chemistry of Troposphere and Stratosphere
Stratosphere - Chapman mechanism - HO_x, NOx cycle
Troposphere - Hydroxyl radicals and other tropospheric oxidants, Photochemical cycles of NO_2, NO and O_3 , Chemistry of NO_x, carbon monoxide, Methane, Definition of tropospheric lifetimes, Importance of gas phase kinetics.

Atmosphere Pollutants
Oxides of nitrogen, Volatile Organic Compounds (VOCs), Halogenated compounds, Sulfur compounds and particulate matter.

Effects of pollution
Photochemical smog - production of ozone and NOx; trends in trophospheric ozone concentration, relationship of VOCs and NOx to O_3, atmospheric chemistry of ozone and its precursors, chemistry of sulfur and nitrogen compounds, Acid Deposition.

Global effects of pollutio
Green House Effect, Global Warming Potential, Stratospheric Ozone Depletion, Ozone depletion Potential, Montreal / Kyoto protocol.

Laboratory and field measurements
Techniques for species identification and quantification, Aerosoles - formation, sampling and characterization. Experimental methods to study reactions of importance in the atmosphere (Laser Induced Fluorescence, Chemiluminescence, Cavity Ring Down Spectroscopy).

References
[1] Introduction to Atmospheric Chemistry, D.J. Jacob, Princeton University Press, 1999.
[2] Atmospheric Chemistry and Physics, from Air Pollution to Climate Change, J.H. Seinfeld and S.N. Pandis, Wiley-Interscience.
[3] Introduction to Atmospheric Chemistry, P.V. Hobbs, Cambridge University Press, 2000.
[4] Chemistry of the Upper and Lower Atmosphere, Finlayson-Pitts and Pitts, Academic Press.
[5] Atmospheric Chemistry, A.M.Holloway and R.P.Wayne, RSC Publishing.
[6] Chemistry of Atmospheres, R. P.Wayne, Oxford University Press, 1991.

CY 710: Statistical Analysis (20)

Population and Sample, Treatment of data, Frequency distribution, Measure of central tendency, Measure of variability, Probability distribution, Probability, Discrete distribution, Continuous distribution, Sampling theory, Sampling distribution, Sampling distribution of means, Statistical inference, Test of hypothesis and significance, One tailed and two tailed tests, Type I and type II errors, Operating characteristic curves and power of a test, Sampling distribution of variance, F distribution, Chi-square distribution, Curve fitting, The method of least squares, Regression, Correlation theory, Linear correlation, Multiple correlation, Analysis of variance, One-way ANOVA, Two-way ANOVA, Factorial designs.

References

[1] Murray R Spiegel, Statistics: Schaum's outline series
[2] F. J. Dixon and W. J. Massey, Introduction to statistical analysis
[3] S. N. Deming and S. L. Morgan, Experimental Design: A chemometric approach
[4] Zivorad R. Lazic, Design of experiments in chemical Engineering
[5] J. N. Miller, J. C. Miller, Statistics and chemometrics for analytical chemistry, Sixth edition

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NON-SUBJECT ASSIGNMENTS

CY 591: Viva Voce

In addition to the formal assessment carried out by the method of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

CY 592: Mini-Project

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the Mini-Project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provide useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.
The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.

CY 593: Seminar

As a part of the course curriculum, all trainees have to make a seminar presentation. For this purpose, the trainee is asked to choose a topic of presentation based upon his/her aptitude and area of research interest. The objective of this exercise is to inculcate skills in the trainee on aspects such as analysis of the experimental data, details discussion on the results and hypothesis presented and drawing of meaningful conclusions. A Seminar Committee constituted for this purpose evaluates the presentation based upon attributes such as scientific content, quality of presentation and ability of the trainee to defend the subject of presentation. A maximum of 100 marks have been allocated for the seminar.

Homi Bhabha National Institute
(A university established under Section 3 of the UGC Act. 1956)
Indira Gandhi Centre for Atomic Research
Kalpakkam – 603 102 Tamil Nadu, India

M.Phil. in Chemical Sciences Courses under IGCAR (Program Code: CHEM02)

Homi Bhabha National Institute
(A university established under Section 3 of the UGC Act. 1956)
Indira Gandhi Centre for Atomic Research
Kalpakkam – 603 102 Tamil Nadu, India

Chemical Sciences Courses offered in HBNI & Course coordinators

CH-1 : Mathematics and Computational methods (6 credits)

CH-2 : Chemical Thermodynamics (6 credits)

CH-3 : Electrochemistry and Corrosion Science (4 credits)

CH-4 : Introduction to Materials Science and Engineering (6 credits)

CH-5 : Analytical Chemistry for Nuclear Fuel Cycle (6 credits)

CH-6 : Chemical Instrumentation and Laboratory Techniques (6 credits)

CH-7 : Health Physics and Radiation Sciences (6 credits)

CH-9 : Chemistry of Fuel Cycle-I(6 credits)

CH-10 : Chemistry of Fuel Cycle-II: Actinide chemistry and separation science (6 credits)

CH-11 : Materials for Nuclear Reactors and Fuel Cycle Processing Systems (6 credits)

CH-12 : Nuclear and Radiochemistry (6 credits)

CH13 : Corrosion Science and Engineering (6 credits)

CH-14 Quantum Chemistry & Group Theory (6 credits)

CH-15 : Molecular Spectroscopy (6 credits)

CH-16 : Lasers and Application (6 credits)

CH-17 : Nanomaterials and Advanced Chemical Sensors (6 credits)

CH-RM: Course on Research Methodology (3 credits)

CH-1: Mathematics, computational methods, numerical analysis and computer programming

Course content

1. **Differential Equations & Integral Transforms:** Linear differential equations: Series method of solution; Legendre, Lagurre and Hermite differential equations. Use of ladder operators for solutions to differential equations; applications to quantum chemistry.

Orthogonal Polynomials and Special functions – Dirac Delta function, gamma function, error function. Introduction to Fourier series, Fourier transform and Laplace transform – applications in quantum chemistry and spectroscopic techniques – FT-NMR, FT-IR.

Convolutions of functions, use of Fourier transforms in convolution, Applications in chemistry.

2. **Vectors:** Vector differentiation and integration: Concepts of gradient, divergence and curl and their physical significance. Orthogonal vectors, Gram-Schmidt process – applications in quantum chemistry. Vector fields in space – Gauss and Stokes theorem with applications.

3. **Matrix Algebra:** Elementary operations and elementary matrices. Rotation matrices, Similarity transformations; Applications of numerical techniques in matrix algebra to evaluate eigenvalues and eigenvectors; Diagonalization and inversion of matrices. Applications in chemistry.

4. **Numerical Methods:** Newton-Raphson method for finding roots, differentiation, integrations by quadrature techniques, solutions of differential equations.

Book suggested

1. Advanced Mathematics for Engineers and Scientists, M.R. Spiegel, Schaum's Outline Series(1983).
2. Mathematical Methods for Physics Engineering, K.F. Riley, M.P. Hobson and S.J. Bence, Cambridge University Press (1998).
3. Theory and Problems of Vector Analysis, M.R. Spiegel, Schaum's Outline Series (1981).
4. Computer Oriented Numerical Analysis, V. RajaRaman, Prentice Halls India, 3rd ed. (1999)
5. Mathematical Physics, E. Butkov, Addison-Wesley Publishing Company, California (1968).

CH-2: Chemical Thermodynamics

Course content

1. **Laws of Chemical Thermodynamics:** Thermodynamic laws, thermodynamic properties of the system, criterion for equilibrium, Heat engines, Helmholtz energy, Gibbs energy, Closed system, Maxwell's equations, Gibbs-Helmholtz equation.

2. **Behaviour of Gases:** Gas laws, ideal gas and deviations from ideality, Vander Waal's equation, equation of state, critical phenomena,Thermodynamic treatment of non-ideal gases, gas mixtures.

3. **Solutions:** Raoult's and Henry's laws, activity of a component in solution, Gibbs-Duhem equation, Properties of Raoultian ideal solutions, Colligative properties, Non ideal and regular solutions, Partial and Integral thermodynamic property evaluation, alpha function, Gibbs free energy of formation of regular solutions, Criteria for stability of regular solutions, Miedema's model, associated solution model, sub-regular solutions, Models for ternary systems such as Colinet's model.

4. **Phase Equilibria:** Phase rule, Gibbs Free energy as a function of temperature and pressure, Equilibrium between a vapor and a condensed phase in a single component system, Graphical representation of phase equilibria in a single component system, Gibbs energy and thermodynamic activity, phase diagrams- single component, binary and ternary diagrams, simple calculation of thermodynamic properties from phase diagram, pressure-composition diagrams, CALPHAD and models for optimization of phase diagrams.

5. **Reactions in Gases and Condensed Phases:** Reaction equilibria in homogeneous and heterogeneous media, effect of temperature and pressure on equilibrium constant, Le Chatlier's principle, Reaction equilibria in H2/ H2O, CO/CO2 systems, Ellingham diagrams, Effect of phase transformation, use of different standard states for representing reactions in condensed phases, phase stability diagrams, application of phase diagrams in material systems.

6. **Statistical Thermodynamics:** Entropy and disorder in an atomic scale, concept of microstate, most probable microstate, influence of temperature, Boltzmann equation, partition functions, configurational entropy and thermal entropy.

7. **Experimental Thermodynamics:** Calorimetry - classification of calorimeters, different types of calorimeters, heat capacity measurements, thermochemical calorimetry, estimation of thermodynamic quantities.

Vapor pressure measurements- static methods, transpiration, boiling point method, isopiestic method, Knudsen effusion method , Langmuir evaporation method, role of mass spectrometry for study of vaporization reactions, second and third law methods, Gibbs energy functions from spectroscopy data, measurements at very high temperatures.

Galvanic cell EMF methods for activity measurements, - solid electrolyte and molten salt EMF methods.

Measurement of oxygen and carbon potentials – gas equilibration/ EMF methods

Determination of phase diagrams- spot technique, thermal analysis, enthalpies of transformations, transformation temperature, order of transformation, DTA, TGA, thermal expansion, resistivity- as a function of temperature , thermal diffusivity, measurement of thermal diffusivity and thermal conductivity.

Books Suggested:

1. Physical Chemistry, G W Castellan, Addison Wesley, 1971
2. Introduction to Metallurgical Thermodynamics, David R Gaskell, McGraw Hill, 1973.
3. Physical Chemistry, P W Atkins, 7th Ed, Cambridge University Press, 2004.
4. Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering, K Denbigh, Cambridge University Press, 1981.
5. Chemical and Process Thermodynamics, 2nd Ed, B G Kyle, Prentice Hall, 1992.
6. Thermodynamics, G N Lewis, M Randall, revised by K S Pitzer and L Brewer, McGraw Hill, 1961.
7. Differential Scanning Calorimetry: An Introduction for Practitioners, G W H Hohne, Springer Verlag, 1996.
8. Characterisation of high temperature vapours, Ed by J L Margrave, John Wiley, New York, 1967.
9. Physicochemical Measurements in Metal Research, Ed by R F Bunshah, Wiley Interscience, New York, 1970.

CH-3: Electrochemistry

Course content

1. **Electrolytes** – Different electrolyte systems (aqueous, ionic melts and solid electrolytes) and their conductivities; Debye-Huckle theory, Techniques for measuring electrical conductivities - DC and AC techniques

2. Electrochemical cells - Electrochemical potentials, Nernst equation and electrochemical series, Molten salt and solid electrolyte based cells

3. Electrode processes and kinetics – Diffusion layers & characteristics of the diffusion layers, over potentials, Butler-Volmer and Tafel equations, polarisable and non-polarisable electrodes, reference electrodes, voltammetric techniques, polarography, Cyclic Voltammetry, rotating electrodes and micro-electrodes, chronpotentiometric and chronoamperometric techniques, elucidation of mechanisms of electrochemical reactions.

4. Applications of electrochemical principles - Electro-analytical techniques and electrochemical sensors; energy conversion and storage systems (fuel cells and batteries); thermochemical data measurements.

Reference Books:

1. "Electrochemical Methods: Fundamentals and Applications**"**, AJ Bard & LR Faulkner, Wiley, New York, 1987.
2. "Electrode Dynamics**"**, AC Fisher, Oxford University Press, Oxford, 1996.
3. "Electrochemistry", **P**.H. Reiger, Prentice-Hall International, Englewood Cliffs, 1995.
4. "Solid electrolytes and their Applications", (Ed) E.C.Subba Rao, Plenum, New York, 1980.
5. "Electrochemistry", C. M. A. Brett and A. M. O. Brett, Oxford University Press, 1993.
6. "Laboratory Techniques in Electroanalytical Chemistry", 2nd Ed., by P. T. Kissinger and W. R.Heineman, Marcel Dekker, 1996.
7. "Chemical Sensor Technology", Vol.2, (ed) T.Seiyama, Kodansha Ltd., Tokyo, 1989.
8. "Chemical Sensor Technology", Vol.3, (ed) N.Yamazoe, Elsevier, Amsterdam, 1991.
9. "Solid State Gas Sensors", P.T.Mosley and B.C.Toefield, Adam Hilger, Bristol, 1987.
10. "Advances in Electroanalytical Chemistry", Vol.2, A.J.Bard, Macel Dekker, New York, 1967.
11. "Fuel Cell Systems", L.J.M.J.Blowmen and M.N.Mugerwa, Plenum Press, New York, 1993.

CH-4: Introduction to Materials Science & Engineering

Course content

1. **Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.

2. **Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.

3. **Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.

5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.

6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.

7. **Phase Diagrams & Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley & Sons, N.Y., 2003.

7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

CH-5: Analytical Chemistry for Nuclear Fuel Cycle

Course content

1. **Instrumental Methods – Principles and Applications:**

Spectrochemical Methods: Detectors- Photomultiplier Tube (PMT), Charge Coupled Device (CCD), Charge Injection Device (CID), Spectrometers – Czerny Turner, Echelle, Sample Introduction Devices – Flame, Electrothermal, Laser Ablation, Direct Sample Insertion Devices, Interferences, detection limits, sensitivity, Absorption Spectrometry – Flame Atomic Absorption Spectrometry, (FAAS), Electrothermal Atomic Absorption Spectrometry (ETAAS), Optical Emission Spectrometry (OES) with Inductively Coupled Plasma (ICPOES), Glow Discharge (GDOES), Fluorescence Spectrometry – Laser Induced Fluorescence (LIF), Recent advances – Continuum Source (CS-AAS), Single Atom Detection.

Mass Spectrometry: Mass Analysers – Magnetic, Quadrupole, Time of Flight (TOF), Ion Cyclotron Resonance, Features – Resolution, Dispersion, Abundance, Sensitivity, Detectors – Faraday Cup, Channeltron, Daly, Ion Sources –Thermal Ionisation (TI), Electron Impact, ICP, GD, Laser Ablation (LA-ICP), Secondary Ionisation (SI), Resonance Ionisation (RI), Matrix Assisted Laser Desorption and Ionisation (MALDI), Hyphenated Technique – ICP-MS, HPLC-MS, GC-MS.

Thermal Methods: Thermogravimetric Analysis (TGA), Derivative Thermogravimetric Analysis (DTG), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Evolved Gas Analysis (EGA).

Nuclear Methods: Activation Analysis – Neutron Activation Analysis (NAA), Charged Particle Activation Analysis (CPAA), X-ray fluorescence (XRF) spectrometry, Ion Beam Analysis – Backscattering Spectrometry (BS), Particle Induced □-ray Emission (PIGE), Nuclear Reaction Analysis (NRA), Elastic Recoil Detection Analysis (ERDA), Particle Induced X-ray Emission (PIXE).

2. **Separation Techniques – Principles and Applications:**

Solvent Extraction Technique: Conventional, Liquid Membranes – Bulk, Supported and Emulsified, Solid Phase Extraction (SPE).

Ion Exchange: Conventional and Membranes.

Chromatography: Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion chromatography (IC).

3. **Statistical Methods in Chemical Analysis:** Methods of sampling and associated errors, Classification of errors, Propagation of errors, treatment of errors, Normal distribution, Tests of Significance and Confidence Limits. Method of Least squares – linear and non-linear, weighted least squares formalism, constrained least squares fitting

4. **Laboratory Experiments (any 5):**

Determination of trace impurities in high purity materials by AAS.

Application of Electroanalytical Methods to trace analysis

TGA and DTA study of inorganic compounds

Neutron Activation Analysis of trace constituents in a complex matrix

Analysis of an alloy sample by EDXRF

Anion analysis by ion selective electrode.

Chromatographic separation and measurement of the components in a mixture

Isotopic Analysis by Mass Spectrometry

Books suggested:

1. Fundamentals of Analytical Chemistry, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
2. Principles of Instrumental Analysis, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
3. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).
4. Statistics for Analytical Chemistry, J. C. Miller and J. N. Miller, 2nd Edition, Wiley (1998).

CH-6: Chemical Instrumentation and Laboratory Techniques

Course content

1. **Passive Circuit Elements and Configurations:** Circuit behaviour of resistors,inductors and capacitors; the potential divider and the wheatstone Bridge (resistive and capacitive), R-L-C-circuits as filters and resonance circuits.

2. **Electronic Devices and Their Role in Power Conversion and Amplification:** The junction diode, SCR, triacs and their role in rectification and AC power control; bipolar transistor and IGBT and their role in linear/switched mode power supplies and in amplification of signals; constant current power supplies Inverter circuits; issues in measurement of signals - Concept of input impedence and the role of J-FETs and MOSFETs.

3. **Operational Amplifiers and their Various Functionalities:** The basic OP-AMP and its desired characteristics; the inverting amplifier, the non-inverting amplifier, summing configuration;

The differentiator and integrator circuits; comparator; precision rectifier; waveform generation.

4. **Fundamental Issues Related to Chemical Instrumentation:** Role of chemical instrumentation in the nuclear fuel cycle, with relation to selectivity, sensitivity and automation amenability.

The basic anatomy of excitation with energy source-interaction with analyte-detection of the effect produced; issues related to selectivity; sensitivity and detection limits; sources of noise and measures to minimize the effect; boxcar integrator, lock-in-amplifier.

5. **UV-VIS-IR Instruments:** Phenomenon of resonant absorption and Beer's law of photometry; implementation of Beer's law in a spectrophotometer; compensation for spectral response of the detector; slit servo mechanism for compensation of optical emission.

Atomic absorption spectrophotometer-flame ionization, compensation for molecular absorption, hollow cathode lamp excitation for high specificity.

Atomic emission spectrometry-principles, instrumentation and data interpretation

Laser fluorescence spectrometry-laser basics, three stage power supply for flash lamp excitation.

Non dispersive spectrometer- FTIR - principle, data collection scheme.

6. **X-Ray Spectrometry:** Generation of X-Rays, The X-Ray tube, setting the energy and intensity; Bragg's law; X-Ray fluorescence, X-Ray diffraction, ESCA for surface analysis.

7. **Mass Spectrometry:** Ion sources-thermal ionization, Knudsen effusion and electron impact ionization, inductively coupled plasma source, Laser induced vapourisation, spark source.

Magnetic analysers, quadrupole analysers, time-of-flight analysers.

Detectors-faraday, SEM, Channeltron.

Mass scanning, peak centering, signal handling and digitization and counting.

8. **Thermal Analysis:** Thermal excitation - furnaces, temperature profiling and furnace power control.

Thermal effects - TGA, DTA, DSC, dilatometry.

Thermal measurements - thermocouples, RTDs, signal conditioning and handling.

9. **Additional Methods of Analysis:** Gas chromatography - mobile and stationary phases; separation on the basis of retention time; TCD and FID detectors.

Instrumentation for pH meters and conductivity meters; automated titro-processors and applications of coulometry.

Radioactive assay based on multi-channel gamma ray spectrometry.

10. **Digital Electronics:** Logic gates; flipflops, counters, astable and monostable multivibrators; decoders; logic families; data conversion-various types of ADCs and DACs.

Microprocessor systems-processor architecture, memory circuits, I/O subsystems; interfacing techniques; assembly language programming.

11. **Laboratory Techniques:** Machine Drawings Projections: orthographic – 1st & 3rd Angles

pictorial; Oblique: Perspective. Conventional representation of common features and sections;

Dimensioning and tolerancing; Scales, lines and lettering; Threads; Fastenings. Brief Introduction of AutoCAD and its use, common drawing and edit commands.

Vacuum systems - equipment for vacuum generation - rotary pumps, diffusion pumps, ion pumps, turbo molecular pumps; Generation of high temperatures, measurement of vacuum and temperatures, centrifuges, chemicals and laboratory safety.

12. **Vacuum Generation and measurements:** Kinetic theory of gases – Velocity distribution – Mean free path – Monolayer formation – vacuum units – Viscous and molecular Flow regimes – Reynold's and Knudsen Numbers viscosity and thermal conductivity of gases – Gas release from solids – vaporization – out gassing – diffusion – permeation – Vacuum pumps – Titanium Sublimation pumps – Ion pumps – Cryogenic pumps and maters for construction of Vacuum chamber.

Gauges: Thermal conductivity, cold cathode, hot cathode ionization gauges and their Principle of operation.

Books suggested:

1. Principles of Instrumental Analysis, D. A. Skoog and J. Leary, McMillan Publishers,
2. Instrumental Methods of Analysis, H. H. Willard, L. L. Merritt, Jr., J. A. Dean, F. A. Settle, Jr. CBS Publishers and Distributors, New Delhi 1986.
3. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).

CH-7: Health Physics and Radiation Sciences

Course content

1. **Interaction of Radiation With Matter:** Ionization in gaseous medium, Bragg's curve, stopping power, Bethe equation, range of particles and straggling, LET, attenuation and absorption of beta particles, backscattering, photoelectric, compton and pair production processes for gamma radiation, variation with gamma energy and Z of medium, attenuation and absorption of gamma rays, elastic and inelastic scattering of neutrons.

2. **Radiation Detection and Measurement:** Principles of radiation detectors, counting characteristics, detection efficiency and energy resolution, dead time and counting statistics, Gas filled detectors, scintillation processes and detectors, organic and inorganic scintillators, NaI(Tl), LaBr3, semiconductor detectors, p-n junctions, germanium and silicon detectors, room temperature semiconductors, neutron detectors including bubble detectors, solid state nuclear track detectors, nuclear probes - positron annihilation, perturbed angular correlation, mossbauer effect.

3. **Shielding and Dose Calculations:** Shielding (beta, gamma and neutron sources).

Shielding from mixed sources; calculation of dose for point, line and volume sources.

4. **Dosimetry:** Definition of various dosimetric terms (exposure, absorbed dose, equivalent dose, effective dose, concept of radiation and tissue weighting factors and their importance, Activity, Specific activity (SI units and Old units), radiological, biological and effective half-life and their relation and the concept of the same and their importance. Concept of ALI and DAC.

5. **Radiation Protection Principles:** Radiation protection philosophy, objectives and principles of radiation protection, Dose limits to occupational workers and members of public, Dose constraints, Investigation limits. Types of exposure (natural, occupational, medical and public).

External and internal exposures; routes of intake of radioactive material. Use of personal dosimeters (Film badge, TLDs, pocket dosimeters). Calculation of internal dose, Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given), exposure-dose relationship, Bragg-Gray principle.

Fundamentals of ICRP respiratory model, entry through ingestion, GI track model, wholebody counting and bioassay techniques.

6. **Radiation Protection Procedures:** Procedures followed in radiation work places, supervised and controlled areas, work permits, contamination control methods (air-borne, surface and personnel), swipe samples, and rubber areas, spill pack (gloves + absorbing paper), decontamination and de-corporation techniques; bore wells and inspection chambers; precautions during radioactive source storage and handling.

Types of radiation monitors / radioactivity measurement methods adopted for radiation protection. Personnel monitoring, area monitoring and stack monitoring.

7. **Waste Management:** Radioactive waste classification and management – An overview.

8. **Emergency Preparedness:** Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, counter measures.

9. **Nuclear Fuel Cycle Applications:** Radiological aspects and environmental impact of FBRs. Criticality safety and Radiological aspects in nuclear cycle facilities.

10. **Regulatory Details:** Atomic Energy Act, National and International regulatory bodies, their role and responsibilities, Radiation Protection Rules, Nature of duties and responsibilities of Radiation Safety Officer / Health Physicist, radio toxicity and classification of laboratories, design of lab for radioactive work, Safe handling of radioisotopes, Transport of radioactive materials.

11. **Basic Radiobiology:** Interaction of ionizing radiation with living cells, Ionizing radiations, excitation and ionization process, basic structure and components of cell, chemical and biological consequences of radiation action, radicals and reactions in cell killing, direct and indirect effect and relevant biological damage.

12. **Molecular and Cellular Effects of Radiation:** Radiation action and organizational level in cell, Damage to DNA, single and double structural breaks in units membrane dose and survival curve, cellular radioactivity, radiobiological effectiveness and linear energy transfer Dzz dose, rate effect, dose fractionation, Mitotic delay, chromosome aberration and mutations by radiation action on cells.

13. **Modification of Biological Effects of Radiation:** Oxygen effect, OER, Chemical radio sensitizers, Chemical radio protectors, Mechanisms of action and importance in nuclear research programme.

14. **Radiobiology and Radiotherapy:** Radiation and cancer, cell cycle and radiosensitivity, rationale of using radiation for tumor cell kill, problems.

15. **Basics of Radiation Chemistry:** Interaction of high energy radiation with matter, G-values, radiation induced reactions in solids, liquids and gases.

Laboratory Experiments:

1. Plancheting, alpha counting and spectroscopy
2. Counting characteristics of gas detectors
3. Half life determination and attenuation coefficient determination
4. High resolution gamma spectrometry
5. Dose Measurements: Whole Body Counting laboratory, Bio-dosimetry laboratory, TLD personnel monitoring services laboratory.

Demonstrations:

1. **Use of Personnel Protective Equipment (PPE):** Proper checking and wearing of gloves, and other plant dresses (shoe covers, boiler suits, overcoats etc).

Respirators (dust, gas mask, self contained breathing apparatus, and fresh air-line) TLD, Film badge, neutron film, criticality badge and bubble detector

2. **Use of Radiation Monitoring Equipment: Installed and Portable Radiation Monitors:** AGM (audio and visual alarm, setting up of alarm limits); staplex air sampler (estimation of air-borne activity-both alpha and beta-gamma), different types of survey meters (low to high range), ALSCIN and GM based contamination monitors (side window and end window, hand and foot monitor, cloth monitor), continuous air monitor, criticality alarm system.

Books suggested:

1. Introduction to Health Physics by Herman Camber
2. Biological Effects of Radiation by J. E. Coggle
3. Radiobiology for Radiologist by Eris J. Hall
4. Detection and Measurement of Radiation - Glenn T Knoll.

CH-9: Chemistry of Fuel Cycle-I

Course content

1. Recovery of the starting compounds bearing U, Pu or Th from their primary and secondary sources. Mining, beneficiation, pre-concentration, purification and recovery.

2. **Oxide Fuels:** Preparation of UO2, PuO2, MOX and ThO2. Physical and chemical properties, phase diagrams of relevance, control of phase composition and stoichiometry, fuel fabrication flow sheet and quality control.

3. **Advanced Ceramic Fuels:** Carbides U-C, Pu-C, U-Pu-C, U-Pu-C-O and U-Pu-C-O-N, Nitrides U-N, Pu-N, U-Pu-N. Physical and chemical properties, phase diagrams of relevance, control of phase composition and stoichiometry, fuel fabrication flow sheet and quality control.

4. **Advanced Fuel Fabrication Techniques:** Oxides, Methods based on sol-gel and novel techniques. Carbides; sol-gel method, direct pressing and arc casting.

5. Preparation of U, Pu and Th.

6. **Alloy Fuels:** Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-RM, U-Pu- MA), dispersions and composites – Salient physical and chemical properties, relevant phase diagrams, fabrication and quality control.

7. **Inert Matrix Fuels for Partitioning and Transmutation:** A brief account on the current developments.

8. **Fuel – Clad Interaction:** Significance of FCCI and FCMI. Specifics pertaining to oxide, carbide and metallic fuels. Role of chemical thermodynamics in the prediction and understanding of Fuel clad chemical compatibility.

9. **In Pile Behaviour of Fuels:** Chemistry and redistribution of fission products, role of chemical potentials of the constituents in the breach of clad in oxide, carbide and alloy fuel pins and detection mechanisms.

Books suggested:

1. Donald R. Olander, Fundamental aspects of nuclear reactor foel elements fundamental aspects of nuclear reactor foel elements, Springfield, BTIS, 1985.
2. H. J. Matzke, Science of Advanced LMFBR fuels, North Holland, Amsterdam, 1986.
3. M. Benedict and T.H. Pigford, Nuclear Chemical Engineering, Mc Graw Hill, New York, 1957. (Specific journal articles and other references will be cited during the lectures)

CH-10: Chemistry of Fuel Cycle–II

Course content

1. **Actinide Chemistry:** Discovery of actinide elements, electronic structure, oxidation states, inter-conversion of oxidation states, complexes of actinide ions, actinide contraction, comparison of actinides with lanthanides. Actinides in environment.

Purification of actinides using techniques such as ion-exchange, Solvent Extraction, Liquid membranes and Chromatographic Methods.

Hydrolysis, colour, spectroscopy and magnetic properties of actinides, nuclear properties of actinides, decay modes.

Thorium: isotopes, occurrence and production; Uranium: isotopes, occurrence, resour0ces and production.

Transuranium Elements: production of transuranic elements, Neptunium, Plutonium, Americium and Curium; Actinide synthesis by heavy ion reactions.

Fission Product Chemistry.

2. **Aqueous Reprocessing:** Introduction to nuclear fuel reprocessing; Need for reprocessing; PUREX, TRUEX, THOREX.

Latest developments. Solvent extraction for actinide purification; basic principles, introduction to extractants, classification of extractants.

Purification of uranium, plutonium; lanthanide actinide separations.

3. **Pyrochemical Reprocessing:** Introduction to non aqueous reprocessing: Objectives and advantages of non aqueous reprocessing in fast reactor fuel cycle, Advanced fuel cycle flowsheets involving non aqueous reprocessing, Recent trends in pyrochemical reprocessing of oxide and metallic fuels.

Oxide electrowinning flowsheet, Pyrochemical reprocessing of metallic fuels (IFR process) - Integral Fast Reactor Concept, Differences in electrorefining and electrowinning.

4. **NUMAC:** Importance of Nuclear Material Accounting; techniques used for analysis of nuclear materials.

NUMAC with techniques such as Potentiometry, Coulometry, Amperometry.

Mass Spectrometry, Calorimetry, Gamma counting, neutron counting etc. Advantages and drawbacks of individual methods.

5. **Post Irradiation Techniques:** Introduction to post-irradiation examination methods of nuclear reactor fuels; importance of PIE methods, burn-up measurements; NDE testing of fresh fuel pins.

Non-destructive evaluation of irradiated fuels (X-ray and neutron radiographic examination of fuel pins, Fission gas analysis, Metallographic examinations).

6. **Nuclear Waste Management:** Introduction - industrial waste, nuclear waste & its speciality, generation of radioactive wastes, radioactivity in the environment, Solid, liquid & gaseous wastes, international classification. Basic philosophy & methods of radioactive waste management, environmental monitoring. HLW & spent fuel waste. Radioactive waste immobilization matrices & their ultimate disposal.

Reference Books

1. "**Handbook of Physics and Chemistry of Rare Earths: Lanthanides Actinides**" G.T. Seaborg, Vol.18,(Eds., K.A. Schneider, Jr., L. Eyring, G.R. Choppin and G.H. Lander), Elsevier Science, Amsterdam (1994).
2. "**The Chemistry of Actinide Elements**", J.J. Katz, G.T. Seaborg and L.R. Morss, Vol. 1 and 2, 2nd Ed., Chapman and Hall, New York (1986).

3. "**Handbook of Physics and Chemistry of Actinides**", A.J. Freeman and C. Keller,North Holland Amsterdam, Vol.3 (1985), Vol.4 (1986), and Vol.6 (1991).

4. "**The Chemistry of Transuranium Elements**", C. Keller,Verlag Chemie GmbH, Germany (1971).
5. "**Summary of the Properties of Lanthanide and Actinide Elements**" G.T. Seaborg and D'E.Hobart in 'Frontiers in Nuclear Chemistry', Eds. D.D. Sood, A.V.R. Reddy and P.K. Pujari, IANCAS publication, Mumbai (1996)
6. "**The Chemistry of Plutonium**" J.M. Cleveland, Gordon and Breach Science Publishers, Newyork, 1970

7. "**Solvent Extraction of Metals**", A. K. De, S. M. Khopkar and R. A. Chalmers, Van Nostrand, Reinhold (1970).
8. "**Ion Exchange and Solvent Extraction : A Series of Advances**", Editors J. A. Marinsky and Y. Marcus, Marcel Dekker Inc. (1998).
9. "**Ion Exchangers**", F. Helfferich, McGraw Hill (1962).
10. "**Introduction to Modern Liquid Chromatography**", L. R. Snyder and J. J. Kirkland, 2nd Edition, Wiley (1979).
11. "**Analytical Chemistry**", R.V.Dilts, Van Nostrand (1974).
12. "**Modern Practice of Gas Chromatography**", by R.L.Grob and E.F.Bary, 4th Edition, Wiley-Interscience.
13. "**Practical Supercritical Fluid Chromatography and Extraction**", M. Caude, D. Thiebaut, Eds.) Harwood Academic Publishers (1999).
14. "**Supercritical Fluid Extraction**", M.A.Mchugh and V.J.Krukonis, Butterworth Heinemann, 2nd Edition, 1994
15. "**Fundamentals of Analytical Chemistry**", D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
16. "**Principles of Instrumental Analysis**", D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
17. "**A text book of Quantitative Analysis**", A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).

CH-11: Materials for Nuclear Reactors and Fuel Cycle Processing Systems

1. Fundamentals of reactor physics and different reactor systems

a) Fission reactors: Thermal reactor, fast reactor, advanced reactor, b) Fusion reactors: Thermonuclear reactor

2. Health Physics and Radiation Sciences

Interaction of radiation with matter, Radiation detection and measurement – use of gas filled detectors, scintillators, semi-conductor detectors, neutron detectors, Radiation Units and Limits.

Hazards Control and Evaluation, Biological effects of radiation, Dose and dose limits for occupational workers and members of public, Radiation Protection Procedures, Dosimeters.

Transport and release, Classification of nuclear waste and their management –Emergency Preparedness, Radiation Chemistry, G-values, radiation induced reactions in solids, liquids and solids.

3. Introduction to Reactor Materials

Moderators (Requirements, properties of D_2O and graphite), C**ontrol rod materials (**Requirements, properties), **Coolants** (Requirements, properties and handling - water, liquid sodium, lead-bismuth alloys, helium, CO_2), **Cover gas (**Cover gas purification, monitoring for hydrogen, fission gases)

4. Introduction to Coolant chemistry:

Na, Pb-Bi and Pb-Li chemistry: Monitoring and maintaining purity of coolants, on-line monitoring using EC monitors, sampling and analysis.

Water chemistry (Introduction to fast reactor water chemistry, condenser cooling and process water chemistry, de-mineralising plant and condensate polishing unit chemistry, on-line monitoring, biological shield cooling water chemistry, related analytical techniques, Chemical aspects of corrosion in liquid metal coolant systems

5. Fuel reprocessing: Chemistry of Actinides with respect to reprocessing, Aqueous methods - Purex, Thorex, use of novel extractants, Non-aqueous methods - pyrochemical processes.

Books Suggested:

1. S. Glasstone, Source Book on Atomic Energy, Allied East-West Press Pvt. Ltd., NewDelhi.
2. S. Glasstone and Sesonske, Nuclear Reactor Engineering, Chapman Hall, London, 1994.
3. H.U. Borgstedt and C.K. Mathews, Applied Chemistry of the Alkali Metals, Plenum Press, 1987.
4. C.C. Addison, The Chemistry of the Liquid Alkali Metals, John Wiley and Sons, 1984.
5. Power Plant Chemistry: A practical guide, Buecher Braid, Penwell, Oklahoma, 1997.
6. Modern Power Station Practice, III Edition, Pergamon, NY, 1992.

CH-12: Nuclear and Radiochemistry (CH12)

Course content

1. **Nuclear Properties:** Concept of nucleus, nuclear spin, parity, electric and magnetic moments, isomerism, nuclear mass and binding energy, elemental abundance, radioactive decay laws, radioactive equilibria, Bateman's equation, liquid drop and shell models.
2. **Nuclear Structure and Decay Modes:** Nuclear force, structure of complex nuclei, liquid drop, shell and collective models, nucleon emission, beta decay, gamma de-excitation and internal conversion, selection rules.
3. **Nuclear Reactions and Accelerators:** Basic principles and energetics, cross sections, nuclear fission, charge and mass distribution in fission, compound nucleus reactions, direct reactions, types and details of accelerators.
4. **Radiochemical Separations:** Concepts of traces, chemical yields, radiochemical purity, applications.
5. **Nuclear Techniques:** Nuclear probes, PAC, NDA and on-line monitoring.
6. **Radio-isotope Production:** Basic principles of isotope production in both reactors and accelerators, Szilard - Chalmers effect and its utility, concept of generators, Moly generators.

7. Applications of Radioisotopes: Concepts of nuclear medicine and radio-pharmaceuticals, SPECT, PET, brachytherapy and and teletherapy Radio-immuno assay, industrial, agricultural and biological applications.

Laboratory Experiments:

1. Fission product separation and transient equilibrium.
2. Separation of actinides using ion-exchange or solvent extraction
3. Neutron activation analysis.

Books Suggested:

1. Nuclear and Radiochemistry (1981) - G. Friedlander, J. Kennedy, J.M. Miller and J.W. Macias
2. Atomic Nuclear (1955) - R.D. Evans
3. Source book of atomic energy (1969) - S. Glasstone
4. Essentials of Nuclear Chemistry (1982) - H.J. Arnikar
5. The chemistry of Transuranium Elements (1971) - J. Keller
6. G.R. Chopin and Rydberg: Nuclear Chemistry, Theory and Applications, Pergamon Press, Great Transuranium elements and transactinides.
7. Manual for reactor produced isotopes, IAEA-TECDOC-1340 (1999)
8. Radionuclides in therapy - R.P. Spencer, R.H. Sievers, A.M. Friedman. CRC Press (1987
9. Radioimmunoassay: Principles and Practice, M.R.A. Pillai and S.D. Bhandarkar, 2nd Edition, BARC, 1998
10. Industrial applications of radioisotopes - G. Foldiak

CH-13: Corrosion Science and Engineering (CH13)

Course content

1. **Thermodynamics of Aqueous Corrosion:** Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.

2. **Kinetics of Aqueous Corrosion:** Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.

3. **Forms of Corrosion:** General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion.

Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.

4. **Corrosion in Reactor and Reprocessing Plants:** Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.

5. **Prevention and Control of Corrosion:** Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.

6. **Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.

7. **Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, "Corrosion and corrosion control – An introduction to corrosion science and engineering", Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, "Corrosion Engineering", Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.
4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

CH-14: Quantum Chemistry and Group Theory

1. Fundamental principles

Brief review of the fundamentals of quantum mechanics – postulates, measurements, operators, de Broglie equation, Heisenberg principle, Schrodinger Equation.

2. Exactly solvable problems

Particle in a box with walls at infitine and finite potential; Double box potential, tunneling, effect of barrier height on splitting of degenerate energy levels and its application in understanding double well potential. Particle in a ring. Simple harmonic oscillator, rigid rotor, hydrogen atom problem solution using both the power series method and ladder operators.

3. Approximation methods

Variation method, perturbation theory for time-independent and time dependent systems; Many-electron systems: Hartree-Fock theory and beyond; Chemical binding in simple molecular systems: Valence bond and molecular orbital theories; Concept of LCAO and introduction to ab-initio and semi-empirical molecular orbital calculations of molecules.

4. Group Theory

Symmetry elements and operations, point groups, matrix representation, reducible and irreducible representations, the Great Orthogonality theorem, direct product representation, projection operators.

5. Applications of Group Theory in Chemistry

Vibrational problem, hybridization, SALC, ligand field theory.

Reference Books

1. "Quantum Chemistry", I. N. Levine, Allyn & Bacon, Inc. (Boston) 5ed. (2000).
2. "Introduction to Quantum Chemistry", F. S. Levine, Cambridge Univ. Press (2002).
3. "Quantum Chemistry", W. Kauzmann, Academic Press (1957).
4. "Chemical Applications of Group Theory", F. A. Cotton, Wiley Eastern Limited, (1989).
5. "Group Theoretical Techniques in Quantum Chemistry", C. D. H. Chisholm, Academic Press (1976).

CH-15: Molecular Spectroscopy

1. Vibrations and rotations of diatomic molecules, selection rules, nuclear spin statistics.

2. Electronic spectroscopy of diatomic molecules, coupling of angular momentum, Hunds coupling cases, term states of molecules, potential energy functions – analytical and numerical (e.g. RKR), Dissociation energy, Franck Condon principle, numerical methods to evaluate Franck Condon factors.

3. Vibrations of polyatomic molecules – classical mechanics of vibrations, symmetry and normal vibrations – applications of group theory.

4. Experimental techniques in spectroscopy: Fourier transform spectroscopy (FTIR, FT-RAMAN), time resolved FTIR and its applications in absorption and emission studies. Laser based experimental methods, Introduction and application of Terahertz spectroscopy.

5. Studies on ultrafast processes: Nanosecond and picosecond laser flash photolysis, fluorescence time domain spectroscopy with special emphasis on energy transfer and electron transfer reactions and studies on excited state properties**.**

6. NMR & ESR: Basics of NMR and ESR, Multipulse techniques in NMR, FTNMR, 2D-NMR. Time domain ESR, Electron Nuclear Double Resonance (ENDOR)-principle and applications.

Reference Books:

1. "Introduction to Lasers Physics", K. Shimoda, Springer Verlag, 1984 Berlin
2. "Laser Spectroscopy basic concepts and Instrumentation", W. Demtroder, Springer 2003, Berlin.
3. "Molecular Spectroscopy", C. N. Banwell, 4 Edn, Tata McGraw Hill, Delhi.
4. "Infra red spectra of Inorganic and coordination compounds", K. Nakamoto, 5 Ed, John Wiley 1978, NewYork.

CH-16: Lasers and Their Applications

Introduction to Lasers

1. Rate equation for absorption, induced and spontaneous emission, Einstein's A and B coefficients – Concepts of laser action and population inversion – rate equations for two, three and four level systems.

2. Laser and its sub-systems – Optical amplifier – optical resonator – excited state pump – Properties of laser beams – Spatial and temporal coherence.

3. Different types of passive resonators, modes of a passive resonator – Active resonators – Gain & Threshold condition for lasing actions – laser modes – Gain saturation and mode competition – spatial and velocity hole burning.

4. Wavelength and Intensity stabilization of lasers – turning of wavelength of lasers – prisms, grating and elations – controlled wavelength turning – Selection of axial modes, Experimental realization of single mode.

5. Generation of short pulses – Q-switching and mode locking – active and passive methods

6. Principles of various types of lasers – UV, vis & IR lasers, metal vapour lasers, solid state lasers, Gas lasers, Dye lasers, Semiconductor-diode laser and free electron laser

Laser Spectroscopic Techniques:

Important features of lasers useful for spectroscopy – monochromaticity, directionality, high intensity, tunability, short pulses etc. Advantages of lasers for spectroscopy – high sensitivity and selectivity. Short review of spectral line broadening mechanisms.

Doppler-limited spectroscopy
a) High sensitivity methods of Absorption – frequency modulation, intracavity absorption.
b) Photoacoustic spectroscopy; c) Resonance ionization spectroscopy combined with mass spectrometry – multiphoton processes; d) Optogalvanic spectroscopy

Laser Induced Fluorescence: a) Molecular Spectroscopy by LIF; b) Experimental aspects and advantages of LIF (c) LIF in supersonic molecular beams

Laser Raman Spectroscopy: (a) Linear Raman Spectroscopy; (b) Non-linear Raman Spectroscopy – Stimulated Raman scattering (c) Coherent Anti-Stokes Raman Spectroscopy (CARS)

Analytical applications of lasers: a)Laser induced break down spectroscopy, cavity ring down spectroscopy; (b) Atmospheric measurements with LIDAR

Laser material interactions: a) Vaporization, desorption and ablation. b) Surface modification; c) Laser cooling (d) Laser Induced Chemical Reactions/ Laser Isotope Separation

Reference Books:

1. “Introduction to Lasers Physics”, K. Shimoda, Springer Verlag, 1984 Berlin
2. “Laser Spectroscopy basic concepts and Instrumentation”, W. Demtroder, Springer 2003, Berlin.
3. “Principles of lasers”, O. Svelto and D. C. Hanna, Plenum, 1989, New York
4. “Chemical and biochemical applications of lasers-vol I & III”, C.B. Moore, (Ed) Academic Press, New York (1974)
5. “Lasers”, P.W. Milonni and J.H. Eberly, World Scientific, Singapore (1981)

CH 17 - Nano materials and advanced chemical sensors

Introduction

Nanoscale– its importance, definitions, nanomaterial science- One dimension, Two dimensions (carbon nanotubes, inorganic nanotubes, nanowires, biopolymers), Threee dimensions (nanoparticles, fullerenes C-60, dendrimers, quantum dots) properties (electrical, optical, mechanical & chemical)

Synthesis and characterization

Synthesis -Chemical methods (precipitation, sol-gel, CVD, ion-exchange, dispersion), Physical methods (milling, PVD, pyrolysis, ion-implantation). Consolidation of nanopowders – sintering introduction, theories of sintering, sintering of nanomaterials, novel methods for consolidation of nanopowders. Characterization – X-ray techniques, spectroscopic techniques, electron beam techniques, optical methods

Applications

Structural and functional ceramics, coatings, sensors, power sources, additives and catalysts, composites, lubricants, magnetic materials, medical implants & nuclear ceramics. Sintering – introduction, theories, methods for consolidation and sintering of nanostructured materials

Introduction to chemical sensors

Fundamental definitions and principles; rationale of sensor design and operation; basic theoretical considerations

Electrochemical Sensors

(Potentiometric sensors, Voltammetric and Amperometric sensors) Ion selective electrodes(ISEs) – principles, solid (glass and fast ion conductor based) and liquid membrane based electrodes, Electrochemical gas sensors, Semiconductor devices (ISFETs, MOSFETs), Conductance gas and vapour sensors based on metal oxides, semiconductors and conducting polymers. Biosensors- oxygen and glucose biosensors; mediated enzyme electrodes and enzyme field effect transistors (ENFETs).

Piezoelectric Sensors

Piezoelectricity and mechanical resonance: stress, strain and polarization; constitutive relationships; equations of wave motion and wave representation.

The transverse-shear mode sensor, or quartz crystal microbalance: application to gas- and liquid-phase sensing; applications to VOC sensing, immunosensing and biosensors.

Optical Sensors

IR and UV sensors - semiconductors - optical irradiation – recombination - Quantum efficiency - p-n junctions - IV characteristics - forward bias and reverse bias - applications.

Micro Electro Mechanical System (MEMS) based sensors and electronic noses

Cantilever based sensors – Sensing Principles, types of cantilevers, use of different detection techniques, examples and applications

Chemometrics as applied to chemical detection and identification; Olfaction and electronic noses; Salient features

Sensor fabrication methods

Sensor configurations and geometries, Use of nano-materials in sensors

Thin/thick film formation techniques (physical, chemical and LB film formation techniques), MEMs based sensor fabrication

Surface analysis and characterization

Practicals

Testing of a solid electrolyte based potentiometric oxygen sensor
Testing of an amperometric sensor for oxygen
Fabrication and testing of a thick-film hydrogen sensor

References

1. Fundamentals of Nanostructured materials, Eds. D. Fiorani (World Scientific, Singapore, 1994)
2. Nanoparticles and Nanostructured Films: Preparation, Characterization and Applications, Ed. J.H. Fendler (Wiley-VCH, New York, 1998)
3. Chemistry of Nanomaterials Vol 1 and 2, Eds. C.N.R. Rao, A. Muller, A.K. Cheetam, (Wiley-VCH, Weinheim, 2004)
4. Nanoscience and Nanotechnology (Ed.) B.S. Thomar, IANCAS Bull., Vol. VI, No.2, April 2007.
5. J. Janata, Principles of Chemical Sensors, Kluwer Academic Publishing Plenum, Dordrecht, 1989.
6. T. Seiyama Ed. , Chemical Sensor Technology, Vol. 1 and 2 Elsevier, Amsterdam, 1988.and 1990
7. Chemical Sensor Technology, Vol. 3, (N. Yamazoe Ed.)Elsevier, Amsterdam, 1991.
8. Chemical Sensor Technology, Vol. 4 (S. Yamauchi Ed), Elsevier, Amsterdam, 1992
9. H. Baltes, W. Gopel, J. Hesse Eds. , Sensors Update Volumes 1 to 6 , Wiley-VCH, Weinheim, 1996.
10. W. Gopel, J. Hesse, J.N. Zemel Eds., Sensors, A Comprehensive Survey, Vol. 7, Wiley-VCH, Weinheim, 1993.
11. R.W. Cattrall, Chemical Sensors, Oxford Univ. Press, Oxford, 1997.
12. K.T.V. Grattan, B.T. Meggitt Eds. , Optical Fiber Sensor Technology, Vol. 4: Chemical and Environmental Sensing, Kluwer Academic Publishing, Dordrecht, 1999.
13. ‘Solid State Gas Sensors’, (eds. P.T. Moseley, B.C. Toefield), 1987, Bristol, Adam Hilger.
14. S.R. Morrison: ‘The Chemical Physics of Surfaces’, 1; 1978, New York, Plenum Press.

CH-RM: Course on Research Methodology

Unit-I - Objectives and types of research: Motivation and objectives – Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Unit-II - Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem – Literature review – Primary and secondary sources – reviews, treatise, monographs-patents – web as a source – searching the web - Critical literature review – Identifying gap areas from literature review - Development of working hypothesis.

Unit-III - Research design and methods – Research design – Basic Principles- Need of research design –– Features of good design – Important concepts relating to research design – Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Unit-IV – Value of Statistics; Errors and Statistics – Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results – students's t test; F-test; Chi Square test; propagation of errors.

Unit-V - Reporting and thesis writing – Structure and components of scientific reports - Types of report – Technical reports and thesis – Significance – Different steps in the preparation – Layout, structure and Language of typical reports – Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation – Planning – Preparation – Practice – Making presentation – Use of visual aids - Importance of effective communication –.Computers in Chemistry, Usage of packages such as, Excel, AIM2000, ChemCraft, etc. Manuscript drafting based on "Experimental data and Literature Survey". **Unit-VI** - Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialisation – Copy right – Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights – Reproduction of published material – Plagiarism - Citation and acknowledgement - Reproducibility and accountability. [7 hrs]

REFERENCES

1. Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction to Research Methodology, RBSA Publishers.
2. Kothari, C.R., 2000, Research Methodology: Methods and Techniques. New Age International.
3. Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Ess Publications (2 volumes)
4. R. Paneer Selvam – Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
5. Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
6. Day, R.A., 1992.How to Write and Publish a Scientific Paper, Cambridge University Press.
7. Vogel's Text Book of Quantitative Inorganic Analysis, ELBS.

BARC

M.Phil. in Physical Science
(Program Code: PHYS02)

SYLLABUS

PHYSICAL SCIENCES

Course work for Training School Officers (OCES)

The course work structure is divided into 5 foundation courses (A1-A5), 9 core courses (B6-B14), 3 experimental and laboratory courses (C15-C17) and 2 elective courses (D18, D19), as given in Table-1. The topic 'Research methodology' is explicitly included as a part of the course work (C16) as per the requirement of UGC. Total lecture hours are 490 + 75 tutorials and 7 weeks duration for a mini project (C17). Total credits are 60 as per the requirement of HBNI. Detailed course structure for individual subjects is provided separately. Some specific issues are as follows:

Research Methodology and methods of Experimental Physics

The course work includes specific topics related to 'research methodology' that are not covered elsewhere in the syllabus. These include design, analysis and presentation of scientific projects, objectives and planning of research, literature survey, statistical methods, mathematical modeling, documentation and presentation, laboratory safety and research ethics. Other topics in are related to the experimental techniques in areas such as vacuum, low temperature, X-ray, neutrons, spectroscopy, lasers and accelerators.

Mini Project

As regards the Mini Project (C17), it is understood that the project will be carried out after the completion of the trimester and allotment of trainees to various units of the DAE. The mini project will run concurrently with the elective courses.

Elective Courses

The elective courses are organized under five broad groups as shown in Table-2, which also provides the list of Divisions of BARC involved in closely related R&D activities. This grouping has been done so as to help a TSO to select an elective course that will help him/her to obtain advanced training required for the R&D work to be carried out in the division where he/she is allotted. Such grouping will ensure minimum number of students opting for a given elective course.

It is recommended that the two elective courses in respect of a TSO will be chosen in the following manner:

Elective-1: This elective will be from the group to which the Division of joining of a TSO belongs to (*cf.* Table-2).

Elective-2: This elective can be chosen from any of the other groups depending on the interest of the TSO.

Training School Physics Committee will advise the TSOs on the selection of the elective courses.

COURSE STRUCTURE- PHYSICS

FOUNDATION COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Mathematical Physics	PH 501	30 + 5*	3	125
2	Quantum Mechanics	PH 502	30 + 5*	3	125
3	Statistical Physics	PH 503	30 + 5*	3	125
4	Electromagnetic Theory	PH 504	30 + 5*	3	125
5	Computational Physics	PH 505	30 + 5*	3	125
	FOUNDATION TOTAL		**150+15***	**15**	**625**

CORE COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Nuclear Physics	PH 601	30 + 6*	3	125
2	Atomic, Molecular & Laser Physics	PH 602	30 + 6*	3	125
3	Plasma Physics & Technology	PH 603	30 + 6*	3	125
4	Physics of Materials and Surfaces	PH 604	30 + 6*	3	125
5	Reactor Physics & Technology	PH 605	30 + 6*	3	125
6	Accelerator Physics & Technology	PH 606	30 + 6*	3	125
7	Astrophysics	PH 607	15+ 3*	2	75
8	Electronics	PH 608	30 + 6*	3	125
9	Health Physics and Radiation Detectors	PH 609	30 + 6*	3	125
	CORE TOTAL		**255 +51***	**26**	**1075**

EXPERIMENTAL AND LAB COURSES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Engineering Drawing & Workshop Practices	PH 610	15	2	75
2	Research Methodologies and Methods of Experimental Physics	PH 611	30 + 50 (Lab Hours)	8	325
	TOTAL		**95**	**10**	**400**

ELECTIVES

S. No	Subject Title	Course Code	Hours	Credits	Marks
1	Elective 1	PH 701-731	20 + 4*	2	75
2	Elective 2	PH 701-731	20 + 4*	2	75
	ELECTIVES TOTAL		**40+ 8***	**4**	**150**

	THEORY TOTAL	**540**	**55**	**2250**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	Viva Voce	PY 591	6	200
2.	Mini Project	PY 593	9	300
		TOTAL	**15**	**500**

*** Tutorials**

Total Contact Hrs: 540; Total Credits: 70; Total Marks: 2750

Note: Credit Requirement for Ph.D: 60

Marks are calculated using the formula (As per BOS decision)

2*Hours + 20*Credits (Nearest multiple of 25)

Course work for Training School Officers (OCES)

The course work structure is divided into 5 foundation courses (A1-A5), 9 core courses (B6-B14), 3 experimental and laboratory courses (C15-C17) and 2 elective courses (D18, D19), as given in Table-1. The topic 'Research methodology' is explicitly included as a part of the course work (C16) as per the requirement of UGC. Total lecture hours are 490 + 75 tutorials and 11 weeks duration for a mini project (C17). Total credits are 60 as per the requirement of HBNI. Detailed course structure for individual subjects is provided separately. Some specific issues are as follows:

Research Methodology and methods of Experimental Physics

The course work includes specific topics related to 'research methodology' that are not covered elsewhere in the syllabus. These include design, analysis and presentation of scientific projects, objectives and planning of research, literature survey, statistical methods, mathematical modeling, documentation and presentation, laboratory safety and research ethics. Other topics in are related to the experimental techniques in areas such as vacuum, low temperature, X-ray, neutrons, spectroscopy, lasers and accelerators.

Mini Project

As regards the Mini Project (C17), it is understood that the project will be carried out after the completion of the second trimester and allotment of trainees to various units of the DAE. The mini project will run concurrently with the elective courses.

Elective Courses

The elective courses are organized under five broad groups as shown in Table-2, which also provides the list of Divisions of BARC involved in closely related R&D activities. This grouping has been done so as to help a TSO to select an elective course that will help him/her to obtain advanced training required for the R&D work to be carried out in the division where he/she is allotted. Such grouping will ensure minimum number of students opting for a given elective course.

It is recommended that the two elective courses in respect of a TSO will be chosen in the following manner:

Elective-1: This elective will be from the group to which the Division of joining of a TSO belongs to (*cf.* Table-2).

Elective-2: This elective can be chosen from any of the other groups depending on the interest of the TSO.

Training School Physics Committee will advise the TSOs on the selection of the elective courses.

FOUNDATION COURSES

PY 501: Mathematical Physics

Symmetries and groups: Point groups, abelian and non-abelian groups, characters, representations of simple groups, Lie groups, symmetric groups, braid group

Functions of a complex variable: Analytic and multi-valued functions, Cauchy residue theorem and complex integration, Riemann surfaces, applications to fluid mechanics and quantum mechanics.

Ordinary differential equations (ODE): Linear and nonlinear first-order equations, classification of ODEs, linear independence and Wronskian, singular points, Frobenius series solutions for second-order differential equations, Green function, system of ODEs, phase portraits, hypergeometric and confluent hypergeometric equations, relation with special functions

Partial differential equations: Classification, characteristics, method of integral transforms, Green functions for Poisson equation, diffusion equation, wave equation, Helmholtz equation

Integral equations: Fredholm, Volterra, Abel integral equations, solutions by Liouville-Neumann, Fredholm method, Hilbert-Schmidt theory, Sturm-Liouville problems

References

1. Groups and Symmetry: A Guide to Discovering Mathematics, D. W. Farmer (Universities Press, 1998).
2. Mathematical Methods in Physics, J. Mathews, R. L. Walker (Addison-Wesley, 1971).
3. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag (Springer, 2010).
4. Elements of Green's Functions and Propagation, G. Barton (Clarendon Press, 1989).
5. Mathematical Methods for Physicists, Seventh ed., G. B. Arfken, H. J. Weber, F. E. Harris (Elsevier, 2013).
6. Fundamentals of Mathematical Physics, E. A. Kraut (McGraw-Hill, 1967).

PY 502: Quantum Mechanics

Background: Recollection of the experimental facts exposing limitations of the classical theory; Bohr model: Quantization of angular momentum, Schrodinger's approach to building a new theory leading to Schrodinger equation; Wavefunction, Statistical Interpretation; Probability, Normalization.

Formalism: Postulates of quantum mechanics: Representation of a state as a vector in Hilbert space; Scalar products; Dirac's bra and ket notation, Schwarz's inequality and linear operations on Hilbert space; representation of observables as hermitian operators; adjoints, eigenvalues and eigenvectors; hypothesis of measurement; Uncertainty relation as a consequence of Schwarz's inequality and the concept of minimum uncertainty states. Quantum mechanics in coordinate and momentum space representations and their relationship.

Quantum mechanics in 1-dimension: Free particle and wave packet, phase and group velocities, completeness; Uncertainty principle, minimum uncertainty, Ehrenfest's theorem; Step potential, transmission and reflection coefficients, transfer matrix;Particle in a well/box, density of states; Simple Harmonic Oscillator potential, creation and annihilation operators.

Quantum mechanics in 2-dimensions; Simple harmonic Oscillator potential, isotropic and non-isotropic.

Quantum Mechanics in 3-dimension: Angular Momentum; Angular momentum algebra; Free particle in 3-d; Particle in central potential; Hydrogen atom; Virial theorem, Feynman-Hellmann theorem;

Identical Particles: Two particle systems; Pauli's principle, Fermions and Bosons; Spin of an electron

Approximation methods: Wentzel-Kramers-Brillouin (WKB) method, Time-independent perturbation theory for non-degenerate as well as degenerate Hamiltonians; Variational method; Time-dependent perturbation theory.

Scattering theory: Lippmann-Schwinger equation, Born approximation, optical theorem, Eikonal approximation, method of partial waves.

References

1. *Introduction to Quantum Mechanics*, D. J. Griffiths, 2nd Edition (Pearson, 2005).
2. *Quantum Mechanics*, B.H.Bransden and C.H.Jochain, 2nd Edition (Pearson, 2000).
3. *Principles of Quantum Mechanics*, P.A.M. Dirac, 4th Edition (Oxford University Press, 2004).
4. *Modern Quantum Mechanics*, J.J.Sakurai (Pearson, 1994).
5. *Quantum Mechanics*, E. Merzbacher (Wiley, 2011).
6. *Mathematical Methods of Quantum Optics* (Chapter 1), R.R.Puri, (Springer-Verlag, Heidelberg, 2001).
7. *Quantum Mechanics* (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz, 3rd Edition (Elsevier, 1981).

PY 503: Statistical Physics

Background: Revision of main results of thermodynamics

Formalism: Introduction to micro-canonical, canonical and grand canonical ensembles with examples for each, derivation of Fermi-Dirac and Bose-Einstein distribution for a quantum ideal gas, Specific heat of a degenerate Fermi gas, Blackbody radiation, Bose-Einstein Condensation.

Phase transitions: Introduction to phase transitions, notion of continuous and discontinuous transitions, Landau Theory-Mean field and Gaussian fluctuations.

Monte Carlo Techniques and applications: Introduction to Monte Carlo methods, Metropolis algorithm, Application to numerical integration, application to Ising Model.

Applications: BBKGY equations, Vlasov equation, Saha ionization formula, Statistical nuclear physics

Irreversible processes: Master equation, Brownian motion and Langevin equation, Fluctuation-Dissipation theorem and calculation of friction constant

References

1. *Statistical Mechanics*, K. Hunag, 2nd Edition (Wiley, 1987)
2. *Statistical Mechanics*, R. K Pathria, 2nd Edition (Butterworth-Heinemann, 1996)
3. *Fundamentals of statistical and thermal physics*, F. Reif, 1st Indian Edition (Levant Books, 2000)
4. *Principles of Condensed Matter Physics*, P M Chaikin and T C Lubensky, 1st paperback Edition (Cambridge University Press, 2000)
5. *Reports on Progress in Physics* 60, 487 (1997), K Binder
6. *Saha Equation*, Hale Bradt, (soft copy available)
7. *Saha and his Formula*, G. Venkataraman, 1st Edition (Universities Press India Ltd., 1995)
8. *Statistical Models for Nuclear Decay*, A. J. Cole (IOP Publishing Ltd, 2000).
9. *Treatise on Heavy Ion Science*, R. Stokstad, Ed. D. A. Bromley (Plenum, New York, 1985), Vol. 3, p. 83.

PY504 : Electromagnetic Theory

Background: Overview of EM theory and revision of basic concepts. Role and scope of EM theory and its applications.Laws of induction.Induced fields.Displacement current.Maxwell's equations in vacuum and media.

Electrostatics and Magneto-statics: Boundary value problems. Separation of variables Numerical methods.Finite difference representation of Poisson's Equation. Relaxation methods and Successive Over Relaxation Method (SOR)

Maxwell's equations: General solutions of Maxwell's Equation and Electromagnetic radiation. Electromagnetic waves in free space. General time dependent solutions of Maxwell's Equation: Wave-guides and cavities. Microwaves.Dipole Radiation.Bremsstrahlung.Cyclotron.Radiation as a diagnostic tool.

Propagation of electromagnetic waves through matter: reflection of waves in bounded media. Phase velocity; group velocity; wave equation; continuity theorem; Brilliouin diagram for empty cavity, etc.; Generation of modes in a cavity/waveguide; TEM, TE, TM modes; mode creation and identification. Boundary conditions; Generation of an electric field in an empty cavity; dispersion relation; frequency mode evaluation, etc.

Potentials and Fields: Gauge transformations. Retarded potentials.Lienard-Wiechert potentials.

Relativistic electrodynamics: Lorentz Transformations. Four Vectors.Covariant and contravariant tensors.Electrodynamics in Tensor Notation.Relativistic Potentials.Invariance.

Dynamics of charged particles in Electromagnetic fields: Orbit theory. Drifts (ExB, grad B perpendicular and parallel to B).Adiabatic invariance.Magnet mirror.

References:

1. *The Feynman Lectures on Physics*, Vol.2, R.P. Feynman, R.B. Leighton and M. Sands, 1st edition, (Addison-Wesley Publication Company, 1963).
2. *Introduction to Electrodynamics*, D.J. Griffith, 3rd Edition (Prentice Hall India, 2000).
3. *Classical Electrodynamics*, J.D. Jackson, 2nd Edition (John Wiley & Sons, 1975).
4. *Electrodynamics of Continuous Media*, Vol. 6 of Course of Theoretical Physics, L.D. Landau and E.M. Lifshitz, 2nd Edition (Butterworth Heinemann, 1998).

PY 505: Computational Physics

Computer Programming: Introduction to Linux, Programming in Fortran, Introduction to C and Parallel Processing, Hands on experience at the computer, Data plotting using programs such as gnuplot.

Numerical Methods: Errors in Numerical Methods, Data Statistics & Curve Fitting, Interpolation and Extrapolation, Integration of Functions, Solution of System of Linear Equations, Solution of Nonlinear Equation or Root Finding, Solution of Ordinary Differential Equations, Solution of Partial Differential Equations, Solution of Integral Equations.

Project Assignments: various realistic physics problems to be solved using numerical algorithms coded into programs to be run on the computer.

References

1. *Computer Programming in FORTRAN 90 and 95*, V. Rajaraman (Prentice-Hall of India Private Limited, 2006).
2. *Upgrading to FORTRAN 90*, C. Redwing (Springer-Verlag New York, 1995).
3. *C: The Complete Reference*, H. Schildt (McGraw-Hill, 1987).
4. *Computer programming in C*, V. Rajaraman (Prentice-Hall of India Private Limited, 1994).
5. *C++ : The Complete Reference*, H. Schildt (Tata McGraw-Hill, 2003).
6. *Numerical Recipes – The Art of Scientific Computing* : W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery (Cambridge University Press, 1996).
7. *Numerical Algorithms: Computations in Science and Engineering*, E. V. Krishnamurthy and S. K. Sen (East-West Press, 1986).
8. *Numerical Methods for Engineers - A Programming Approach*, D. V. Griffiths & I. M. Smith (Chapman and Hall, 2006).
9. *Numerical Methods for Scientists and Engineers*, H. M. Antia (Birkhauser, 2002).

CORE COURSES

PY 601: Nuclear Physics

Background: Basic properties of nuclei, systematic of nuclear ground states (low lying states) properties, size, shape, electric and magnetic moment, nuclei away from the line of stability, isomers, nuclear decay, symmetries.

Nuclear Forces: Phenomenological description of nuclear forces, deuteron problem, N-N scattering, microscopic description, meson theory of nuclear forces, N-B interaction with fundamental degrees of freedom, nuclear resonances, quarks and gluons, QCD and chiral symmetry, colour quantum number, standard model, GUT.

Nuclear structure: Multipole composition of radiation, transition matrix, selection rules for multipole transitions, collective and single particle excitations, shell and collective models, giant resonances, high spin states and shape deformations, relativistic mean field theory, Fermi gas model, weak interaction, beta decay, neutrino interaction and oscillations.

Nuclear reactions: Definition of cross-sections, phase shifts, low energy behavior and astrophysics, compound nucleus theory, optical model, statistical model, direct reactions, heavy ion reactions and fission, semiclassical description of nuclear reactions, impact parameter representation, Galuber model, relativistic heavy ion collisions, energy density and rapidity, equation of state of QGP and hadronic matter phase transition, QGP in RHIC, LHC, experimental signatures.

Applied nuclear physics: RBS, NRA, NAA, AMS etc.

References

1. *Introductory Nuclear Physics*, Kenneth S. Krane (Wiley, New York, 1988).
2. *Introductory Nuclear Physics*, Samuel S.M. Wong (Wiley Interscience).
3. *Basic Ideas & Concepts in Nuclear Physics*, K. Heyde (3rd Ed. Taylor & Francis 2004).
4. *Particles and Nuclei*, B.Povh, K.Rith, C.Scholz and F.Zetsche, 5th Edition (Springer 2006).
5. *Introduction to Elementary Particle Physics*, E. Griffiths (Wiley, New York 1987).
6. *Introduction to High Energy Heavy Ion Collisions*, Cheuk-Yin Wong (World Scientific).

PY 602: Atomic, Molecular and Laser Physics

Atomic and Molecular Physics

Background of atomic and molecular structure: Energy level structure, effect of external electric and magnetic fields, Rydberg and autoionizing levels, Nuclear effects: hyperfine structure and isotope shifts, Radiative and non-radiative

processes, Born-Oppenheimer approximation, Vibrational, rotational and electronic spectroscopy of diatomic molecules including selection rules and intensities. Frank-Condon principle, Rotational and vibrational, Raman spectroscopy.
Molecular symmetry and group theory: Groups, Symmetry operations, Point groups, Character tables, Application to molecular problems.

Polyatomic molecules: Rotational energy levels and nuclear spin statistical weight effect, Vibrational spectra of polyatomic molecules: normal modes, energy levels and selection rules, types of bands, group theoretical treatment, inversion, torsional vibrations, etc. Designation of electronic states of diatomic molecules, coupling cases, Molecular orbital theory.

Accelerator based atomic/molecular physics: Spectroscopy with Synchrotron radiation: VUV and soft X-ray spectroscopy of atoms and molecules, photo-ionization /dissociation/ fragmentation, inner shell processes, techniques of electron spectroscopy, Beam foil spectroscopy and Collinear fast beam spectroscopy with ion accelerators.

Laser spectroscopy: Atomic/molecular beam and vapour sources, Theory and practice of Doppler-limited spectroscopic techniques: absorption, fluorescence, opto-galvanic, opto-acoustic spectroscopy. Non-linear and Doppler-free laser spectroscopy: Saturated absorption, polarization and two-photon spectroscopy. Multi-photon and multi-step processes and spectroscopy: Multi-step Resonance excitation/ionization, Multi-photon absorption/ionization.

Applications of laser spectroscopy: Trace analysis, Laser isotope separation, Laser cooling and trapping, Ion traps.

Laser Physics

Theory of Optical Resonators: Resonator modes, Stability criterion, Gaussian beams and their propagation.
Principles of laser oscillation: Pumping mechanisms, Rate equation for three/four level laser systems, Population inversion, Gain coefficient and threshold population inversion, Gain clamping, Single mode and multimode oscillations, Spatial and spectral Hole burning.

Intense and ultra-intense lasers: Techniques for generation of short laser pulse, Q-switching and mode-locking including active/passive schemes, Chirped pulsed amplification.

Types of Lasers: Solid state lasers- Nd:YAG, Ti:S; Gas and metal vapour Laser, Dye lasers, Semiconductor lasers and Diode pumped solid state lasers.

Non-linear Optics: Classical theory of nonlinear response, Wave propagation in nonlinear media, General properties of polarizability tensor, Three wave mixing– Second harmonic generation, Phase matching condition, Sum and difference frequency generation, Optical parametric oscillator and amplifier, Four wave mixing: Third order non linearity, Intensity dependent refractive index, Third harmonic generation, Elementary treatment of stimulated Raman scattering, Stimulated Brillouin scattering, Self phase modulation, and Optical phase conjugation.

Laser Applications: Laser Fusion, Laser accelerators, Laser material processing

References

1. *Atomic Physics*, C.J. Foot, Oxford Master Series in Atomic, Optical and Laser Physics (Oxford University Press 2008).
2. *Laser Spectroscopy Basic Concepts and Instrumentation*, W. Demtröder, 3rd Edition (Springer-Verlag 2003).
3. *Spectra of Atoms and Molecules*, P.F. Bernath, 2nd edition (Oxford University Press 2005).
4. *Modern Spectroscopy*, J.M. Hollas, 4th Edition (Wiley India Pvt. Ltd.
5. *Fundamentals of Molecular Spectroscopy*, C.N. Banwell and E.M. McCash, 4th Edition, (Tata McGraw Hill, 2010).
6. *Laser Fundamentals*, W.T.Sylfvast, 2nd Edition (Cambridge University Press , 2004).
7. *Photonics*, Ralf Menzel, 2nd Edition (Springer, 2007).

PY 603: Plasma Physics and Technology

Background: Introduction to Plasma, the fourth state of matter, collective behaviour, charge neutrality, space and time scales. Concept of plasma temperature, Debye length, plasma frequency, plasma parameters. Debye shielding, plasma sheath and dielectric properties, plasma in nature and laboratory: elementary concepts of thermal, nonthermal plasmas, laser produced plasmas, non-neutral plasmas.

Basic processes in plasmas: Collisions in plasmas, significance of small angle scatterings, ionisation, recombination, concepts of diffusion, mobility, ambipolar diffusion. Thermal ionisation and the Saha equation, LTE and equilibrium models.

Plasma Theory: Fluid theory of plasmas, single & multi fluid approximations, generalized Ohm's law. MHD equations, Waves and instabilities in plasmas.

Plasma production and diagnostics: Various plasma production techniques, Electrical breakdown in gases using dc, rf, microwave and high frequency fields, Glow and arc discharge. Langmuir probes, magnetic probes, spectroscopic diagnostics, active and passive techniques.

High temperature plasma applications: controlled thermonuclear fusion, Introduction to thermonuclear fusion, fusion reactions, cross sections, radiative processes in plasmas, energy loss, Lawson criterion, break even and ignition, magnetic and inertial confinement scheme and devices, emission of X rays and neutrons, fusion plasma diagnostics.

Low temperature plasma applications: plasma processing of materials, Physics of high and low pressure plasma sources and applications to materials processing, brief review of plasma based surface coatings in low pressure and high pressure plasmas Plasma applications to metal cutting, melting, spraying and waste processing in nuclear, space and semiconductor industries.

References

1. *Plasma Physics: An Introductory Course*, Ed. R.O. Dendy (Cambridge University Press 1995)
2. *Introduction to Plasma Physics* (Plasma Physics Series) by R.J. Goldstan, P. H. Rutherford (Institute of Physics, 1995)
3. *Principles of Plasma Physics*, N.A. Krall and A. W Trivelpiece (McGraw Hill, 1973)
4. *Introduction to Plasma Theory*, D.R. Nicholson, (Wiley, 1992)
5. *Principles of Plasma Diagnostics* by I.H. Hutchinson (Cambridge University Press, 2002)
6. *Thermal Plasma Diagnostics* ,A.A. Ovsyannikov (Cambridge International Science Publishing, 2001)
7. *Inertial Confinement fusion*, J.J. Dudesrstadt and G.A. Mosses, (Wiley, 1982)
8. *Fusion: An introduction to the Physics and Technology of Magnetic Confinement Fusion*, W. M. Stacy (Wiley, 1984)
9. *Industrial Plasma Engineering*, J. Reece Roth (IOP Publications, 2000)

PY 604: Physics of Materials and Surfaces

Background: Symmetry, nature of bonding, crystalline structure and classification, 2D and 3D lattice types, symmetry tables, constraints on physical properties by symmetry, diffraction for structure studies, nuclear and magnetic scattering, small angle scattering.

Lattice vibrations and phonons: Debye model, dynamical matrix, acoustic and optical branches, outline of experimental techniques, like neutron inelastic scattering, Raman and Brillouin scattering; special features in phonon spectra like softening, Kohn anomaly, etc.

Molecular dynamics simulation technique: simulations as a function of pressure and temperature.

Electron states, independent particle picture and periodic boundary conditions, metal-insulator-semiconductor bands, Fermi surface, relation to many electron system and total energy, exchange-correlation terms, relation to experiments like photoemission, optical absorption, etc.

Magnetism: Magnetic materials, types of magnetic ordering and interactions, principles of adiabatic demagnetization and cooling, magnetic domains, linearized spin waves in ferromagnets.

Superconductivity: Meissner effect, energy gap, London equation, type-I and type-II superconductors, vortices, tunneling junctions, outline of modern superconductivity theories, new superconducting materials.

Semiconductors: Intrinsic and extrinsic semiconductors, p-n junction and its applications, heterostructures and semiconductor superlattices.

Dielectrics and Ferroelectrics: Dielectric relaxation and loss, ferroelectric and related materials, comparison with ferromagnets.;

Introduction to surface structures, stability and reactivity.Surface reconstructions and relaxation.Surface processes: Physisorption and chemisorptions.

Surface modification techniques: Physical vapor deposition (thermal evaporation, electron beam, laser ablation, sputtering, molecular beam epitaxy), chemical vapor deposition. Self-assembled monolayers, Langmuir-Blodgett techniques.

Surface characterization techniques: Morphology (optical, scanning electron, atomic force, scanning tunneling and tunneling electron microcopies); Structure (low energy electron diffraction, high energy reflected electron beam diffraction, grazing x-ray diffraction); composition (X-ray photoelectron spectroscopy, energy dispersive X-ray analysis, Rutherford back scattering, secondary ion mass spectrometry).

References

1. *Solid State Physics*, N.W. Ashcroft and N.D. Mermin (Saunders College, 1976)
2. *Introduction to Solid State Physics*, C. Kittel 8th edition (Wiley, 2004)
3. *Solid State Physics*, A.J. Dekker (Macmillan India Limited, 2000)
4. *Physics of Surfaces and Interfaces*, *H. Ibach* (Springer, 2006)

PY 605: Reactor Physics and Technology

Basics Neutron Physics Concepts: Fission process, Definition of flux, current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section. International Nuclear Data files & processing for reactor application.

Steady State Neutron Transport Equation: Transport equation : Differential & integral forms, Diffusion approximation, One speed neutron diffusion theory, Boundary conditions, Source-sink problem, Sub-critical reactors with flux independent source, K-infinity, four factor formula, Critical reactor and concept of K, Separation of space and energy.

Homogeneous Reactor: Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector savings.

Slowing Down and Energy Dependence: Elastic scattering, Inelastic scattering, Anisotropy, average energy loss per neutron, Concept of lethargy. Fermi age theory, age of neutron, Logarithmic energy decrement, Slowing down spectra, Slowing down in hydrogen, Definition of resonance integral, Shape of thermal neutron-Maxwell spectrum.

Resonance Absorption: Resonance cross sections, Resolved and unresolved region, Spatial and energy self shielding, Narrow resonance and intermediate resonance approximation, Concept of potential scattering cross section, Resonance integral in homogeneous media, Doppler broadening of resonance.

Multi-group Diffusion Theory: Energy group and group fluxes, Flux weighted group constants, One group theory for thermal neutrons, Two group theory, Two group two region model core with reflector.

Reactor Kinetics: Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, One group delayed neutrons, One dollar of reactivity, Prompt criticality.

Reactor Control: Cold start-up, Hot power operation, Temperature loads, Effects of burnup and fission products. Function of control rods. Theory of control rods, Xenon load during operation, Xenon iodine concentrations after shutdown, Xenon override, Xenon poison out condition, Samarium poisoning. Temperature coefficient of reactivity, Density temperature coefficient.

Experimental reactor physics aspects: Neutronic Instrumentation (source and power range monitors/detectors); Neutron Sources - requirement vis a vis reactor type (eg external localised sources in LWRs & Fast Reactors; internal distributed spontaneous fission/photo neutron sources in PHWRs) ; Approach to criticality in different reactors; different steps of initial start up in different reactors (research and power reactors); Low power experiments for validation of reactor physics evaluations - subcritical and critical experiments; experimental determination of reactivity coefficients; General methods of flux measurement - foil/wire activation methods; spectrum unfolding; differential measurements for reaction rates; Dynamic methods for reactivity evaluation - power run-down experiments and period measurements; Process parameter measurements using neutronics - eg., coolant flow measurement with N-16 gamma signals; Delayed neutron and noble gas fission

Nuclear Fuel Cycles: Uranium-Plutonium, Uranium-Thorium. Brief Description of Nuclear Reactors like PHWRs, AHWR,VVER, HTR and FBR. Brief discussion of Accelerated Driven Subcritical System (ADSS)

References

1. *The Elements of Nuclear Reactor Theory*, Samuel Glasstone and M.C.Edlund, (Van Noostrand, 1952).
2. *Nuclear Reactor Theory*, Lamarsh J.R., (Addison-Wesley, 1966).
3. *Nuclear Reactor theory*, Duderstadt and Hamilton, (Wiley, 1976).
4. *Nuclear Reactor Engineering*, Glasstone and Sesonske , (Reprint CBS Publishers, 2004)
5. *The Physical Theory of Neutron Chain Reactors*, Weinberg A. M. and Wigner E.P., (Chicago Press, 1958).
6. *Nuclear Reactor Theory*, Bell and Glasstone (Van Nostrand Reinhold Co., 1970).
7. *Physics of Nuclear Reactors*, Jakeman D. (American Elsevier, 1966).
8. *Physics of Nuclear Reactors*, Garg, Feroz Ahemad and Kothari L.S. (Tata McGraw Hill, 1986).
9. *Nuclear Reactor Physics,* Weston M. Stacey, (Wiley, 2001).

PY 606: Accelerator Physics and Technology

Basic Accelerator Physics

Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons; intersecting storage rings; ion sources.

General equations of motion in a combined electric and magnetic field, in Cartesian co-ordinate system; in cylindrical co-ordinate system; beam rigidity; relativistic expressions.

Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.

Expression for vertical betatron frequency; expression for horizontal betatron frequency; weak focusing principle; stop bands.

Tunes and Resonances in betatron oscillations; imperfection resonances; sum and difference resonances; non-linear resonances; tune diagram; working point of an accelerator; general design of a cyclic accelerator.

Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;

Matrix techniques in beam optics; first order transfer matrix of dipole/quadrupole, transfer matrix of a drift space; quadrupole doublet; condition for double focusing; other focusing conditions; aberrations; second order transfer matrix; matching and design of beam transport systems.

Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters

Strong focusing principle; analysis of betatron frequencies using matrix technique; condition for strong focusing; lattice design.

Momentum compaction; Longitudinal stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.

Physics of synchrotron radiation sources; spectrum of emitted radiation; Schwinger's expressions; brilliance of a source; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators, FEL; fundamental wavelength.

RF Linacs

Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.

Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac

Transit time factor and the energy gained in a linac.

Longitudinal stability; stability criteria; separatrix ; synchronous oscillation with small and large amplitudes; longitudinal wave vector; time period; phase damping; acceleration through v=c traveling wave linac and damping phenomena; acceleration conditions therein etc.

Transverse stability; stability criteria; impulse due to radial field; focal strength of a radial defocusing impulse.

Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.

General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature structures; superconducting structures (SC); general advantages of SC systems over room temperature ones; Breakdown mechanisms in SC cavities.

Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac

Introduction to space charge effects.Linear space charge and KV envelope equations.

Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Applications: Accelerator Driven Systems.

High power DC and pulsed electron accelerators

Electron emission processes; thermionic cathodes; field emission; explosive field emission.

Pulse power systems; Marx generators; Tesla transformer, transmission line spark gaps; induction linac.

Relativistic electron beam generation, propagation and applications in generation of microwaves, neutrons, ion beams and X-rays.

Industrial DC electron accelerators.

References

1. *Principles of RF Linear Accelerators*, T. P. Wangler (John Wiley & Sons Inc., 1998)
2. *Introduction to Accelerator Physics,* Arvind Jain (Macmillan India 2007)
3. *Electron Beam Technology*, S. Shiller, U. Heisig and S. Panzer (John Wiley & Sons, 1982)
4. *An Introduction to the Physics of Particle Accelerators*, M. Conte, W.W. Mac Kay (World Scientific Publishing Company, 2008)
5. *Handbook of Accelerator Physics and Engineering*, A. Chao, M. Tigner (1999)

6. *Particle Accelerator Physics*, Vol 1 and 2, Helmut Widemann (Springer 1999 & 2012)
7. *Principles of Charged Particle Acceleration*, Stanley Humphries (Wiley-Interscience, 1986)
8. *Fundamentals of Beam Physics*, James Rosenzweig (Oxford University Press, 2003)
9. *An Introduction to Particle Accelerators*, E. J. N. Wilson (Oxford University Press, 2001)
10. *Accelerator Physics*, S. Y. Lee (World Scientific Publishing Company, 2004)
11. *The Physics of Particle Accelerator:An Introduction*, Klaus Wille (Oxford University Press, 2001)
12. *The Principles of Circular Accelerators and Storage Rings*, Philip Byrant (Cambridge University Press, 2005)

PY 607: Astrophysics

Introduction to Astrophysics and Astronomy: Celestial sphere, coordinate system, time references, cosmic-rays, multi-wavelength observations.

Astrophysical Objects: Stars, clusters, galaxies, x-ray binaries, pulsars, supernova remnants, active galactic nuclei etc.

Non Thermal Universe: Cosmic-ray spectrum and composition, Cosmic emissions at keV-TeV energies, first order and second order Fermi acceleration, diffusive shock acceleration.

Experimental Techniques in Astronomy: Gas filled detectors, solid state detectors, satellite based experiments, ground based experiments, extensive air showers, simulation studies, atmospheric Cherenkov technique.

Fundamentals of Radiative Transfer: Electromagnetic spectrum, radiative flux, specific intensity and its moments, basic equations of radiative transfer, bremsstrahlung, synchrotron and inverse Compton process, proton-proton collision, neutral pion decay, proton-photon interaction.

Theory of Accretion: Spherical accretion, Eddington luminosity, disc accretion and its basic equations, equations for structure of discs and their standard solution.

Jets and Outflows: Microquasars, Blazars and Radio Galaxies, radiation emission from jets, Doppler boosting, Lorenz transformations, observed spectra and spectral models.

References

1. *High Energy Astrophysics*, Vol 1 & 2, M.Longair (Cambridge University Press, 2004).
2. *Very High Energy Gamma-Ray Astronomy*, Trevor Weekes (IOP Publishing, 2003).
3. *Radiative Processes in Astrophysics*, G.B.Rybicki and A.P.Lightman (John Wiley & Sons, 1979).
4. *Accretion Power in Astrophysics*, J.Frank, A.King, D.Raine (Cambridge University Press, 2003).

Note: First four topics (with first three references) constitute the regular 15 lecture course (See Table-1) while all the topics together constitute the 30 lecture course (see Table-3).

PY 608: Electronics

Digital Electronics

Overview of Digital Integrated Circuits: Boolean Algebra and Truth Tables, Integrated circuit Families and their applications, Digital Gates, Flip-Flops, Counters, Multiplexer, Memories.

Number system: Binary, Octal, Hexadecimal with examples. Conversion from one to the other.

Half Adder, Full Adder, 4 bit Adder/Subtractor.

Digital Computer Systems: Basics of Digital computers, 8085 microprocessor architecture and interfacing of memory and I/O peripheral devices.

Buses: Synchronous, Asynchronous. Basics of ISA and PCI buses

Interface standards: RS232, USB; basic protocol, voltage levels, data transfer rate, length etc.
SCADA – Overview

Analog Electronics

Overview of Electronic Devices and Circuits: Diodes, Zeners, Transistors and FETS. Switching Circuits.

Linear Integrated Circuits: Characteristics of OP AMP, Applications of OP AMP (Amplifier, Integrator, Differentiator etc) and Comparator.

Power Supplies: Linear and Switch Mode Power Supplies, High Voltage and Power supplies.

Data Converters: Sampling Theorem, Analog to Digital Converters, Digital to Analog Converters, Sample and Hold Circuits

Reference

1. *Modern Digital Electronics,* R. P. Jain, 3rd Edition (Tata McGraw-Hill Publishing, 2003).
2. *Microprocessor Architecture, Programming, and Applicationswith the 8085,* Ramesh Gaonkar, 5th Edition (Prentice Hall, 2002).
3. *Electronic Principles,* A. P. Malvino, 7th Edition (Tata McGraw-Hill Publishing).

PY 609: Health Physics and Radiation Detectors

Part-I: Nuclear and Radiation Detectors

Interaction of radiation with matter: Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe-Bloch formulae), Cherenkov radiation.Energy loss of electrons and positrons: Electronic stopping and energy loss by bremsstrahlung radiation,Interaction of photons: Photoelectric absorption, Compton scattering, pair production, Electromagnetic shower in high energy photon and electron interaction with matter**,** Interaction of Neutrons: elastic scattering, radiative capture, positive Q-value reactions such as (n,p), (n,a), (n,fission) and hadron shower production at high energies.

Radiation detectors: General characteristics of detectors: efficiency, response in energy, time, position and corresponding resolutions, recovery time or count rate handling capability**,** Gas detectors: Basic processes, Q-V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter. Large area MWPC, PPAC.Semiconductor detectors: Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium detectors (planar and cylindrical geometry). Photovoltaic cells, charged coupled devices.Scintillation detectors: Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes**,** Compton suppressed high purity germanium detectors for high-resolution gamma spectroscopy,Miscellaneous detectors:Cryogenic detectors, thermal detectors, channeltrons and microchannel plates, plastic track detectors, hybrid detectors.

Experimental techniques: Electronics modules for pulse processing: Preamplifiers(charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), timing discriminators(leading edge and constant fraction types), gate and delay generators, coincidence(fast and slow) units, linear gate and stretchers, scalers and rate dividers, SCA, TAC, ADC, QDC, TDC, MCA, computer based data acquisition systems (DAQ). Particle identification methods (dE-E telescope, pulse shape discrimination, Cerenkov radiation), time of flight technique, magnetic spectrometers including recoil mass separator.Monte Carlo simulation of detectors.

Part-II: Health Physics

Introduction: Radiation sources, quantities and units: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given). Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given), Exposure dose relationship, Bragg-Grayprinciple.

Biological effects, Radiation Protection and Regulation: Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell.Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Importance of radiation protection programme in DAE. Types of exposure (natural, occupational, medical and public).National and International regulatory bodies, their role and responsibilities. Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems).Latest recommendations of ICRP-103.Fundamentals of ICRP respiratory model (only basics), entry through ingestion, GI track model (only basics).Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Radiation protection and measurement (External and Internal): Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources.Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area monitoring, air monitoring. bioassay, whole body counting and Liquid Scintillation Spectrometry (LSS) techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures: Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation.

Nuclear Accidents, Emergency Preparedness and Management: Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

Industrial Safety (Non radioactive): Principles of industrial safety and industrial hygiene; legislation related to health and safety and major hazard control.

References:

1. *Radiation Detection and Measurement*, G.F. Knoll, 4th edition (John Wiley & Sons, New York, 2010)
2. *Techniques for Nuclear and Particle Physics Experiments*, W.R. Leo, 2nd Edition. Springer International Student Edition (Narosa Publishing House, New Delhi, 1995).
3. *Introduction to Health Physics*, Herman Cember, 4th Edition (McGRAW-HILL, 2009)
4. *Physics for Radiation Protection*, James E. Martin, 2nd Edition (Wiley-VCH Verlag GmbH, 2006)
5. *IAEA Regional Basic Professional Training Course on Radiation Protection* (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
6. *Nuclear Radiation Detection*, W.J. Price, 2nd Edition, (McGRAW-HILL,1964)
7. *Radiobiology for radiologists,* Eric J. Hall, 7th Edition, (Lippincott Williams & Lippincott, 2012)
8. *Accident Prevention Manual for Industrial Operation*, Vol. 2, National Safety Council, 11th Edition, (National Safety Council, USA, 1997).

PY 610: Engineering Drawing and Workshop Practices

Overview of Engineering Drawing

Drawing Instruments, Standards and Codes: Introduction; Drafting Instruments-Drawing board, T-square, Set-square, Compass, Dividers, Scales, French curves and Drafting machines; Various Indian and International standards and codes related to drafting.

*Sheet Layout and Sketching***:** Sheet layout; Sheet sizes; Scales and scale drawing.

*Types of drawing***:** Assembly drawing- General assembly drawing, Schematic assembly drawing, Exploded assembly drawing; Sub assembly drawing; Part drawing; Production drawing; Drawing for manual and catalogue.

*Lines, Lettering and Dimensioning***:** Introduction; Types of lines; Types and sizes of letter; Dimensioning- Types, Terms and notations, Placing of dimensions, Unit of dimensioning, general rules and practical hints on dimensioning.

*Orthographic Projection***:** Introduction, principle of projection; Methods of projection, Orthographic projection, Planes of projection, First angle projection, Third angle projection, B.I.S. code of practice and conventions employed.

Sectional Views: Introduction; Cutting plane line; Types of sectional views- Full section, Half section, Partial or broken section, Revolved section, Removed section and Offset section; Sectioning conventions; Hatching or section lines and conventions of section lines.

*Tolerances, Limits and Fits:*Introduction;Linear and angular tolerances; Tolerance zone – limits and deviations; Tolerance sizes, Standard tolerance grades; Geometric tolerances; Classification of fits – Clearance, Transition and Interference; System of fits – Hole basis and Shaft basis.

Surface Parameters: Surface texture; Surface irregularities; Surface roughness assessment methods; Roughness grades – symbols, values and grade numbers; Principle reasons for controlling the surface texture; Factors affecting the surface roughness; Disadvantages of excessive roughness; surface roughness achievable from different manufacturing process.

Computer Aided Drafting: Introduction; Benefits and limitations of CAD; Hardware and software of CAD system; AutoCAD–Brief introduction; Drawing environment, layout and sketching; How to access commands;Getting help; Starting a drawing**-**Existing drawing & New drawing**;** Basic settings – Units, Scale, Limits**,** Grids, & Snap**;** Elements of drawing-Line, Multi-line, Rectangle, Polygon, Curve, Circle, Donut, Points, Sketch, Spline, Ellipse, Hatch & Fill;Object Properties - Line type, Colour and Layer; Undoing mistakes;Drawing accurately; Viewing and Editing commands– Zoom, PAN, Move, Align, Rotate, Copy, Mirror, Array, Offset, Trim, Extend, Chamfer, Fillet and Erase;Text; Dimensioning and Printing / Plotting of drawing. Brief introduction of Solid modeling software and its command.

Threads and fasteners: Introduction; Parts of threads; Forms of threads; Single and multiple start threads; LH & RH threads; Brief introduction of bolts, studs, screws, plain & spring washers, set screw and split pin.

Overview of Workshop Practices

Manufacturing Process: Introduction; Classification of manufacturing process- Machining, Joining and Forming.

Metal Cutting using machine tools: Introduction; Theory of metal cutting; Process of metal cutting; Single point and Multipoint cutting tools; Tool signature; Machine reference system; Commonly used metal cutting machines, its parts and related operations / processes viz. Turning, Drilling, Boring, Milling, Shapers, Planer, Grinding etc.

*Unconventional machining operations***:** Introduction; Various types of machines and its operations viz. AJM, USM, ECM, EDM, EBM, and LBM.

*Metal Cutting using hand tools***:** Introduction; Various types of hand tools, its parts and related machining operations viz. saws, Files, Hand drills, Taps, and Reamers.

*Metal Forming***:** Introduction; Various types of forming tools, its parts and related forming process viz. Rolling, Bending, Spinning and Drawing.

*Joining Methods***:** Introduction; Various metal joining tools and related processes viz. Soldering, Brazing and Welding; Various types of demountable joints, flanges and coupling.

References

1. *Engineering Drawing Practice for Schools & Colleges (SP 46:2003)*, Bureau of Indian Standards.
2. *Geometrical and Machine Drawing*, N.D. Bhatt, V.M. Panchal, **(**Charotar Publishing House, Anand 2000).
3. *Manufacturing Science*, A. Ghose, A. Mallik (Tata McGrow Hill, 1997).

PY 611. Research Methodology and Methods of Experimental Physics

Research Methodology: Definition and characteristics of research,Objectives, importance and planning of research, types and stages of research, scientific methods, accessing scientific literature, *Experimental design*: control of errors, calibration of instruments, data analysis,*Statistical methods*:Definition of precision, accuracy, systematic and random errors**,** propagation of errors in experimental data and their estimation, estimation of confidence level.*Mathematical modeling*: measurement of functional relationships, order of magnitude analysis, function fitting, *Documentation*: preparing scientific papers/reports and presentations, *Laboratory safety*: Safe practices, *Research ethics:* acknowledgment of the source of ideas, awareness of plagiarism and other scientific misconducts.

Vacuum Techniques: Definition of Vacuum, Basic theory of Gas dynamics**,** Importance of Vacuum for various experiments, Low temp, Accelerators etc.**,** Flow Regimes in vacuum systems**,** Line Conductance, Calculation of pump-down time**,** Pumps and their ranges: Rotary vane pumps, Diffusion pumps, Ion pumps, Cryo-pumps, Sorption pumps, Gettering pumps**,** Vacuum Gauges in various ranges: Thermal Conductivity gauges, Ionization gauges, Ultrahigh vacuum gauges**,** Vacuum valves**,** Design of vacuum systems**,** Leak detection

Low Temperature Techniques: Requirement of Low Temperature *techniques* for experiments, Heat transfer mechanisms at low *temp*: conduction, convection and radiation, Thermal properties of materials at low temp: Sp. Heat, Thermal conductance etc.Thermodynamic properties of liquid cryogens, Liq. $N_2$and Liq. He, Low *temp* thermometry, Design of small scale laboratory cryostats: Material selection, their properties, Vacuum components, type of measurements, Superconducting magnets, Various inserts, Experiments at low temp: Transport properties, Magnetic properties, Faraday balance, Vibrating Sample magnetometer, SQUID, A.C. Susceptibility, Torque magnetometry

X- ray and Neutron Techniques for Condensed matter studies: Neutrons and X-rays as probes for condensed matter. Complementarities of the techniques**,** Neutron and X-ray sources: Nuclear reactors, Spallation Neutron Sources, Laboratory X-ray sources, Synchrotron X-ray sources**,** Elastic scattering of neutrons and X-rays. Experiments and examples**,** Inelastic scattering of neutrons. Dynamics in solids**,** Possible inelastic experiments in synchrotron sources using X-rays

Laser-Raman and Infrared spectroscopy: Theory of Raman spectroscopy, Laser Raman spectrometer, Molecular symmetry and Raman active modes, Some typical examples, Theory Infrared spectroscopy, Fourier Transform IR (FTIR) Instrument, Typical examples. Comparison with Laser-Raman spectroscopy, IR experiments in synchrotron sources

Laser and Laser spectroscopy Techniques: *Laser diagnostic techniques*: measurement of energy/intensity/power, pulse width, bandwidth, polarization etc. Synchronization of laser pulses, optical alignment. *Laser spectroscopy*: Techniques of some laser spectroscopy experiments in brief i.e. Intracavity laser absorption spectroscopy, CRDS, fluorescence, Saturation absorption spectroscopy, optical pumping and double resonance techniques, Design and implementation, maximization of signal, calibration of frequency

Plasma Physics and Technology: Understanding operation of plasma torches: construction of plasma torches, I-V characteristics of arcs, requirement of I-V characteristics of power supplies for plasma torches, gases suitable to be used for production of plasma, method of ignition of plasma, water cooling systems, interlocks etc. Determination of temperature in thermal plasma jets by spectroscopy techniques.

Experiments in accelerator physics and nuclear physics.

Reference

1. *Research methodology for science*, M.P. Marder (Cambridge University Press 2011).

ELECTIVE COURSES

Elective Courses in General Physics

PY 701: Special topics in Mathematical Physics

Difference equations: Homogeneous linear difference equations (constant-coefficient equations, linear independence, initial and boundary-value problems, Euler equations, generating functions, eigenvalue problems); Inhomogeneous linear and nonlinear difference equations

Local analysis: Singular points, local behaviour of solutions at irregular singular points of homogeneous linear equations, inhomogeneous linear equations, asymptotic relations, asymptotic series, approximate solutions of nonlinear differential equations, nonlinear autonomous systems, singular points of difference equations and local behaviour of solutions, regular and singular perturbation theory, perturbative eigenvalue problems

Global analysis: Boundary layer theory (examples, mathematical structure, simple boundary layer problems), Multiple-scale analysis (resonance and secular behaviour, formal theory, examples), Floquet theory of stability, Mathieu equation, Fermi-Pasta-Ulam problem

Reference

1. *Advanced Mathematical Methods for Scientists and Engineers,* C. M. Bender, S. A. Orszag (Springer, 2010).

PY 702: Selected Topics in Classical Mechanics

Basic concepts: Principle of least time, connection with Huygens principle, optics-mechanics analogy – the basic ideas of Hamilton's mechanics, Euler-Lagrange equations and Hamilton's equations, applications

Transformation theory of mechanics: Generating functions, contact transformations, canonical transformations, canonical group, motion in phase space, Poincaré-Cartan invariant, action-angle variables, adiabatic invariance, examples

Integrable systems: One degree of freedom, Liouville-Arnold theorem, dynamical systems, more than one freedom, noncanonical variables

Canonical perturbation theory: Resonances, classical perturbation theory, adiabatic perturbation theory, secular perturbation theory, applications

Near–integrable systems: KAM stability, three-body problem, applications to celestial mechanics, plasma physics

References

1. *Regular and chaotic dynamics,* A. J. Lichtenberg and M. A. Lieberman (Springer, 1992).
2. *Chaos in dynamical systems,* E. Ott (Cambridge University Press, 2001).
3. *Classical dynamics - a contemporary approach,* J. V. Jose, E. J. Saletan (Cambridge University Press, 2002).

PY 703: Chaos and Nonequilibrium Statistical Mechanics

Introduction: Laws of mechanics and the law of large numbers, Boltzmann ergodic hypothesis, Gibbs' mixing hypothesis, problems in modern nonequilibrium statistical mechanics

Boltzmann and Liouville equation: Derivation, H-theorem, Kac ring, diffusion, BBGKY heierarchy, Poincare recurrence theorem, Birkhoff ergodic theorem, mixing systems, distribution functions

Green-Kubo formulae: Linear response theory, van Kampen's objections, Green-Kubo formula for diffusion

Nonlinear maps: Baker map, Boltzmann equation for Baker map, Bernoulli sequences, irreversibility, Arnold cat map, Kolmogorov-Sinai entropy, Pesin's theorem, Markov partitions, Frobenius-Perron equation

Open systems: Smale horseshoe, escape-rate formalism, thermodynamic formalism for chaos, transport coefficients, deterministic diffusion, Sinai-Ruelle-Bowen measures, entropy, Gallavotti-Cohen fluctuation formula

Dynamical foundation of Boltzmann equation: Lorentz gas, Sinai formula, Lorentz-Boltzmann equation

References

1. *An introduction to chaos in nonequilibrium statistical mechanics,* J. R. Dorfman (Cambridge University Press, 1999).
2. *Chaos, scattering, and statistical mechanics,* P. Gaspard (Cambridge University Press, 1998).

PY 704: Nonlinear Dynamics

Introduction to Nonlinear Dynamics: Introduction to nonlinear dynamical systems (continuous-time): local and global bifurcations, Explanations of Feigenbaum sequence and other routes-to-chaos through standard maps. Characterization of chaos: fractal dimension and other measures; Feigenbaum universal constants. Nonintegrable Hamiltonian dynamics: KAM theorem, Transition from regular to chaotic state, KAM Torus Breakdown.

Instabilities and chaos of periodically forced nonlinear oscillators: Harmonic and various subharmonic resonances. Period doubling, tripling, quadrupling, n-tupling bifurcations, Synthesis of bifurcation structure: recurrent features. Multistability and basins of attraction; Crises of chaotic attractors.

Examples of bifurcations and chaos in laboratory-scale systems: Feigenbaum sequence, multistability and crises in lasers, Instabilities and chaos in electronic circuits, Fluid dynamical instabilities in natural circulation thermal hydraulics and in plasma. Dynamical diseases: cardiac and neurological. Introduction to soliton wave propagation.

Control and synchronization of nonlinear phenomena: Control of Chaos-theoretical concepts, Control of multistability and multi-state hopping intermittency, Coupled nonlinear dynamical systems: various modes of synchronization, secure communication.

Experiments and Numerical projects: Hands-on experience on analyzing various types of bifurcations, crises, chaos, multistability, noise-induced intermittency etc with nonlinear electronic circuits. Computations of subharmonic bifurcation curves of the periodically forced nonlinear systems.Analysis of nonlinear phenomena in the case of autonomous nonlinear systems.

References

1. *Nonlinear Oscillations, Dynamical Systems, and Bifurcation of Vector Fields*, John Guckenheimer and Philip Holmes (Springer Verlag, New York, 1983).
2. *Chaos*, Hao Bai-Lin (World Scientific, 1984).
3. *Universality in chaos*, P. Cvitanovic' (Adam Hilger Ltd, Bristol, 1984).
4. *Deterministic Chaos*, H G Schuster (Springer-Verlag, 1984).
5. *Nonlinear Dynamics and Chaos*, J M T Thompson and H B Stewart (Wiley, 1986).
6. *Chaotic Vibrations –An Introduction for Applied Scientists and Engineers*, F. C. Moon, (John Wiley & Sons New York 1987).
7. *Chaotic and Fractal Dynamics*, F C Moon (J Wiley, 1992).
8. *Chaos in Dynamical Systems*, E Ott (Cambridge Univ Press,1993).
9. *Introduction to Nonlinear Dynamics for Physicists*, H D I Abarbanel, M I Rabinovich and M M Sushchik, (World Scientific,1993).
10. *Nonlinear Dynamics and Chaos*, S H Strogatz (Addison Wesley, 1994).
11. *Applied Nonlinear Dynamics, Analytical, Computational, and Experimental Methods*, A. H. Nayfeh and B. Balachandran, (John Wiley \& Sons, Inc New York 1993).
12. *Nonlinear Spatio-temporal Dynamics and Chaos in Semiconductor*, E. Scholl, (Cambridge Univ Press, 2001).
13. *Handbook of Chaos Control*, Ed. H. G. Schuster, Wiley-VCH 271(1999).
14. *Elementary Stability and Bifurcation Theory*, G. Iooss and D. D. Joseph, (Springer-Verlag New York Heidelberg Berlin), 1990.
15. *Nonlinear Oscillations in Physical Systems*, Ch. Hayashi (McGraw-Hill: New York San Francisco Toronto London, 1964).
16. *Chaotic motions in Nonlinear Dynamical Systems*, (CISM Courses and Lectures 298), W. Szemplin'ska-Stupnicka, G. Iooss and F. C. Moon (Springer-Verlag, Wien New York, 1988).
17. *Perturbation Methods*, A. H. Nayfeh (Wiley: New York Chichester Brisbane Toronto, 1973).
18. *Nonlinear Oscillations*, A. H. Nayfeh and D. T. Mook (Wiley: New York Chichester Brisbane Toronto Singapore, 1979).
19. *Multiple Attractors in the self-similar bifurcation-structure*, B. K. Goswami, Rivista del Nuivo Cimenta, Vol. 27, 2005.

PY 705: Advanced Computational Physics

ScientificProgramming: Introduction to ComputerProgramming, Familiarization with Unix andWINDOWS,Computerarithmetic, High Level Languages, FORTRAN&CstatementsandimplementationonPCs,Sampleassignmentstowriteprogramsforscientificcomputation.

NumericalMethods: Solutionofnon-linearsystemofequations.Curvefittingsofgivendata.Numericalintegration Solutionoflinearsystemsandeigenvalueproblems.Solutionofordinaryandpartialdifferentialequations, MonteCarloMethods.

Physicsproblemsand solutions basedonscientificprogramming: Scatteringbyacentralpotential,Partialwavesolutionofquantumscattering, ASchematicshellModel,Thedynamicsofmanyparticlesystems,(moleculardynamics,deterministicmethod),Optimizationmethods, Neutrontransmissionthroughashield(MonteCarloMethod). Multi-dimensionalMonteCarlointegration,importancesampling,randomwalkmethods,Theapproachtoequilibrium(MonteCarlomethod),Microcanonicalensemble,CanonicalensembleandMetropolisalgorithm.

References:

1. *NumericalRecipesinFortran*,W.H.Presset.al., (CambridgeUniv.Press, 1992)
2. *NumericalMethodsforEngineeringApplication*,J.H.Ferziger, (JohnWiley, 1998)
3. *TheMonteCarloMethod*,I.M.Sobolov (MIRPublishers,1971).
4. *AnIntroductiontoComputerSimulationMethods*, H.GouldandJ.Tobochnik,Part-1&2 (Addision-Wesley, 1988)
5. *ComputationalPhysics*,S.E.Koonin (Addision Wesley, 1986)
6. *TheoreticalPhysicsonthePersonalComputers*,E.W.Schmidtet.al (Springer-Verlag,1988).

PY 706: Stochastic Physics

Classical theory of Brownian Motion*: Langevin's Formulation***:** Motion of a particle in a fluid; Continuum theory of viscous drag; Molecular fluctuations- resolution into mean and fluctuating force; Langevin's equation for a free particle; Force correlations and ensemble averaging; Approach to equilibrium; fluctuation dissipation theorem; implications; Stochastic motion of a harmonically bound particle. *Random-walk Model*: Markov process; Simple Markovian random-walks; position distribution using Fourier transforms; Levy flights; asymptotic law of root mean square displacements; continuous time random walks; random walk with memory; Monte-Carlo techniques of random walk simulations. *Passage to Differential equation*:Concept ofTransition probability;Constraints on moments;Integral formulation; Derivation of phase space Fokker-Planck equation (FPE); special solutions. *Diffusion approximation***:** Moments Equations of FPE; Closure problem; Reduction to diffusion equation; Discussion on boundary conditions.

Nucleation and Coagulation theory: *Homogeneous nucleation theory*: Thermodynamics of phase equilibrium; Free energy of a spherical drop; concept of critical size; Free energy barrier; cluster size distribution; detailed balancing; derivation of nucleation rate-Becker-Doring theory; Zeldovich Factor; Lifshitz-Slozov theory; Experimental studies on homogeneous nucleation rates; multi-component and ion-induced nucleation. *Mathematical theory of coagulation*: Onset of irreversibility post nucleation; The absorption condition; Derivation of formulae for Kernels; Smoluchowski's formulation of colloid coagulation; Integro-differential formulation; scaling theory; self-preserving distributions; Classification of Kernels; Gelation condition; numerical approaches; Practical examples in aerosols. *Escape over barrier*: Transition state theory; Kramer's rate formula.

Growth Models: *Aggregation theory*: fractal concepts; compact and fractal aggregates; mathematical and statistical fractals; Ballistic Aggregates; Eden clusters. *Fractal aggregates:*Diffusion limited growth; Mullins-Sekerka instability; Diffusion Limited Aggregate (DLAs); Witten-Sanders Model; spectral, walker and chemical dimensions; Current state of understanding of DLAs; Cluster-cluster aggregation Model; Relation to coagulation problem; dynamic scaling theory. *Numerical simulation techniques*: Lattice and off-lattice simulations; Monte-Carlo techniques.

References

1. *Stochastic problems in Physics and Astronomy*, S. Chandrasekhar**,** Rev. Mod. Phys. **15**,1-89 (1943).
2. *Noise and fluctuations: An Introduction,* D.K.C. MacDonald (Wiley 1962).
3. *The Fokker-Planck Equation*, H Risken, ed. H. Haken, (Springer-Verlag 1984)
4. *Wonderful world of random walks*, E.W. Montrol and M.F. Shlesinger in *Studies in Statistical mechanics, Vol XI*: Eds. E.W. Montrol and J.L. Lebowitz (Elsevier1984).
5. *Homogeneous Nucleation Theory*, F.F. Abraham (Academic 1974).
6. *Nucleation*, A.C. ettlemoyer (Ed.) (Marcel Dekker, 1969).
7. *Homogeneous nucleation theory and Experiment: A survey*, J.L. Katz, Pure and Appl. Chem. **64**, 1661-1666 (1992).
8. *Nucleation theory*, D.T. Wu in Solid-state Physics: Advances in Research and Applications **50**, 37 (1997).
9. *A general mathematical survey of the coagulation equation,* R.L. Drake, in International Reviews in Physics and Chemistry, Vol.3, Eds. G.M. Hidy and J.R. Brock (Pergamon1972).
10. *The effect of coalescence on the surface area of a coagulating aerosol,* W. Kochand S.K. Friedlander, J. Colloid & Interface Sci. 140, 419 (1990).
11. *Kinetics of clustering in irreversible aggregation*, M.H. Ernstin Fractals in Physics, (Eds.) L.Pietronero and E. Tossatti, (North Holland 1986).
12. *Diffusion limited aggregates-a kinetic critical phenomenon*, T.A. Witten and L.M. Sander, Phys. Rev. Lett. 47, 1400 (1981).
13. *Fractal growth phenomena*, T. Vicsek (World Scientific 1989).
14. *Scaling of kinetically growing cluster*, M. Kolb, R. Botet and R. Jullien, R, Phys. Rev. Lett. **51**,1123 (1983).
15. *Kinetics of aggregation and gelation*: F. Family and D.P. Landau, (North_Holland 1984).

Elective Courses in Nuclear and Accelerator Physics

PY 707: Selected Topics in Nuclear Physics

Brief introduction to heavy ion fusion reactions: General features, Energy dependence at low energy, Limitation at high energy

Decay of the compound nucleus and the statistical model analysis: Bohr hypothesis and Hauser-Feshbach evaporation model, Optical model, Transmission coefficients, Nuclear level densities (NLD)

Particle evaporation spectra and nuclear level densities: Evaporation spectra of neutron and charged particles, Experimental measurements, Extraction of NLD from evaporation spectra

Electromagnetic decay of excited nuclei: Electromagnetic interaction in nuclei – a brief introduction, Single particle and collective gamma transition

Brief introduction to giant resonances in nuclei: Giant resonances – definition, Energy and width systematic, Macroscopic and microscopic description – brief treatment, Giant Dipole Resonance (GDR) in deformed nuclei

Giant Dipole Resonance in excited nuclei: Brink-Axel hypothesis, GDR on excited states in proton capture reactions, GDR in hot nuclei formed in heavy ion reactions

Properties of GDR from high energy gamma spectra using statistical model: Inclusion of GDR emission in statistical model, Measurement of high energy gamma spectra – detectors, experimental procedures, Extraction of GDR information from measured spectra using statistical model, Shape evolution and fluctuation of hot rotating nuclei

Experiments with radioactive Ion Beams (RIB) and future directions: Production of RIB – different methods, GDR in exotic nuclei

References

1. *Treatise on Heavy-Ion Science*, Vol. 2, 3, ed. D. A. Bromley
2. *Nuclear Structure* (Vols. I and II), A. Bohr and B. R. Mottelson (Benjamin, Reading, Massachusetts, 1969 and 1975)
3. *Introductory Nuclear Physics*, S.S.M. Wong (Prentice Hall of India, 1990)
4. *Theoretical Nuclear Physics*, A. de Shalit and H. Feshbach (Wiley, NY 1974)

PY 708: Advanced Accelerator Physics & Technology

Proton and Heavy Ion Accelerators:DC Accelerators, Linacs, Cyclotrons, Synchrotrons etc,Positive and negative ion sources, Ionization, Recombination, Charge transfer and other processes in ion sources, Beam extraction, Low energy beam transport - matching to an accelerator, Radio Frequency Quadrupole, DTL, CCDTL and CCL, High Current Accelerators, Introduction to ADS Systems, Linacs for ADS. Normal and Superconducting accelerator structures, Space charge effects, Waveguide resonators etc.

Gigawatt Pulsed Power and Industrial Electron Accelerators: Electron emission processes and technology of cathodes, Electron gun design and related areas. Gigawatt to Terrawatt power pulsed electron guns, beam transport, HPM generation, Flash X Ray generation and applications. DC and RF Industrial Electron Accelerators- sub systems and applications

Beam Dynamics and advanced accelerators: Beam emittance, Liouville's theorem, Beam transfer lines, FODO cells, quadropole triplet, phase space matching, emittance dilution, Synchrotrons & Storage Rings, Synchrotron Radiation (SR) Sources, Linac Based SR Sources.
New Accelerators: Free Electron Lasers, Laser Acceleration, Plasma Beat Wave Accelerators

References

1. *Introduction to Accelerator Physics,* Arvind Jain (Macmillan India 2007)
2. *Electron Beam Technology,* S. Schiller (John Wiley & Sons Inc 1982)
3. *Industrial Electron Accelerators and Applications,* E.A. Abramyan (Springer 1988)
4. *Accelerator Physics,* 2nd ed., S.Y. Lee (World Scientific, 2004)
5. *Free Electron Lasers*, C. A Brau, (Academic Press, Oxford, 1990)

PY 709: Introduction to Neutrino Physics

The course is intended to introduce the basics of neutrino physics. By the end of the course it is hoped that one will be able to appreciate the intense activity worldwide in thisfield. A brief exposition of a non-invasive method of monitoring fissile materials using neutrinos will also be given.

Present understanding of fundamental particles and their interactions: neutrinos and their properties. Weak decays such as nuclear beta decay, muon and pion decay. Higher order processes such as double beta decay in nuclei.

Neutrino sources: Stellar (including the sun and supernovae), atmospheric, natural radioactivity, reactors and particle accelerators

Interactions of neutrino with matter: charged and neutral current processes, quasielastic and deep inelastic scattering

Neutrino oscillations: two flavour oscillations in vacuum and matter, three flavor oscillations

Some key experiments in neutrino physics: discovery experiments of ν_e,ν_μ,$\nu_\tau$etc.; what has been learnt and what we do not yet know; ongoing and planned experiments

References

1. *Neutrino Astrophysics*, J.N. Bahcall, (Cambridge University Press, Cambridge, England, 1989).
2. *Massive Neutrinos in Physics and Astrophysics*, R. N. Mohapatra and P.B. Pal, (3rd Ed. World Scientific, 2004)
3. *The Neutrino Matrix*, APS Multidivisional Study Group report (2004)

PY 710: High Energy Astrophysics

Introduction to Astrophysics and Astronomy: Celestial sphere, coordinate system, time references, cosmic-rays, multi-wavelength observations.

Astrophysical Objects: Stars, clusters, x-ray binaries, pulsars, supernova remnants, active galactic nuclei etc.

Non Thermal Universe: Cosmic-ray spectrum and composition, Cosmic emissions at keV-TeV energies, first order and second order Fermi acceleration, diffusive shock acceleration.

X- ray and Gamma-ray emission: Observed spectra from galactic and extragalactic sources, bremsstrahlung, synchrotron and inverse Compton scattering, IC spectra from optically thin and thick sources, electron-positron pair physics, thermal electrons and radiation, non-thermal electrons and radiation, gamma-rays from proton-proton and proton-photon interactions.

Theory of Accretion: Spherical accretion, Eddington luminosity, disc accretion and its basic equations, a alpha prescription of viscosity, equations for structure of discs and their standard solution.

Jets and Outflows: Microquasars, Blazars and Radio galaxies, radiation emission from jets, Doppler boosting, Lorenz transformations, observed spectra and spectral models.

Experimental Techniques in Astronomy: Satellite based experiments, ground based experiments, extensive air showers, simulation studies, atmospheric Cherenkov technique.

References:

1. *High Energy Astrophysics*, Vol 1 & 2, M.Longair (Cambridge University Press, 2004).
2. *Very High Energy Gamma-Ray Astronomy*, Trevor Weekes (IOP Publishing, 2003).
3. *Radiative processes in Astrophysics*, G.B.Rybicki and A.P.Lightman (John Wiley and Sons, 1979).
4. *Accretion Power in Astrophysics*, J.Frank, A.King, D.Raine (Cambridge University Press, 2003).

Elective Courses in Atomic, Molecular, Laser and Plasma Physics

PY711: Synchrotron Radiation and its Applications

Production and properties of SR: Physics of production of SR, general properties and advantages of SR, Storage rings, properties of bending magnet radiation, important relations/equations, Radiation from insertion devices (Wiggler, undulator), FELs, Historical development and current scenario, overview of Indus-1 & Indus-2.

Basics of Beamline Instrumentation: Considerations in optical design of beamlines, Special requirements in VUV, Soft-X-ray, Hard X-Ray, IR, types of monochromators, Mirrors, gratings, detectors, vacuum systems, electronics etc.

Experimental Techniques: Overview of typical experiments carried out at synchrotron facilities, brief introduction to various techniques, Spectroscopy (VUV, soft X-ray/hard X-ray spectroscopy, PES, ARPES, IR, THz), Scattering (Diffraction, crystallography, small angle scattering, Inelastic X-ray scattering, etc), Imaging (X-ray imaging, IR imaging, Microscopy, Lithography), Special techniques utilizing the polarization or time structure of SR

Atomic, Molecular & Cluster Physics using SR: Physics of autoionisation, Rydberg states, superexcited states, chemical dynamics, advantages of using SR to study these phenomena. Techniques: Photoabsorption, photoionization, fluorescence, PES (incl. ZEKE, MATI, etc.), Laser + SR, coincidence experiments, etc: Basic principles, design of experimental stations, information obtained. Recent developments & current status of the field internationally. Currently available facilities & ongoing research programs of AMPD at Indus-1(PPBL, HRVUV, photoabsorption studies of stable gases/free radicals, matrix isolation spectroscopy, etc.; Beamline & experimental stations planned at Indus-2.

References:

1. *Introduction to Synchrotron Radiation*, Giorgio Margaritondo (Oxford University Press, 1988).
2. *Soft X-Rays and Extreme Ultraviolet Radiation*, David Attwood *(*Cambridge University Press, 1999).
3. *Synchrotron Radiation: Production and Properties*,Philip John Duke, Oxford Series on Synchrotron Radiation 3 (Oxford 2008).
4. *Handbook on Synchrotron Radiation, Volume 1a*:Ernst-Eckhard Koch (Ed.)(North Holland, 1983).
5. *Handbook on Synchrotron Radiation, Volume 2*: *Vacuum Ultraviolet and Soft X-ray Processes*:G.V. Marr (Ed.) (North Holland, 1987).

PY 712: Selected Topics in Atomic and Molecular Physics

Coherent spectroscopy: Transition from Doppler to sub-Doppler to natural linewidth to sub-natural linewidth, theory and practice of sub-natural linewidth spectroscopy, atomic frequency stabilization techniques, error signals and stability, applications of coherent spectroscopy including slow light generation.

Physics with trapped ions and atoms: Techniques ofion-traps (Paul trap, linear quadrupole trap etc) and atom traps (magneto-optical trap, dipole trap), ultra-precision measurements of atomic parameters and fundamental constants, quantum jumps and parity violation in atoms/ions, quantum degenerate gases, ultra-cold molecules.

Atoms and molecules in intense fields: Multi-photon processes in atomic and molecular systems, cross-sections, Intense and super-intense laser-atom/molecule interaction, pondermotive force, Keldysh parameter, above threshold ionization, high harmonic generation, atomic stabilization, theoretical techniques involving Floquet and split operator methods, experimental techniques. Atoms in high magnetic fields.

R**eferences**

1. *Laser spectroscopy: Basic Concepts and Instruments*, W. Demtroder, 2nd Edition, (Springer Verlag, 1996).
2. *Atomic Physics*, C.J. Foot, Oxford Master Series in Atomic, Optical and Laser Physics (Oxford University Press 2008).
3. *Laser Cooling and Trapping*, H.J. Metcalf and P. van der Straten, (Springer 1999).
4. *Atomic and Molecular Processes with Short Intense Laser Pulses*, A.D. Bandrauk (Ed.), NATO ASI Series: B Physics, Vol **171**, Plenum Press (1988).

PY 713: Advanced Photonics

Review of wave optics: wave-particle duality concepts and experiments, Maxwell's equations, wave equation for light. Light propagation in conducting and non conducting medium, sources of light, characteristics of light (coherence and polarization), light in bulk materials.

Basics of lasers: emission and absorption of light, Einstein coefficients, population inversion, threshold condition, laser beam characteristics and parameters.

Fiber and non-linear optics: Reflection and refraction at plane wave interface, total internal reflection, TE and TM polarization, Goos-Hanchen shift, modes in optical waveguides, step index and graded index fibers, fiber in optical communication, fiber amplifiers and fiber lasers. Non-linear optics of materials, when and how non-linear response arise, dispersion relations, phase matching conditions, second and third harmonic non- linear optical effects, frequency mixing, Kerr effect and electro-optics effect. Applications of non-linear optics

Introduction to nanophotonics: Optical materials from bulk to nano-scale, why nanophotonics, light scattering mechanism in nano-scale structures, optics of quantum dots, nano-plasmonic crystals, surface plasmons, Fermi-Golden rule, photon density of states, different approaches to fabricate nanophotonic structures, application of nanophotonics.

Meta-materials: What are meta-materials, classes of materials and their exotic properties, photonic band gaps, one, two and three-dimensional band gaps for light, wave equation in photonic crystals, different methods to calculate photonic band structure, origin of band gap, spontaneous emission in photonic band gap, nanophotonics switching, optics of cavities, experimental realization of photonic crystals, different characterization techniques.

References

1. *Optics*, E. Hecht and A. R. Ganesan, (Pearson, 2008)
2. *Laser Fundamentals*, W. T. Silfvast, (University Press, 1996)
3. *Nanophotonics*, P. N. Prasad, (John Wiley & Sons, 2004)
4. *Photonic Crystals: Molding the flow of light, J. D.* Joannopoulos, S. G. Johnson, J. N. Winn and R. D. Meade, (Princeton University Press, 2008)
5. *Nanophotonic Materials: Photonic Crystals, Plasmonics and Metamaterials,* Editor(s): R. B. Wehrspohn, H.-S. Kitzerow, K. Busch, (John Wiley & Sons, 2008)

PY 714: Quantum Optics and Information

Quantum theory of radiation: Quantum states of radiation field, non-classical states, squeezing, photon statistics, correlations, noise properties of light.

Quantum theory of light-atom interaction: Optical Bloch equations, quantum theory of damping and master equation, dressed atom approach, quantum theory of lasers, coherent control, electromagnetically induced transparency.

Ultra-cold atoms and quantum degenerate gases: Laser cooling and trapping of atoms, interactions involving ultra-cold atoms, ultra-cold quantum gases, Bose-Einstein condensation, Gross-Pietavskii equation.

Elements of Atom optics: Atom optical elements, atom interferometry, non-linear atom optics, quantum atom optics.

Elements of Quantum information: Entanglement and its measures, quantum measurement, quantum teleportation, quantum communication, physical realization of quantum computer.

References

1. *Concepts of Quantum Optics*, P.L. Night and L. Allen (Pergamon,1983).
2. *The Quantum Theory of Light*, R. Loudon (Oxford University Press, NY, 1983).
3. *Elements of Quantum Optics*, P. Mystre and M. Sargent III (Springer Verlag 1990).
4. *Laser Cooling and Trapping*, H.J. Metcalf and P. van der Straten, (Springer 1999).
5. *Quantum Computation and Quantum Information*, M.A. Nielsen and I.L. Chuang (Cambridge University Press, 2000).

PY 715: High Power Lasers and Applications

Basics: Coherence, Resonator modes, Gaussian & Non-Gaussian beams, propagation through optical systems, beam quality, focusing, atmospheric propagation effects and adaptive optics techniques.

Nonlinear optical processes: Second Harmonic Generation, Third Harmonic G with pulsed and cavity enhanced CWorking lasers, Parametric generation, SRS, Two-photon absorption, Self-focusing and Self phase modulation, Nonlinear optical effects in optical fibers.

Types of lasers: Excitation techniques & Laser properties in different media: Gas (He-Ne, CO_2, Excimer, Cu Vapor, Chemical), Solid state : (Nd:YAG, Nd:Glass, Yb:YAG), Semiconductor diode, Free Eelectron Laser. Tunable lasers: Dye, Diode, Ti:Sapphire, Optical Parametric Oscillator, Frequency selection & tuning techniques, frequency stabilization.

Laser dynamics & pulse generation: Brief recapitulation of Relaxation oscillations, Q-switching, cavity dumping

Ultrashort pulse generation: Mode locking, Group Velocity Dispersion compensation in Kerr Lens Modelocking cavities, Pulse compression.

Power scaling: Special resonators, Pulsed laser amplifiers (CO2, Nd:YAG/Glass, Dye, CVL, Master Oscillator Power Amplifier chains) – gain saturation, efficiency, spectral narrowing, Injection locking. Diode laser arrays & amplifiers, Diode Pumped Solid State Lasers, Fiber lasers

Ultrashort pulse amplification and compression: Chirped pulse amplification in Ti:S, Opt Para CPA, regenerative amplifier, multipass amplifier – typical system architectures.

Applications: Laser Ionization Spectroscopy – applications in science & technology. Laser requirements and system architecture. Material processing, Reflection, transmission & absorption of laser beams in materials, ultrafast material processing.

High intensity laser interaction with materials: Basic phenomenology of: High intensity effects, High order harmonic generation, production and acceleration of charged particles, laser induced nuclear reactions, X-ray lasers, Laser fusion.

References

1. *Principles of Lasers*, O. Svelto and D C Hanna, 4th edition, (Plenum Press,1988).
2. *Solid State Laser Engineering*, W Koechner, Springer Series in Optical Sciences, 6th revised and updated edition, (Spinger, 2006)
3. *Laser Electronics*, J.T. Verdeyen, 3rd edition (Prentice Hall, 1995).
4. *Dye Lasers*, L.G. Nair, Progress in Quantum Electronics, 7, 153-268 (1982).
5. *Dye Lasers*, K. Dasgupta in Wiley Encyclopedia of Electric and Electronics Engineering (Wiley, New York, 1999).
6. *Fundamentals of Nonlinear Optics*, Peter E Powers (CRC Press, 2011).
7. *High Power Laser Handbook*, H. Injeyan & G.D. Goodno (McGraw Hill, 2011).

PY 716: Laser-Matter Interactions and Applications to Advanced Material Processing

Introduction to Laser Matter Interaction; Basics ofPulsed, Ultrashort and CW lasers typically employed for Laser processing; Mode Locking, Kerr Lens Modelocking, Pulse Compression, Chirped Pulse Amplification

S**urface Characterization, Measurement & Diagnostic Techniques:** (i). SEM, Optical microscope, X-ray Diffraction Technique (XRD), Atomic Force Microscopy (AFM), X-ray photoelectron spectroscopy (XPS), Electron probe X-ray micro-analysis (EPMA), Auger electron Microscopy (AES) Energy Dispersive X-ray spectroscopy (EDX), Differential Thermal Analysis (DTA) Surface Profilometer Surface hardness, Micro-indentation test

Plasma and Vapour diagnostics: Time of Flight (TOF), Langmuir Probe, LIBS, TRLIF etc.

Laser diagnostics: Short pulse – autocorrelator, FROG (frequency resolved optical gating), SPIDER (spectral phase interferometry for direct electric field reconstruction), Spatial profilometer- array detector

Laser Matter Interaction: Excitation Mechanisms, and Relaxation Times, Multiphoton Excitation, Photochemical Process- Catalytic Effects, Photophysical & Thermal Processes ; Heating & Surface melting, Evaporation

References

1. *Laser Processing and Chemistr*y, D.Bauerle, 4th Edition (Springer, 2011).
2. *Laser Material Processing*, W.M.Steen, 4th Edition (Springer, 2010).
3. *Pulsed Laser Deposition of Thin Films*, D.B.Chrisey and G.K.Hubler (Wiley Interscience, 2007).

PY 717: Computational Plasma Physics: Introduction to Particle in Cell (PIC) Technique

Basics: Necessity for plasma simulation. Approaches to plasma simulation, fluid and kinetic theory methods, examples of physical systems appropriate for each of the different approaches.

Introduction to the PIC method: The mathematical model. The physical model, Principles of finite differencing, Converting Maxwell’s equations into their finite difference form.

Solution of Maxwell’s equation: Interative methods for solving Poisson’s equation, Solution of curl equations using FDTD method, The concept of superparticles, Weighing methods, Shape factor, Realtion between particles and fields.

Self consistent charge and current density: Lorentz force integrator with and without magnetic fields. The computational cycle.Electrostatic programs.Electromagnetic programs.

Sources of errors and stability

References

1. *Plasma Physics via Computer Simulation*, C. K. Birdsall, A. B. Langdon (McGraw-Hill, 2004).
2. *Computer Simulation Using Particles*, R.W Hockney, J.W Eastwood (CRC Press, 1989).
3. *Electromagnetic Simulation using the FDTD Method, D. M. Sullivan (IEEE Press, 2013)*
4. *Numerical Techniques in Electromagnetics,* Matthew N.O. Sadiku (CRC Press, 2009)
5. *The Finite-Difference Time Domain Method for Electromagnetics,* K. S. Kunz, R. J. Luebbers (CRC Press, 1993).
6. *Introduction to Electrodynamics,* D. J. Griffith (Prentice-Hall, 2012).
7. *Classical Electrodynamics, J. D. Jackson (Wiley, 1998)*
8. *Introduction to Plasma Physics, F. F. Chen (Plenum Press, 1974).*

PY 718: Nonlinear Plasma Theory

Basics: Revision of linear theory, including Langmuir waves, ion-acoustic waves, Alfven waves, waves from local pulsed source, Cerenkov emission and Kelvin wakes, wakes in ion-acoustic waves, Vlasov equation, Chandrasekhar equation, cold plasma waves, Landau damping.

Nonlinear waves: beams of non-interacting particles, ordinary progressive waves, waves in weakly dispersive media, Korteweg de Vries equation (KdV), solitons, Analytical solution of the KdV equation, Ion-acoustic wave overturn

Nonlinear wave-wave interaction: Three wave processes, dispersion laws and decay spectra, triads, Manley-Rowe conservation laws and nonlinear superposition, analogy with Euler equations for rigid bodies, resonant interactions between plasma waves, many-wave interaction in random phase approximation, nonlinear explosive instability, Interaction of low-frequency waves with high-frequency waves, plasma turbulence, kinetic equation and instabilities.

Wave-particle interaction: Statistical preliminaries, Random phase approximation, quasilinear diffusion equation in two and three dimensions, single and many waves, quasi-linear theory of some instabilities, non-resonant wave-particle interaction, effect of transverse waves on ions, quasilinear theory of Alfven wave turbulence.

Nonlinear wave-particle interaction: Electron plasma oscillation turbulence, nonlinear theory of the drift instability, and the effect of thermal fluctuations.

Reference

1. *Nonlinear Plasma Theory*, R. Z. Sagdeev and A. A. Galeev (W. A. Benjamin Inc., New York, 1969).
2. *Plasma physics for astrophysics,* R. M. Kulsrud (Princeton University Press, 2004).
3. *Plasma turbulence,* B. B. Kadomtsev (Academic Press, 1965).
4. *Nonlinear resonance analysis,* E. Kartashova (Cambridge University Press, 2010).
5. *Reviews of Plasma Physics,* vol. 7, Ed. M. A. Leontovich (Consultants Bureau, 1979).

Elective Courses in Condensed Matter Physics

PY 719: Modeling and Simulations in Physics

Basics: Modeling in different domains: Continuum, Mesoscopic, Atomistic and Quantum descriptions, Setting up a computer experiment: Starting structure and dynamics length and time scales

Electronic structure Theory: Many-body Schroedinger Equation, Born-Oppenheimer approximation, Hartree-Fock theory and Slater Determinants, Density Functional theory(DFT)
Thomas-Fermi and Exchange and Correlation(and different xc types)

Methods of Solution: Basis sets: Gaussian and Plane Wave, Analytic gradients and Hessians, The potential surface, Geometry optimization, Transition state calculations.

Simulation Methods:***Monte Carlo (MC):***Monte Carlo integration, Averaging procedure in various ensembles, Importance sampling, Metropolis scheme, ***Classical Molecular Dynamics (MD):*** Newtonian, Lagrangean and Hamiltonian dynamics, Basic algorithms, Time averages and ensemble averages, Molecular Dynamics in various ensembles, Interatomic potentials (pair potentials and beyond), Force-fields and their parameterization, Handling long-range forces, Analysis of Simulation results, ***First Principles MD:*** Born-Oppenheimer Molecular Dynamics, Car-Parrinello Molecular Dynamics (CPMD), Mermin functional and Free Energy MD (FEMD), ***Hybrid schemes:*** Combined classical MD and DFT – hybrid QM/MM schemes, ***Reactive schemes:*** General problem in chemical reactions, Path sampling methods, Blue Moon ensemble approach, Metadynamics

Beyond DFT: Time dependent DFT, Dynamical Mean Field Theory, GW-Approximation

Quantum Chemistry Methods: Configuration interaction, Many-body perturbation theory, Moller-Plesset perturbation theory, Multi-Configuration self consistent field theory, Coupled cluster theory

References

1. *Electronic Structure – Basic Theory and Practical Methods*, Richard Martin (Cambridge University Press, 2004).
2. *Electronic Structure Calculations for Solids and Molecules*, Jorge Kohanoff (Cambridge University Press, 2006).
3. *Computer Simulation of Liquids*, M P Allen and D J Tildesley (Oxford Science Publications, 1989).
4. *The Art of Molecular Dynamics Simulations*, D C Rapport (Cambridge University Press, 2004).
5. *Ab Initio Molecular Dynamics - Basic Theory and Advanced Methods*, Dominik Marx and Juerg Hutter (Cambridge University Press, 2009).

PY 720: Selected topics in Condensed Matter Theory

The course will deal with the theory and application of quantum mechanical and atomistic lattice dynamics and computer simulations to model, understand, and predict the properties of real materials. It is designed for students in Physics, Chemistry, Engineering and Materials Science interested in (i) the modeling of the properties of materials with advanced quantum mechanical and atomistic techniques and (ii) experimentalists using theory for the interpretation and analysis of complex experimental data. The course will have a strong focus on applications. However a minimal background in quantum mechanics and solid state physics (or equivalent) will be required.

First principles calculations of the total energies, electronic structure and phonon spectra: Density functional theory, Electronic structure calculations, Lattice vibrations, Theoretical calculations for the interpretation and analysis of experimental Raman, infrared, neutron and synchrotron data.

Lattice dynamics calculations and molecular dynamics simulations of complex solids: Microscopic to Macroscopic: From phonon spectra to thermodynamic properties. Studies of phase transitions, thermodynamic properties and melting at extreme conditions of pressure and temperature.

Project work: First principles calculations of the total energies, Electronic structure Calculations, Calculations of crystal structure, long-wavelength phonons, elastic constants, Calculations of the Phonon density of states, Calculations of the thermodynamic properties

References

1. *Electronic Structure: Basic Theory and Practical Methods*, Richard M. Martin (Cambridge University Press, 2004)
2. *Dynamics of perfect crystals*, G. Venkataraman, L.A. Feldcamp and V.C. Sahni (MIT Press, Cambridge, 1975).
3. *Phonons: theory and experiments*, P. Bruesch (Springer-Verlag Berlin, Heidelberg, New York;1982)
4. *Computer Simulation of Liquids*, M.P. Allen and D.J. Tildesley (Clarendon, Oxford, 1987)
5. *Simulations for Solid State Physics*, R H. Silsbee, J Draeger (Cambridge University Press, 1997).

PY 721: Organic Semiconductor Devices

Introduction to organic semiconductors: Organic materials: bonding, hybridization, conjugation and origin of semiconducting properties, Comparison of inorganic and organic semiconductors, types of organic semiconductor: molecular and polymeric, donor and acceptor materials, molecular ordering, light absorption and emission, different charge carriers and excitations, charge carrier injection: organic metal contacts and interfaces, charge transport models: tunnelling, Schottky, Poole-Frankel, space charge limited conduction, variable range hopping etc.

Organic thin films and their characterization: ***Preparation techniques***:*Thin/thick film*: Drop casting, doctor blading, spin casting, screen printing, inkjet printing, chemical polymerization, electrochemical polymerization and interfacial polymerization, physical vapour deposition, *Monolayer/multilayer*: Self-assembly, Langmuir-Blodgett and electrografting. ***Characterization techniques***: *Spectroscopic techniques*: UV/Vis, Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy, Auger electron spectroscopy, electron energy loss spectroscopy (EELS) etc. ***Structure and surface analysis techniques***: X-Ray diffraction (XRD), low-energy electron diffraction (LEED), SEM, TEM, AFM, NSOM, confocal microscopy and contact angle measurements. ***Thickness measurements***: x- ray reflectivity (XRR), ellipsometery and profilometer. ***Electrical characterization***: current-voltage measurement and impedance analysis.

Organic devices: ***Molecular electronics***: Basic concepts of molecular electronics, making contact to single molecule molecular and self-assembled monolayer, molecular rectifiers, molecular resonant tunnel diodes, molecular memory, molecular transistors. ***Organic electronics***: Fabrication and characterization of organic field effect transistors and organic light emitting diodes. ***Organic solar cells***:Solar spectrum, interaction of photons with materials, solar cell operational parameters, bulk hetrojunction polymer solar cells, small molecule based solar cells and dye sensitized solar cells. ***Organic gas sensors*:** Gas sensors and their necessity, interaction between toxic gases with organic films, fabrication and characterization of chemi-resistive gas sensors.

References

1. ***Molecular and Organic Electronics Devices*, D.K. Aswal and J.V. Yakhmi (Nova Science, USA, 2010)**
2. *Organic Electronics: Materials, Processing, Devices and Applications*, Franky So (CRC Press,2010)

PY722: Single Crystal Growth and Devices

Introduction: History, importance, applications and scope of single crystals and related devices.

Transportation, nucleation, growth and thermodynamics: Phase diagram, material synthesis and characterization of synthesized materials.Transportation of reactants to the growth surface.Absorption at the growth surface and nucleation (first order phase transformation) thereafter.Growth of nucleus (minimization of Gibbs free energy due to interplay of entropy and enthalpy).

Single crystal growth techniques: ***Growth from the liquid-phase*****:** From melt**,** Czochralski growth technique**,** Bridgman, Float Zone**,** ***From solution*****:**TSSG (top seed solution growth)**,** Aqueous solution growth**,** ***Growth from vapour phase***:PVD**,** MBE**,** Thermal evaporation technique**,** Electron-beam evaporation technique**,** CVD**,** MOCVD

Characterization: ***Crystallography***: Symmetry operations and crystal structure determination (single crystal XRD).Orientation and topography (Laue back reflection method).***Crystal defect analysis***: Point defects, Dislocation lines, Sub-grain boundaries.Defect formation during single crystal growth.***Electronic structure and Electrical properties***: Band structure (theory and first principle calculations).Electrical and thermal conductivity.Luminescence properties: Photo-luminescence process**,** Thermo-luminescence process, Scintillation process

Specific single crystals and related devices: ***Scintillator/phosphor single crystals*****:** Doped alkali halides**,** CsI:Tl, NaI:Tl, $LaBr_3$:Ce etc**,** Doped and un-doped Oxide**,** LBO, LSO, BGO, YAP etc**,** Gamma detectors**,** TL readers**.** ***Optical Window*****:** Fluorides, Sapphire**,** ***Solid state laser crystals***:YAG, Sapphire, Double tungstates**,** Laser cavity (diode pumped)**, Non-linear crystals**: KDP, BBO, LBO etc**,** Second harmonic generation**,** SAW devices**,** ***Ferroelectric crystals*****:** $BaTiO_3$, $LiTaO_3$ etc**,** Remote temperature sensors**,** ***Semiconductor crystals***: Si, Ge, GaAs etc**. Superconductors:** $YBa_2Cu_3O_{7-\delta}$, $Bi_2Sr_2CaCu_2O_{8+\delta}$ etc

References

1. *Crystal Growth Technology: From Fundamentals and Simulation to Large-scale Production,* Hans J. Scheel, Peter Capper (John Wiley & Sons, 2011).
2. *Kinetic Processes: Crystal Growth, Diffusion, and Phase Transitions in Materials,*Kenneth A. Jackson (John Wiley & Sons, 2010).
3. *Bulk Crystal Growth of Electronic, Optical and Optoelectronic Materials,* Peter Capper (John Wiley & Sons, 2005).
4. *Handbook of crystal growth,* Govindhan Dhanaraj, Kullaiah Byrappa, Vishwanath Prasad (Springer, 2010).
5. *Fundamentals of Solid State Engineering,* M. Razeghi (Springer, 2009).
6. *Luminescence,* Cees Ronda (John Wiley & Sons, 2008).
7. *Thermoluminescence of Solids,* S. W. S. McKeever(Cambridge University Press, 1988).
8. *Springer Handbook of Electronic and Photonic Materials,* Safa Kasap, Peter Capper (Springer, 2006).
9. *Elements of X Ray Diffraction,* Bernard Dennis Cullity, Stuart R. Stock (Prentice Hall, 2001).

PY 723: Advanced Magnetism and Superconductivity

Magnetism: Types of phase transitions- first and second order; Examples of magnetic and superconducting phase transitions

Type of magnetic exchange interactions: Direct exchange, Indirect exchange, Superexchange, Double exchange, RKKY exchange, D-M interaction, Dipolar interaction, etc.

Classification of magnetic systems: Diamagnetism, paramagnetism, ferromagnetism, ferrimagnetism, antiferromagnetism, superparamagnetism, spin-glass, cluster spin-glass, metamagnetism, modulated spin structures, etc.; Magnetic ordering under external perturbations such as magnetic field, pressure, ion irradiation, quenched disorder, etc

Low dimensional magnetism: 1D, Quasi-1D, 2D, and Quasi-2D.

Spintronics; Magneto-caloric effect; Gaint magnetoresistance (GMR) and colossal magnetoresistance (CMR); Magnetic nanoparticles, molecular magnetism

Superconductivity: Thermodynamics of Superconductors; London Theory–A phenomenological approach to understand Superconductivity; Application of London theory – Electrodynamics of Superconductors; Ginzburg – Landau Theory - Origin of vortex state, vortex structure, flux pinning; Josephson effect

Co-existence of superconductivity and magnetism

Neutron scattering in magnetism and superconductivity

References

1. *Magnetism- Principles and Applications*, Derek Craik (Wiley, New York 1995)

2. *Magnetism in the Solid State: An Introduction*, Peter Mohn, 2nd Edition (Springer, 2005)
3. *Introduction to Superconductivity*, M. Tinkham (Dover Publications, 1996)

PY 724: Neutron as a Probe of Condensed Matter

The short-range strong interaction of neutron with matter and its inherent magnetic moment of neutron make neutron scattering a unique probe in condensed matter research. The other important advantage of neutrons over other forms of radiation in the study of structure and dynamics on a microscopic level are they are uncharged, which allows them to penetrate the bulk of materials. They interact via strong nuclear force with the nuclei of the material and the scattering cross section varies randomly between various elements and even between isotopes. This allows one to observe light atoms such as hydrogen in the presence of heavier ones and distinguish neighbouring elements in the periodic table easily. One can exploit isotopic substitution and contrast variation methods. Matching wavelength and energy of thermal neutron to the lattice spacing and excitations in condensed matter makes it an indispensable tool to both study structure and dynamics. Over and above neutron has a magnetic moment that suits to study magnetic structures and the fluctuations and excitations of spin systems.

Why neutron scattering? basic properties of neutron; Basics principles of Neutron Scattering, Neutron scattering cross-section, correlation functions, coherent and incoherent scattering, Principle of detailed balance, magnetic scattering, polarized neutron.

Neutron sources: Reactor and spallation, Moderation of neutrons.

Structural study by Diffraction: Cross section, structure factors, Scattering of neutrons by atoms, Diffraction by crystals and polycrystals, Extinction and absorption, Experimental technique for diffraction, Principles of magnetic scattering, Investigation of magnetic materials, Diffraction by gases, amorphous materials and liquids.

Small-Angle Neutron Scattering: Scattering from general Two Phase Systems, Scattering from Fractal Aggregates, Nuclear vs. Magnetic Scattering, Small-Angle Neutron Scattering Instrumentation (Experimental Aspects, Data Treatment), Analysis of Small-Angle Neutron Scattering Data (Model Independent Analysis, Model Dependent Analysis, Contrast Variation),
Applications (Nanomaterials, Colloids, Biological Systems, Porous and Fractal Structures)

Neutron Reflectometery: Theoretical aspects of neutron reflectivity from Stratified Media, specular reflectivity from thin films and multilayers, description of Rough Multilayers, Reflectivity on Non-Magnetic Systems, Neutron Reflectivity on Magnetic Systems, Polarized Neutron Reflectometry on Magnetic Systems, instrumental setup for neutron reflectivity, Off-Specular (diffuse) reflectivity

Dynamics in condensed matter: ***Deterministic*****:** Basic Lattice Dynamics and Neutron Inelastic Scattering**:** Theoretical lattice dynamics (LD): Debye model, dynamical matrix, acoustic and optical branches. One phonon scattering, phonon dispersion relations: monoatomic and diatomic crystals, Incoherent scattering: phonon density of states, Coherent scattering. ***Stochastic (Diffusion)*****:** Theoretical formalism of quasielastic neutron scattering (QENS), self and distinct van Hove correlation functions. Different kinds of motions and contributions to scattering law, different model for translation motion: continuous diffusion, jump diffusion and localized translational diffusion. Different models for rotational motions:continuous rotational diffusion on a circle, jump rotation among N equivalent sites on a circle and isotropic rotational diffusion on a surface of a sphere.Instruments and methods for quasielastic neutron scattering, general aspects of data analysis, examples of QENS studies.

Reference

1. *Neutron Diffraction, G. Bacon (Clarendon, Oxford 1975)*
2. *Thermal Neutron Scattering, P.A. .Egelstaff (Academic Press)*
3. *Theory of Thermal Neutron Scattering, W. Marshall and S.W. Lovesey, (Clarendon, Oxford 1971)*
4. *Thermal Neutron Scattering, G.L. Squires, (Cambridge University Press, 1978)*
5. *Methods in Experimental Physics, Vol. 23 (eds. D.L. Price, Kurt Skold), (Academic Inc.USA1987)*
6. *Neutron scattering in condensed matter, A. Furrer, J. Mesot, T Strässle (world Scientific)*
7. *Methods of Experimental Physics Ed. D.L. Price and K. Sköld P 99:Neutron Sources J.M. Carpentar and W.B. Yelon,(Academic Press)*
8. *Topics in Current Physics, Vol 6 'Neutron Diffraction' H. Dachs (Springer)*
9. *Structure Analysis by Small-Angle X-Ray and Neutron Scattering, L.A. Feigin and D.I. Svergun (Plenum Press, New York, 1987)*
10. *Neutron, X-Ray and Light Scattering, P. Lindner and T. Zemb (North-Holland, Amsterdam, 1991)*
11. *Neutron Scattering from Polymers, J.S. Higgins and H. Benoit (Clarendon, Oxford, 1994)*
12. *Analysis of Small-angle Scattering Data from Polymeric and Colloidal Systems: Modelling and Least-squares Fitting, J. S. Pedersen, Advances in Colloid and Interface Science 70, 171-201 (1997).*

13. *Small-angle Scattering Studies of Biological Macromolecules in Solution, D.I. Svergun and M.H.J. Koch, Reports on Progress in Physics 66, 1735–1782 (2003).*
14. *X-ray and Neutron Reflectivity: Principles and Applications, Daillant, J., Gibaud, A. (Eds.), Lect. Notes Phys. 770 (Springer, Berlin Heidelberg 2009),*
15. *Theory of reflection of electromagnetic and particle waves, Lekner, J. (Martinus Nijhoff, Dordrecht, (1987) 188*
16. *Coherent inelastic Scattering in lattice dynamics, B Dorner,(Springer 1982)*
17. *Methods of Experimental Physics, Vol 23, Part A, Ed. D.L. Price and K. Sköld P 369: Lattice Dynamics.*
18. *Quasielastic Neutron Scattering, M. Bee (Adam-Hilger, Bristol, 1988)*
19. *Single Particle rotations in Molecular Crystals, W. Press, (Springer, Berlin, 1981)*

PY 725: Structure and Crystallography of Biomolecules

1. Brief introduction to structure and functioning of a bacterial cell.
2. Introduction to important molecular components of the cell.
3. Methods of protein production, purification.
4. Introduction to three dimensional structures of proteins and nucleic acids.
5. Computational and experimental methods of determining 3D structures.
6. X-ray sources and diffraction.
7. Macromoleculer crystallisation and crystal characterization.
8. Methods of diffraction data collection, data processing
9. Phase problem.
10. Current status of the methods for solving the phase problem.
11. Crystallographic refinement.
12. Electron density maps.
13. Structure-based drug design.
14. Laboratory experiments: a) High-throughput crystallization, b) Crystal mounting, diffraction data collection and processing, and c) Interpretation of electron density maps.

References

1. *Structure Determination by X-ray Crystallography*, 4th ed., Mark Ladd and Rex Palmer**,** (Kluwer Academic/Plenum, New York, 2003).
2. *Crystallography Made Crystal Clear, A Guide for Users of Macromolecular Models*, 3rd ed., Gale Rhodes (Complementary Science Series, 2006) .
3. *Protein Structure and Function*, Gregory A Petsko and Dagmar Ringe (Blackwell Science and Sinauer Associates, 2004).

Elective Courses in Condensed Matter Physics

PY 726: Advanced Reactor Physics

Neutron Transport theory: Various formulations of neutron transport theory: Integro-differential equation, Integral equation, surface integral equation, invariant imbedding theory; Transport equations for special geometries; Numerical methods for solution of transport equation: Energy groups and group cross sections, Pn method and diffusion theory, Discrete ordinates and discrete Sn methods, Collision probability and related methods and their applications, Method of characteristics; Adjoint equation, perturbation theory, variational method.

Numerical methods for solution of the Multi-group neutron diffusion equation: Finite difference method and nodal methods

The Monte Carlo method: Random numbers: methods of generation and properties tests for randomness; Methods for sampling distributions; Mechanics of particle transport; Source and criticality problems; Errors and variance reduction methods.

Methods for burnup and control rod worth calculation

Reactor Dynamics: Point kinetics: point kinetics equations, Stability Analysis, Linear Stability theory, Routh's stability criterion, Root-Locus method, Nyquist plot, Non linear stability analysis; Space dependent reactor Dynamics and related topics; Accident analysis for thermal and fast reactors

Reactor Noise and its applications: Stochastic kinetics and zero power Reactor Noise, Power reactor noise, Reactor Noise in Accelerator Driven Systems

References

1. *Nuclear Reactor Theory*, G.I.Bell & S.Glasstone (Van Nostrtand,1970).
2. *Computing Methods in Reactor Physics*, H.Greenspan (Ed.) (Gordon and Breach, 1968).
3. *Dynamics of Nuclear Reactors*, D.L.Hetrick, (University of Chicago Press, 1971).
4. *Random Processes in Nuclear Reactors*, M.M.R.Williams (Pergamon, 1974).
5. *Neutron Fluctuations - A Treatise on the Theory of Branching Processes*, L.Pal and Imre Pazsit,(Elsevier Publishing Company, 2007).
6. *Computational Methods of Neutron Transport*, E.E.Lewis and W.F.Miller, Jr., (Wiley, 1984).
7. *Nuclear Reactor Physics*, W.M.Stacey (Wiley, 2001).
8. *Particle Transport Simulation with the Monte Carlo Method* L.L.Carter and E.D.Cashwell, Report TID-26607 (1975).

PY727: High Energy Density Physics: Theory

This course is intended for those interested in acquiring basic knowledge in the physics of matter existing at very high temperatures and / or densities as occurring in inertial confinement fusion system, astrophysical objects etc.

Introduction to High Energy Density Physics (HEDP): Static and dynamic high pressures, parameters defining High Energy Density, Laboratory generation of HED matter using lasers and particle beams, Basic processes involved in HEDP.
Hydrodynamic and shock waves: Hydrodynamic flow of compressible fluids, Equations of gas-dynamics, Euler and Lagrange formulation, Rarefaction and Compression Waves, Rankine-Hugoniot Relation, Hugoniot curves, self similar solutions, artificial viscosity, numerical methods.
Equation of State and radiation opacities: Thermodynamic properties of Gases, Entropy, Thermodynamic Equilibrium and Equipartition, Specific Heats and Thermodynamic Exponent, Thermodynamics of Condensed Matter, Gamma-Law Equations of State, Matter At High Pressures, Thomas-Fermi Theory, Radiation opacities and emissivities, Rosseland and Planck means, models to calculate opacities.
Radiation Hydrodynamic: Radiation Transfer Equation, Equilibrium Diffusion Limit, Non-equilibrium Diffusion, Marshak Waves, Three-Temperature Model, Radiation matter coupling, Basic radiation hydrodynamic equations, approximate solutions, Numerical Methods
Hydrodynamic Instabilities: Rayleigh–Taylor, Richtmyer–Meskov & Kelvin–Helmholtz Instabilities, Fluid-Dynamics Description, R-T Instability with Two Uniform Fluids, Effects of Viscosity, Effect Density Gradients
Inertial Confinement Fusion: Fusion reaction, Thermonuclear burn and ignition schemes, central hot spot ignition, fusion Energy gain, direct and indirect ICF Schemes.

References

1. *High-Energy-Density-Physics – Fundamentals, Inertial Fusion and Experimental Astrophysics*, R. Paul Drake (Springer Verlag, 2006)
2. *The Physics of Inertial Fusion – Beam Plasma Interaction, Hydrodynamics, Hot Dense Matter*, S. Atzeni, J. Meyer-ter-Vehn (Clarendon Press 2004)
3. *Introduction to Inertial Confinement Fusion*,S. Pfalzner (Taylor & Francis 2006)
4. *Physics of shock Waves and High temperature Hydrodynamic Phenomena*, Zel'dovich YB and Raizer YP (Academic Press, NY 1967)
5. *Inertial Confinement Fusion: The Quest for Ignition and Energy Gain using indirect drive*, J. D. Lindl, (Springer, 1998)
6. *The equations of radiation Hydrodynamics*,G. C. Pomraning (Pergamon Press, Oxford 1973).
7. *Hydrodynamic and Hydromagnetic Stability*,S. Chandrasekhar (Oxford University Press 1968).

PY 728: High Energy Density Physics: Experimental

Physics of High Energy Density Effects in Matter: Tensor representation of strain and strain. Linear and nonlinear waves, ideal shock wave; Rankine Hugoniot relations, Shock representation in x-t and p-u_p plane, p-x and p-t plots, entropy and temperature under shock compression. Interaction of Shock waves, reflection of shock wave from rigid boundary etc. Development of rarefaction waves, interaction involving rarefactions, Negative pressures/ isentropic compression in materials.

Energy Storage Systems, Energetic Materials and Applications: Various Types of Energy Storage Systems and their Characteristics. Ideal detonation (ZND model); Chapman Jouget (CJ) pressure and density; detonation interaction.Concept of reaction zone; effect of diameter on detonation velocity, detonation failure diameter, effect of density/ temperature.Initiation, critical energy fluence, run distance versus pressure, impactor thickness and diameter effect on impact initiation. Wave shaping and lens design. Single stage gas gun, two stage light gas gun, propellant gun; electric gun and, rail gun. Ultra high magnetic field and magnetic pressures using flux compression generators. Pulse radiation, lasers and particle beams. Z-pinch, Gas-Puff and Plasma Focus devices for Thermonuclear Fusion.

Diagnostic Techniques and Data Interpretation: Measurement of shock velocity; particle velocity and stress history; shock temperature, sound velocity behind shock front; shock overtaking experiments. Velocity measurement using Displacement, VISAR, Fabry-Perot interferometers. Macroscopic measurements in shock compressed materials. Inductive Loops, Rogowski Coil, Voltage Dividers, Faraday Rotation. Visible and x-ray spectroscopy, Faraday cup, Thomson Parabola, X-ray, Ion and Neutron Imaging. Determination of equation of state, Hugoniot elastic limit, phase transition pressure and spall from experimental data. *Ab-initio* calculations for determination of isotherm, Hugoniot and phase transition pressures for interpreting the experimental shock wave data.

References

1. *Physics of High Energy Density*, G. E. Duvall (Academic Press, 1971).
2. *High Pressure Shock Compression of Solids*, J. R. Asay and M. Shainpoor (eds) (Springer-Verlag, 1993).
3. *Explosive Engineering*, P. W. Cooper (Wiley-VCH, 1996).
4. *Pulsed High Magnetic Fields*, H. Knoepfel (North Holland Publishing Co. 1970).

PY 729: Nuclear Data Physics for Advanced Nuclear Applications

Introduction to nuclear physics data: Types of Nuclear data, Variation of cross section with energy, Simple nuclear interactions theory, Measurement and model based predictions, Transmission experiment for total cross section, measurement of differential scattering cross section, Time-of-flight method, sources of errors in measurement, Optical model, Statistical model etc., exposition to SAMMY, EMPIRE. Training in online retrieval of data using Indian Mirror Website: www-nds.indcentre.org.in.

Representation of nuclear data : General purpose and special purpose ENDF libraries, Sub libraries for neutron, photon and charged particle interactions, Radioactive decay data, Fission product yields, formats and procedures, Tabulated and parametric representations in ENDF, Mathematical formalisms for Resonance representation viz. , single and multi-level resonance formalisms, Rieche-Moore, R-Matrix formalism, Breit- wigner formalism, interpolations schemes.

Nuclear data processing: Steps for processing evaluated data, linearization, resonance reconstruction, tolerances, Doppler broadening, , importance of target temperature for Thermal scattering data, Group averaging, PREPRO code systems, SIGACE package.

Multi-grouping: Multigrouping techniques, Energy groups and limits, considerations for grouping, , weighting functions: flux and current weighting, self-shielding, anisotropy and Legendre moments, group-to-group transfer cross sections, GROUPIE/GROUPR, transport cross section, group collapsing , Photon production cross section, Photo-atomic interaction cross sections, GAMINR, activation cross sections, coupled neutron-gamma cross section sets,
Continuous energy data for Monte Carlo codes (ACER), Nuclear data for ADSS applications (MATXSR).

Concept of critical facility; AHWR CF, Difference between critical facility and actual reactors, ICSBEP criticality benchmarking, Illustrati ons with benchmarking of KAMINI, PURNIMA-I and PURNIMA-II in the US-DOE ICSBEP International Handbook.

Exposure to Error Propagation and sensitivity studies, Variance-Covariance error matrix in nuclear data, Propagation of errors in assessment of uncertainty margins. Philosophy and mathematics of adjustment of cross sections to fit integral data from critical experiments.

References:

1. *Handbook of Nuclear Engineering,* DanGabriel Cacuci (Springer 2010).
2. *The Elements of Neutron Interaction Theory,* Foderaro, Anthony Harolde(MIT Press 1971).
3. *Handbook of nuclear reactor calculations,* Vols I-III, Ed. Yigel Ronen (CRC Press 1986).
4. *ENDF-6 Formats Manual (2010),* http://www.oecd-nea.org/dbdata/data/manual-endf/endf102.pdf
5. *Manual of Nuclear model code EMPIRE* (http://www-nds.iaea.org/empire218 /manual.pdf)
6. *Special Issues on Evaluated Nuclear Data File ENDF/B-VII.0,* J.K.Tuli, Nuclear Data Sheets, Vol-107 (2006).
7. *ENDF/B Preprocessing codes,* Cullen, D. E., (IAEA-NDS-39, Rev. 10, 2000) http://www-nds.iaea.org/public/endf/prepro/DOCUMENT/PDF/Overview.pdf
8. *Methods of steady-state reactor physics in nuclear design,* Stamm'ler, and R. J. J., Abbate, M. J., (Academic press, London., 1983).
9. *See: http://www-nds.indcentre.iaea.org.in/~wlup/ WIMS Library Update Project. WLUP.*
10. *Proc. of the workshop on Nuclear Reactors,- Physics, design and Safety,* Eds. A. Gandini, S. Ganesan and J.J. Schmidt,(IAEA publication, 1994).
11. *WIMS-D Library Update,* Leszczynski, F., López Aldama, D. and Trkov, A.(STI/PUB/1264, ISBN 92-105006-2. IAEA, 2007)
12. *Theoretical Nuclear Physics,* John Markus Blatt and Victor Frederick Weisskopf (Wileyand Sons 1952).

PY 730: Advanced Computational Methods for Steady State and Transient Behaviour of Neutron Transport

Solution of transport equation: P_N method (Plane and curved geometries)**,** Discrete ordinates method (Plane and curved geometries, Quadrature sets)**,** Collision probabilities methods Collision probability method in 1-D and 2-D geometries, Interface current method, Characteristics method. Discrete ordinates methods in 1-D, 2-D and 3-D geometries.Diamond differencing scheme.Solution procedures**.**

Neutron thermalization: Neutron scattering laws, Scattering from mono-atomic gas, bound-atom scattering, Liquid moderators, Nelkin model.

Treatment of resonances: NR, IR and WR approximations, Sub-group method

Solution of time dependent transport equation: Differencing of time dependent transport equation, Point kinetic equations, Space-time kinetics, Adiabatic approximation. IQS; explicit andimplicit time differencing methods

Solution of the fuel depletion equations: Formalism of the detailed burnup chain, Formulation of fuel depletion equations, production-destruction of actinides and fission products, branching ratios **,**Solution of the burnup equations, Constant flux and constant power approximations. Solution for decay heat and other potential reactor applications

Monte Carlo methods: Exposition to neutron and particle tracking principles

References

1. *Computational Methods of Neutron Transport,* E.E.Lewis and W.F. Miller (Wiley, 1984) and ANS (1993).
2. *Nuclear Reactor Theory,* G.I.Bell and S. Glasstone (Van Nostrand, 1970).
3. *Nuclear Reactor Analysis,* A.F. Henry(MIT Press, 1975).
4. *Numerical Methods of Reactor Analysis,* M. Clark and K.F. Hansen(Academic Press, 1964).
5. *Nuclear Reactor Physics,* Weston M. Stacey, (Wiley, 2001)
6. *A primer for the Monte Carlo Method*, IIYA, M. Sobol, CRC Press

PY 731: Accelerator Driven Systems

Neutron Source: Various types of accelerator based neutron sources and their properties: Electron accelerator based source, spallation source and fusion source - advantages and limitations.

The spallation process: Theory and mechanism, various types of targets and projectiles. Neutron yield, energy spectrum, angular and spatial distribution in the target. Spallation products; Heat distribution; Codes in use.

Spallation target: Thermal hydraulics of spallation targets: heat removal and suitable coolants; Radiation damage in window and other structural materials; Windowless designs; Radioactivity of coolant / target.

Sub-critical Reactor: Neutron multiplication in sub-critical reactors, source importance, Ks, Keff and reactivity; Power and power distribution in ADS; Considerations in deciding the degree of sub-criticality of an ADS.

Theoretical Techniques and analysis: Transport theory and Monte Carlo methods: computer codes for ADS analysis; Nuclear data requirements and sources; Burnup and its effect on fuel and core properties; ADS kinetics and safety issues – comparison with critical reactors.

ADS related experiments: Measurements of parameters, Reactor noise in ADS.

Comparative study: Breeding in critical reactors and sub-critical ADS, Fuels and fuel cycles for ADS.

Waste transmutation: Issues in waste management, Waste transmutation in different types of reactor systems, Advantages of ADS.

ADS Types: Proposed ADS types for power generation, breeding and waste transmutation.

References

1. *Accelerator Driven Sub-critical Reactors*, H. Nifenecker, O.Meplan and S.David (Institute of Physics Publishing, 2003).
2. *Conceptual Design of a Fast Energy Amplifier*, C. Rubbia et al ReportCERN/AT/95-44 (ET)(1995).
3. *Accelerator Driven Systems and Fast Reactors in Advanced Nuclear Fuel Cycles – A Comparative Study, OECD Report,* NEA (2002).
4. *Accelerator Driven Systems in the Nuclear Power Program*, INS NewsVol 6, No. 2 (2009).
5. *One Dimensional Thermal Hydraulic Design Codes for Buoyancy and Gas Driven Window and Windowless Spallation Target Loops of ADS Reactors,* K. Biswas, P.Satyamurthy and A.K.Ray, Report BARC/2003/I-007.

NON-SUBJECT ASSIGNMENTS

PY 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

PY 592:

Experiments

PY593: Mini

Project

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.

IGCAR
SYLLABUS FOR

M.Phil. in Physical Science
(Program Code: PHYS02)

SYLLABUS SUMMARY

Nuclear Reactor Physics

Course Code	Course Name	Hours	Credits
PY1	Mathematical Methods	45	6
PY2	Computational Methods	45	6
PY3	Introductory Reactor Physics and Engineering	35	4
PY4	Nuclear Physics and Nuclear Data	30	4
PY5	Engineering Drawing and Laboratory Practices and Experimental Methods	20	2
PY6	Reactor Materials	30	4
PY7	Radiation Detection and Measurements	20	2
PY8	Reactor Types and Advanced Reactor Concepts	20	2
PY9	Radiation Shielding Design and Protection	40	5
PY10	Reactor Dynamics and Safety Analysis	35	4
PY11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
PY12	Fluid Dynamics and Thermal Hydraulics	25	2
PY13	Advanced Computational Methods in Reactor Physics	35	4
PY14	Experimental and Operational Reactor Physics	35	4
PY15	Design Methods in Thermal and Fast Reactors and Computer codes	35	4
PY16	In Core of Fuel Management	25	2
Total		**505**	**59**

1. Mathematical Methods (PY1) : (45 lectures)

S.No	Course content
1.	Linear vector spaces, linear dependence and independence, basis and dimension. Linear transformations. Inner product, norm, continuity, convergence, completeness. Hilbert spaces.
2.	Fundamentals of matrices, eigenvalues, eigenfunctions, adjoints, inverse etc sparse matrices; diagonal dominance; non-positive and non-negative matrices; positivity theorems; large set of simultaneous equations.
3.	Functions of a complex variable. Rieman surfaces, Analytic functions Cauchy Rieman conditions and harmonic functions. Contour integration and Cauchy's integration formula. Residue theorem and evaluation of integrals.
4.	Ordinary differential equations - Order and degree of a differential equation, appearance and number of arbitrary constants in the solution of a n-th order differential equation, families of curves and orthogonal trajectories, first order homogeneous and exact equations, methods of reduction of order of some specific differential equations, second order linear homogeneous equations, superposition principle, method of finding second independent solution when one solution is known, qualitative properties of the solution, Sturm comparison theorem, operator methods for second order linear equation with constant coefficients, power series solution for second order linear equations, ordinary and regular singular points of a differential equation, indices corresponding to a regular singular points, hypergeometric and confluent hypergeometric equation, explicit example through solution of Bessel's equation.
5.	Partial differential equations – First order partial differential equations, complete integral and general solution, methods of solution of a first order partial differential equation, second order partial differential equations, Laplace's equation, wave equation, diffusion equations, system of surfaces.
6.	Integral equations – Definition, homogeneous, inhomogeneous, linear, non-linear equations, Fredholm and Volterra equations, eigenfuctions, Schmidt-Hilbert method of solutions.
7.	Integral Transforms. Fourier, Laplace Transforms and the inverse transforms, connection to physical problems Other transforms such as Mellin and Hankel transforms, and transforms generated by Green's function. Applications for obtaining solution of ordinary/partial differential equations.

Books suggested

1. Mathematical Methods for Physicists, G. B. Arfkin and H. J. Weber, Academic Press(2001) Also Prism Books, Bangalore
2. Elements of Partial Differential Equations, I. Sneddon, McGraw Hill (1957)
3. Theory of Functions of a Complex Variable, E. T. Copson, Oxford University Press (1935)

2. Computational Methods in Physics (PY2): (35 lectures + 10 Tutorials)

S.No	Course content
1.	**Computers, Computational Physics and Scientific Programming**
	a) Introduction to Computational Physics
	b) Components of a high performance computer- memory hierarchy, CPU design, Vector processing, Virtual memory, Number representation- Arithmetic of Fixed and Floating

point numbers, Machine precision, Errors and uncertainties in computation Types of errors, Error propagation

c) Computing software basics

d) Computer languages, Programming concepts, Programme design, Structured programming, Introduction to Fortran and C, C & Unix, Dialects of C, Functions and Program structure, Basic Data Types, Arrays, Strings, Expressions and Operators, Precedence of C Operators, C Preprocessors, Control Statements, Pointers, Pointer arithmetic, Arrays handling with Pointers, Functions in detail, Input and Output Operations and C file handling Operations, Structures & Unions in C, Dynamic Memory allocation, Macro definitions, Compilation and Execution of C program, Fortran to C Linking procedures.

e) Introduction to Parallel processing, High performance computing, Profiling and tuning, Visualization of scientific data

f) Highlights of FORTRAN-90 programming language. Programming in MATLAB

2. **Numerical Methods**

Linear algebra

a) Matrices

b) Solution of Linear Algebraic Equations and Singular Value Decomposition

c) Eigenvalue problems, Computing Eigenvalues and Eigenvectors

d) Iterative methods for Linear systems

e) Software for linear systems- LINPACK and LAPACK

Solution of Nonlinear equations

a) Bracketing and Bisection

b) Secant Method, False Position Method, and Ridders' Method

c) Newton-Raphson method

d) Software for nonlinear equations

Interpolation, Extrapolation and Numerical Differentiation

a) Differentiation- Forward, backward and central differences

b) Polynomial Interpolation and Extrapolation

c) Rational Function Interpolation and Extrapolation

d) Interpolation using Splines

Optimization methods

a) Optimization in one dimension

b) Multivariate problems- Steepest descent, Newton and quasi-Newton methods, Conjugate gradient methods. Constrained optimization

c) Maximum entropy and Genetic methods

d) Least square fitting, Non-linear least square fitting, Goodness of fit

e) Software for optimization- energy minimization

Numerical Integration

a) Integration- Newton-Cotes integration formulae, Gaussian quadrature

b) Integral equations

Probability , Random numbers and Monte Carlo methods

a) Uniformly distributed Pseudo random numbers

b) Exponentially and Normally distributed Pseudo random numbers

c) Testing of pseudo random number sequences

d) Simulation of radioactive decay

e) Numerical Integration

f) Monte Carlo simulation techniques

Fourier and Wavelet transforms

a) Fast Fourier Transform- Convolution and deconvolution, Correlation, Filtering, Power spectrum estimation

b) Wavelet transforms- Wavelets, de-noising, de-trending, Texture analysis, Pattern recognition, Image compression

Ordinary Differential equations

a) Initial value problems for systems of ode's

b) Runge-Kutta Method, and adaptive step size control

c) Stiff differential equations

d) Boundary value problems

e) Galerkin method

Partial differential equations

a) Finite difference methods for Parabolic, Hyperbolic and Elliptic equations

b) Truncation errors, consistency, stability

c) Introduction to finite element methods.

Tutorials: Assignments of problems and computations based on these and other methods using FORTRAN-77 / FORTRAN-90/ C++

Books Suggested:

1. Computational physics- Problem solving with computers, Rubin H. Landau, Manuel J. Paez, John Wiley & sons 1997.
2. Numerical Recipes in Fortran-77 / F-90 / C, W.H. Press et. al., Cambridge Univ. Press.(1996)
3. A First Course in Computational Physics, P.L. DeVries, John Wiley and Sons (1994)
4. Numerical Methods for Engineering Application, J.H. Ferziger, John Wiley and Sons (1998)
5. Scientific Computing: An Introduction with Parallel Computing, G. Golub and J.M. Ortega, Academic Press, (1993)
6. Scientific Computing: An Introductory Survey, Michael T. Heath, McGraw-Hill, New York,

2002.
7. Computational Physics, J. M. Thijssen, Cambridge University Press, Cambridge, 1999.
8. Guide to Neural Computing Applications, L. Tarassenko, Arnold Publishers, 1998.
9. Genetic Algorithms in Search, Optimization, and Machine Learning, D. E. Goldberg, Addison Wesley, Reading, Massachusetts, 1989.

3. Introductory Reactor Physics and Engineering (PY3): (35 lectures)

S.No.	Course content
	Part I
1.	Basic nuclear physics concepts. Properties of nuclei. Nuclear forces. Nuclear models. Nuclear decay. Liquid drop model and nuclear stability. Nuclear reactions including fission. Compound nucleus formation. Microscopic cross-section. Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	Chain reaction; four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.
5.	**Reactor Kinetics**: Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.
	Part II
1.	Neutron distribution in a system; assumptions in setting up the neutron balance equation; applicability of Maxwell-Boltzmann statistics; Time dependent neutron balance (transport) equation, with delayed neutrons
2.	**Steady State Neutron Transport Equation:** Transport equation – differential & integral forms, Diffusion approximation, One speed neutron diffusion theory, Boundary conditions, Source-sink problem, Sub-critical reactors with flux independent source, Separation of space and energy.
3.	**Slowing Down and Energy Dependence:** Elastic scattering, Inelastic scattering, Anisotropy, average energy loss per neutron, Concept of lethargy. Fermi age theory, age of neutron, Logarithmic energy decrement, Slowing down spectra, Slowing down in hydrogen, Definition of resonance integral, Shape of thermal neutron-Maxwell spectrum.
4.	**Resonance Absorption:** Resonance cross sections, Resolved and unresolved region, Spatial and energy self shielding, Narrow resonance and intermediate resonance approximation, Concept of potential scattering cross section, Resonance integral in homogeneous media, Doppler broadening of resonance and importance for safety.
5.	**Multigroup Diffusion Theory:** Energy group and group fluxes, Flux weighted group constants, One group theory for thermal neutrons, Two group theory, Two group two region

model core with reflector. Adjoint equation.

6. **Reactor Control:** Cold start-up, Hot power operation, Temperature loads, Effects of burnup and fission products. Function of control rods. Theory of control rods, Xenon load during operation, Xenon iodine concentrations after shutdown, Xenon override, Xenon poison out condition, Samarium poisoning. Temperature coefficient of reactivity.

   Density temperature coefficient.

7. **Fast Reactors:** Fast reactors as breeders, comparison of fast and thermal reactors, role of fast reactors in Indian 3 stage nuclear power program

8. Neutron spectrum in FBR, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, delayed neutron fraction, fuel expansion and bowing, sodium void reactivity effect, Optimisation of blanket thickness. Effect of burnup on fuel composition and reactivity coefficients

9. General features of FBR core, specific power, linear rating, fluence, requirement and choice of core materials (fuel, coolant and structural materials), types of fast reactors – pool and loop type. Optimisation of core height and pin diameter. Salient physics aspects of FBTR and PFBR

Books suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C.Edlund. Van Nostrand, 1952.
2. Introduction to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Nuclear Reactor Engineering, Glasstone and Sesonske, Van Nostrand, 1990
4. The Physical Theory of Neutron Chain Reactors, Weinberg A. M. and Wigner E.P.
5. Nuclear Reactor Theory, Bell and Glasstone, Van Nostrand, 1970
6. Physics of Nuclear Reactors, Jakeman D.
7. A. E. Walter and A. B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981
8. Weston M. Stacey, "Nuclear Reactor Physics", John Wiley & Sons, Inc., 2001

4. Nuclear Physics and Nuclear data (PY4): (30 lectures)

S.No	Course content
	Part I - Nuclear Physics
1.	Properties of Nuclei; Binding Energy Curve; Stability Curve – neutron rich isotopes; nuclear interactions: neutron scattering, isotropic and anisotropic scattering. neutron capture, (n,xn) reactions; reaction thresholds, fission; Variation of cross-section with respect to (nuclide) material, reaction and incident energy; Resonance (Resolved/Unresolved) and Continuum regions; Mathematical formalisms to represent these data.
2.	**Nuclear models:** Nuclear potential; liquid drop, shell and optical models. Fission process; Fission barrier; (n,f) - thermal and high energy neutron induced fissions; Fission products and decay; FP elemental mass/isotope chains and distribution; prompt fission and delayed fission neutron energy distributions; energy yield per fission; neutron yield in fission with neutron energy (nu-p); photo neutron.
3.	Important neutron reactions with fuel, control and structural materials in reactor systems.

4. High energy proton interactions with heavy metals; spallation process; spallation products; neutron source distribution from spallation.

Part II - Nuclear Data

1. Four major kinds of nuclear data, viz. nuclear constants data, nuclear structure data, nuclear decay data, and nuclear reaction data. Importance to application areas, like therapeutic treatments, agriculture, and nuclear energy. Kinds of data, like neutron interaction data, neutron/gamma production data, gamma-atom interaction data, etc., pertinent to reactor physics applications.

   Measurements and model based predictions; Transmission experiment for total cross-section, measurement of differential scattering cross-section; Time of flight method, sources of errors in measurement – energy resolution; Optical model, Statistical Model, etc.; Examples of model based computer codes.

2. **Nuclear data Evaluation:** Problems of scarcity and/or abundance of nuclear data, need of nuclear data evaluation; Evaluated nuclear data files (ENDF), ENDF/A, ENDF/B,JENDL and JEFF; General purpose and Special purpose libraries; Sublibraries for neutron, photon, and charged particle interactions, Fission product yields and decay data; Problems of multiple evaluations; Formats and procedures; MAT, MF, MT conventions; Representation of different kinds of data, tabulated and parametric representations, single/multi level resonance formalisms in the resolved/unresolved region, BW formulation, partial & total widths, negative resonance energies, interpolation schemes. IAEA-NDS; Related websites.

3. **Nuclear data Processing:** Need for processing of an evaluated data Steps of processing; Simplifying assumptions and tolerances; Precautions on consistency and accuracy. Popular processing cods: PREPRO and NJOY and their modules, Linearisation: Advantages of linearization; interval halving procedure, tolerance (error criterion), probable pitfall – position of maximum deviation; Program LINEAR.

   Resonance Reconstruction. Doppler broadening: Effect of target temperature on cross-sections – for low energies, for resonances and for threshold reactions; kernel broadening approach, submerging small resonances due to broadening. Validation of evaluated and processed cross-sections.

4. **Multigrouping:** Consideration for deciding the number of groups and group limits. Neutron cross-section averaging: conservation of reaction rate, transport cross-sections, flux and current weighting, self-shielding, dilution and temperature dependences, multigroup cross-section set, effective cross-sections, mixture cross-sections, collapsing of cross-sections, group-to-group transfer cross-sections; Anisotropy and Legendre moments. GROUPIE/GROUPR programs; Validation of multigroup cross-sections.

   Photon production cross-sections; photo-atomic interaction cross-sections; coupled multigroup cross-section set; GAMINR program.Activation cross-sections; relevance of residual nuclear levels. Displacement cross-sections; relevance to radiation damage in reactor materials.

Books suggested:

1. Handbook of nuclear reactor calculations: Vols I-III, Yigel Ronen (Ed.) CRC Press, West PalmBeach, Florida (1986).
2. ENDF – 102, Data Formats and Procedures for the Evaluated Nuclear Data for ENDF – VI, M.Herman (Ed.) BNL-NCS-44945-05, (2005)
3. Special Issues on Evaluated Nuclear Data File ENDF/B-VII.0, J.K.Tuli, Nuclear Data Sheets, Vol-107 (2006)
4. Introduction to Nuclear Reactor Theory, Lamarsh J.R., ANS, (2002)

5. Engineering Drawing and Laboratory Practices (PY5 & PY5A): (20 lectures)

S.No	Course content
1.	**Machine Drawings Projections:** orthographic – 1st & 3rd Angles pictorial; Oblique: Perspective.
2.	Introduction; Indian and International standards for drafting and related subjects.
3.	**Line, lettering and dimensioning:** Outline hidden lines, Centre lines, Dimensional lines, Extension/Projection lines, Construction lines, Section lines, Leader/pointer lines, Cutting plane lines, Border lines, Short & long break lines, Representation of welded joints.
4.	**Dimensioning and tolerancing:** Definition and general principles, Arrangement of dimensions - Chain and parallel dimensioning, method of dimensioning common features; Rules for inscription of tolerancing. Limits fits. Tolerances and surface finish.
5.	**Scales, lines and lettering:** Recommended scales; Different type of lines, their illustration and application; Recommended size of letters and numerals.
6.	**Sections:** Full Section, Half section, Partial section, Revolved section.
7.	**Projections:** Orthographic – 1st & 3rd Angles; Pictorial – Oblique and Isometric
8.	**Conventional representation of common features and sections:** Conventional representation of gears and gear assembly, Threads, springs, bearing, welded joints. Hatching, sectioning, cutting planes.
9.	**Fastenings:** Bolts, studs, screw, washers, set screw, split pins.
10.	Brief Introduction of AutoCAD and its use, common drawing and edit commands.

Laboratory Practices:

1. Errors in measurement. Accuracy and precision. Software, data analysis, filtering and plotting.

Electronic components of detector systems.Analog electronics, Electromagnetic interference, shieldind and grounding of electronic equipments. Measurement of temperature, pressure, mass, volume and flow. Instrument time constant and response time.
Production and measurement of (low pressures)vacuum and high pressures.
Production and measurement of high temperature and low temperatures.

Computer hardware. Intelligent systems, Computer control and automatic data acquisition. User friendly experimental automation with G (graphical) language.

Books suggested:

1. Indian Standard Code of Practice for General Engineering Drawings (Second Revision); Bureau of Indian Standards.
2. Geometrical and Machine Drawing by N.D. Bhatt; Charotar Publishing House, Anand (WR), India

6. Reactor Materials (PY6): (30 lectures)

S.No	Course content
1.	Properties of fuel materials. Uranium metal, Uranium dioxide, Carbide and nitride fuels. Plutonium fuel materials. MOX fuels. Thorium fuel materials. Fabrication of fuel pellets: sintered and vibropacked.
2.	Dispersion type fuels. Inert matrix fuels, Metallic fuels, sol-gel process. Fuel for HTRs – coated particle / TRISO/ spherical fuel balls for high powered systems.
3.	General requirements of structure and clad materials. (neutronic and physical) Aluminum and alloys. SS and low alloy steels. Nickel alloys. Zirconium and alloys. Properties of moderator and coolant materials. Graphite, Beryllium, water and heavy water. Liquid metals. Heat transfer coefficients.
4.	Mechanical properties of materials. Stress-train relationships. Ductile and brittle failure. Ductile to brittle transition, Fatigue failure, Creep and dilation.
5.	Stress analysis, Thermal stress in fuel clad. Thermal stress in hollow cylinder with no heat generation, Thermal stress in hollow cylinder with exponential heat source, Factors affecting thermal stress.
6.	Radiation effects in materials. Atomic displacements. Mechanisms in radiation damage, General irradiation effects in metals. Thermo-physical properties of fuel (pellet) materials; variations with burnup Temperature dependent swelling. Helium embrittlement. Typical limits of irradiation damage
7.	Corrosion of metals. Chemical corrosion, erosion and fretting corrosion, Stress- corrosion cracking, Hydrogen embrittlement. Fuel clad failure process.
8.	Advaced materials for future FBR, ADS and high temperature reactor. Ferritic steels, oxide dispersed steels and carbon based materials

Books suggested:

1. Nuclear Reactor Engineering, Glasstone and Sesonske, Van Nostrand.
2. Fundamental Aspects of Nuclear Reactor Fuel Elements, D.R. Olander, ERDA report, TID 26711-P1 (1976).

7. Radiation Detection and Measurement (PY7): (20 lectures)

S.No	Course content
I	**Interaction of radiation with matter:**
1.	Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe-Bloch formulae), Cherenkov radiation. Energy loss of electrons and positrons – Electronic stopping and energy loss by Bremsstrahlung radiation.
2.	Interaction of photons – Photoelectric absorption, Compton scattering, pair production, Electromagnetic shower in high energy photon and electron interaction with matter.
3.	Interaction of Neutrons – elastic scattering, radiative capture, positive Q-value reactions such as (n,p), (n,gamma), (n,fission) and hadron shower production at high energies.

II **Radiation detectors:**

1. General characteristics of detectors – efficiency, response in energy, time, position and corresponding resolutions, recovery time or count rate handling capability.
2. Gas detectors Basic processes, Q-V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter.
3. Semiconductor detectors Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium detectors (planar and cylindrical geometry). Photovoltaic cells, charged coupled devices.
4. Scintillation detectors. Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes.
5. Techniques and detectors for neutron and spectrum measurements. Fission ionization chambers. Boron filled and coated detectors. Gamma compensation. Self powered neutron detectors.
6. Pulse processing instrumentation, preamplifiers(charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), single channel analyzers, timing discriminators(leading edge and constant fraction types), gate and delay generators, coincidence(fast and slow) units, linear gate and stretchers, time to amplitude converter(TAC), scalers and rate dividers, analog to digital converter(ADC), charge to digital converter(QDC), time to digital converter(TDC), data acquisition systems (multichannel analysers and computer based multiparameter systems).
7. Experimental techniques and simulation - Particle identification methods (pulse shape discrimination, Cerenkov radiation), Compton suppressed high purity germanium detectors for high-resolution gamma spectroscopy, magnetic spectrometers including recoil mass separator. Monte Carlo simulation of detectors.

Books suggested:

1. Techniques for Nuclear and Particle Physics Experiments – W.R. Leo, 2nd Ed. (Springer International Student Edition published by Narosa Publishing House, New Delhi 1995).
2. Radiation Detection and Measurement – G.F. Knoll, 3rd edition (John Wiley, New York 2000)
3. Nuclear Radiation Detectors – S.S. Kapoor and V.S. Ramamurthy (Wiley Eastern Ltd, New Delhi 1986)
4. Radiation Detectors, C.F.G. Delaney and E.C. Finch (Clarendon Press 1992).

8. Reactor Types and Advanced Reactor Concepts (PY8): (20 lectures)

S.No	Course content
1.	**Thermal Reactors:**
	History. Development of Gas Cooled Reactors (GCR). Reactor types AGR and RBMK. Development of BWR. Development of PWR and VVER. Development of PHWR and SGHWR.
2.	**Fast Reactors:**

History. Development of LMFBR.

3. **Advanced Reactors:**

Different generation of nuclear reactors. Evolutionary improvements and revolutionary improvements. High Temperature Reactor(HTR) and Advanced Heavy Water Reactor (AHWR).

Metal fuelled FBR and increased fuel breeding.

Accelerator driven systems (ADS)

Fusion Systems. JET and ITER. Concept and need for tritium breeding.

4. **Indian Reactors (Experimental and power producing):** For each type of reactor - brief principles of the reactor; typical Power/ Research reactor system; Fuel cluster/assembly; number of channels; core; coolant/moderator/reflector/blanket and shield as the case maybe; average neutron energy spectrum; control and shut down systems.

- APSARA/ CIRUS/ DHRUVA
- PHWR –India (220, 540 and 700 MWe)
- LWRs
- BWR (TAPS 1&2, modern BWRs,)
- VVER (KK)
- FBTR and PFBR

5. International Initiatives in Advanced Nuclear Systems: INPRO (IAEA) and GEN-IV. US proposal GNEP. International concerns. Nonproliferation, (proliferation indices), NPT, FMCT, CTBT.

Books Suggested:

1. W. Marshall ed. Nuclear Power Technology, Volumes I to IV, Clarendon Press, Oxford, (1984).

9. Radiation Shielding Design and Protection (PY9): (40 lectures)

S.No **Course content**

1. **Basics of radiation physics and dosimetry**

Radiation sources, its interaction with matter; natural and induced radioactive sources, half-life, decay constant, specific activity; basic interaction mechanisms of alpha, beta, gamma/x-rays and neutrons with matter (*summary only*).

Definition of various dosimetric terms (exposure, absorbed dose, equivalent dose, effetive dose, concept of radiation and tissue weighting factors and their importance, Activity, Specific activity (SI units and Old units), radiological, biological and effective halflife and their relation and their importance. Concept of ALI and DAC with suitable problems.

Human Body: cells, tissues and organs, structure of cell, cellular effects. Factors which influence the damage of cell. Interaction of radiation with biological matter. stochastic and deterministic effects. Acute and delayed effects. LD 50/60, Doubling dose. Radiation toxicity, Risk factor.

2. **Radiation Protection**

Radiation protection philosophy, objectives and principles of radiation protection ALARA, stochastic and deterministic effects, justification, optimization and dose limitation, Dose limits to occupational workers and members of public, Dose constraints, Investigation limits. Types

of exposure (natural, occupational, medical and public).

External and internal exposures; internal routes of intake of radioactive material. Use of personal dosimeters (TLDs, pocket dosimeters). Calculation of dose, Exposure measurement: Free air and air wall chambers (concept of wall thickness should be given), exposure-dose relationship, Fundamentals of ICRP respiratory model, ingestion, Gastro intestinal track model, wholebody counting and bioassay techniques.

Atomic Energy Act, National and international regulatory bodies, their role and responsibilities, Radiation protection rules, Safety during transport of radioactive materials, Radioactive waste classification and management.

3. **Radiation Shielding**

Shielding concepts- gamma shielding- Attenuation factors. Buildup factor concept for homogeneous and multiple layers. Semi-analytical methods for gamma shield design. Dose rates of gamma rays for various source geometries. Gamma energy dependence of dose. Half layer thickness of different materials. Heat generation.

Neutron shielding. Shielding in thermal reactors. Importance of shielding in fast reactors. In-vessel shields and reduction of dose to components and operating personnel. Activation of structural material and heat generation. Shielding in accelerators and fusion systems.

Computational problems. Transport theory methods. Large problem size and large flux attenuation. Importance of anisotropy effects in scattering. Neutron slowing down and need for fine energy treatment. Monte Carlo methods. Streaming through gaps, voids and pipes. Analytical methods. Complementary shielding.

Selection of shield materials. Shielding from mixed sources. Life of shield materials.

4. **Nuclear Emergency management**

Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, countermeasures. Aerosol physics for core disruptive accidents, Atmospheric transport processes, environmental impact studies.

Books suggested:

1. Nuclear Radiation Detection - W.J. Price, McGraw Hill (1964)
2. Radiation Detection and Measurement - G.F. Knoll, John Wiley and Sons (1989)
3. Biological Effects of Radiation – J.E. Coggle, Taylor and Francis (1983)
4. Atoms,Radiation and Radiation Protection by James E.Turner, Wiley (2007)
5. Problems and Solutions in Radiation Protection by James E. Turner et al., Wiley, (1988)
6. Introduction to Health Physics – Herman Cember, McGraw Hill (1996)
7. Introduction to Radiation Protection –Alan Martin and Samuel Harbison, Chapman and Hall (1986)
8. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998.
9. Radiation Shielding- Three volumes of Compendium on Radiation Shielding, O.Sisman and J. Jaeger et.al., ed. (1975)
10. Radiation Shielding Manual T Rockwell et.al ed. AEC-US, (1958).

10. Reactor Dynamics and Safety Analysis (PY10): (35 Lectures)

S.No	Course content
1.	**Reactor Dynamics** Neutron kinetics and thermal effects. Feed back effects. Time constants. Loosely and strongly coupled reactor systems; Reactor size and eigenvalue separation; fundamental and higher modes. Description of main reactor systems. Coolant system behaviour. Plant dynamics (open loop and closed loop). Flow perturbations. Reactivity perturbations. Thermal perturbations. System stability. Linear and non-linear stability analysis; Nyquist critera; Liapunov methods. Xe dynamics equations; spatial and time dependent oscillations and stability. Safety concepts. Defence in Depth (5 levels) Accident Categories / classification: Design basis events (DBE) and Beyond DBE (BDBE). Loss of Regulation Accident(LORA), Transient Over Power Accident(TOPA), Loss of Coolant Accident(LOCA), Loss of Flow Accident(LOFA), cold coolant additions – with shut down action; Anticipated Transients with out SCRAM(ATWS)- Un protected Loss of Flow (ULOF) and Unprotected Transient over Power (UTOP). Accident scenarios in thermal and fast reactors. Brief description of accidents at Three Mile Island, Chernobyl and FERMI reactor. Computer codes for modeling accidents in thermal and fast reactors. RELAP and SAS4A. Kinetics of ADS.
2.	**Safety Systems** Engineered safety systems. Safety Critical Systems (SCS); Safety Groups, SCS, actuation systems, safety support systems. Shut down Systems. Different shut down states; Shut down margins (SDM). Guaranteed shutdown states (GSS). General safety criteria. Examples of safety analysis of PHWR, LWR and FBR.
3.	**Introduction to Reliability and Probabilistic Safety Analysis (PSA)** Probability, random variable, probability distributions used in Reliability Analysis; uniform, exponential, Weibull, Normal and χ^2 distributions, Central Limit Theorem. Basic component reliability models, definition and other measures of reliability such as Availability, failure frequency, dependability, fail safe design, safe failures/unsafe failures. Reliability Block Diagram, series and parallel systems, minimal cutsets, Combinatorial (Fault Tree / Event Tree) and State Space methods (Markov Models), Binary Decision Diagram. Common Cause Failures, Human Reliability Analysis: Models of Common Cause failures and Human Reliability Analysis, independence, redundancy, diversity. Probabilistic Safety Assessment of Nuclear reactor, measures of risk, core damage frequency, Level-1, Level-2, Level-3 PSA (introduction).

Books suggested:

1. Fast Reactor Safety, John Graham, Academic Press (1972).

2. The Technology of Nuclear Reactor Safety, Vol-I and II, T.J.Thompson and J.G.Beckerley, MIT Press (1971).
3. Reactivity Coefficients in Large Fast Power Reactors, H.H.Hummel and D.Okrent, ANS (1970).

11. Fuel Cycle Physics and Introduction to Fuel Cycle (PY11) : (30 lectures)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.
8.	Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9.	U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10.	Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11.	Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12.	Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13.	Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14.	Isotopic separation operation of bred uranium in thorium cycles to remove U-232. MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Fluid Mechanics and Thermal Hydraulics PY12 (25 lectures)

S.No	Course content
1.	**Fluid Mechanics** Fluid continuum – Properties of fluids – Methods of describing fluid motion – Kinematics of fluid streamlines, streak lines, path lines – equation of Continuity, Euler's equations of motion – Navier Stokes equations. Hydrostatics – Manometry – Fluid force on planes and curved surfaces, – Aerostatics – variation of pressure, temperature and density with altitude – stability of atmosphere – Fluids subjected to uniform linear acceleration and uniform rotation. Analysis of fluid motion in integral form – Concept of a system and a control volume – equations of continuity, energy, linear momentum and angular momentum as applied to a control volume in fluid flow and their applications to propellers, pumps and turbines. Dimensional analysis, similitude and model testing – Laminar and turbulent flows – Viscous effects – Boundary layer – Separation phenomena – Losses in pipes.
2.	**Thermal hydraulics** **Conduction:** Steady state conduction in one and two-dimensional systems – One dimensional unsteady state conduction; analytical and numerical methods. Heat generation in cylindrical and plate fuel elements; Steady state heat transfer from fuel to coolant; concept of $\int KdT$; Axial temperature distribution in the fuel element; Maximum clad surface temperature. **Convection:** Basic equations, Boundary layers; Forced convection: External and internal flows, correlations, Natural convection. Natural circulation cooling during pump trip transients; flow coastdown; decay heat removal; natural circulation in advanced reactor concepts, flow instabilities. **Radiation heat transfer:** Basic laws, Properties of surfaces, view factors, network method and enclosure analysis for gray – diffuse enclosures containing transparent media, Engineering treatment of gas radiation. **Boiling heat transfer:** bubble nucleation; transition and film boiling (a) pool boiling and (b) flow boiling; heat transfer coefficients in pool and flow boiling. Horizontal and vertical surfaces. Two-phase flow; flow regimes; mixture quality; void fraction; mixture density; pressure drop. **Concept of pressure drop in nuclear channels:** objectives and methods of flow orificing; orificing in BWRs and FBRs. Hot spot factors; classification; determination of subfactors; overall hot spot factor-statistical and multiplicative approaches. **Condensation:** Surface tension- bulk Condensation – Dropwise condensation on solid surfaces, Film condensation, Nusselt's theory. **Critical heat flux:** mechanism of dryout and Departure from Nucleate Boiling (DNB); thermal margin – MCHFR; MDNBR; critical power concept.

Books Suggested:

1. Thermal Hydraulic Fundamentals, Neil E. Todreas, Hemisphere (1990).
2. Fluid Mechanics, F. Dougles et al., Pearson Education, 2006.

3. Heat Transfer, J.P. Holman, Eighth Edition, McGraw Hill, 1997.
4. F.P. Incropera and D.P. Dewitt, “Fundamentals of Heat and Mass Transfer, John Wiley and Sons, Fourth Edition, 1998.
5. Fast Breeder Reactors, Waltar A.E. and Reynolds A.B, Pergamon Publishers, New York, 1981.

13. Advanced Computational Methods in Reactor Physics (PY13): (35 lectures)

S.No.	Course content
1.	**Methods of solving neutron Diffusion equation:** Finite differencing of diffusion equation. Centre and corner mesh differencing schemes. Rectangular and triangular (hexagonal) meshes; Inner and outer iteration schemes. Acceleration methods for inner iteration scheme. Spectral radius and determination of acceleration parameter. Acceleration methods for outer iteration scheme. Power iteration and dominance ratio.
2.	Modern nodal methods. General weighted residual methods. Finite element method- its advantages and disadvantages. Coarse mesh rebalancing.
3.	Estimation of fundamental and higher harmonics; subtraction methods
4.	**Methods of solving neutron transport equation**
	(i) Lattice: (a) P_N method (b) Discrete ordinates method (c) Collision probabilities methods Collision probability method in 1-D and 2-D geometries. Interface current method. (d) Characteristics method.
5.	**(ii) Core and Shield:** Discrete ordinates methods in 1-D, 2-D and 3-D geometries. Diamond differencing scheme. Computer code ATES-3.
	Monte Carlo methods for core calculation; deep penetration problems. Computer code MCNP.
6.	Detailed burnup chain with all minor actinides. Solution of the burnup equations. Constant flux and constant power approximations. (ORIGIN
7.	Differencing of kinetic equations in time. Approximate solution of point kinetic equations. Space time kinetics. Adiabatic approximation. IQS; explicit and implicit time differencing methods.

Books suggested:

1. E.E.Lewis and W.F. Miller, Computational Methods of Neutron Transport, Wiley (1984) and ANS (1993).
2. G.I.Bell and S. Glasstone, Nuclear Reactor Theory, Van Nostrand (1970).
3. A.F. Henry, Nuclear Reactor Analysis, MIT Press (1975).
4. M. Clark and K.F. Hansen, Numerical Methods of Reactor Analysis, Academic Press (1964).

14. Experimental and Operational Reactor Physics (PY14): (35 lectures)

S.No	Course content
	I. Experimental Reactor Physics (10 hrs)
1.	Source and power range neutron detectors; Neutron sources- requirement vis-à-vis reactor type-External localised sources in LWRs and FBRs - internal distributed spontaneous fission / photo-neutron sources in PHWRs. Different steps of initial start-up in different research and power reactors.

2. Moderator experiments-measurement of diffusion length, age, migration length. Exponential experiment-Alpha dieaway (decay) experiment. Subcritical multiplication experiments-Critical mass measurements.
3. Low power experiments at criticality for validation of reactor physics evaluations-Measurement of neutron flux-Thermal and fast-Activation analysis-cadmium ratio-General methods of flux measurement- foil/wire activation methods, Measurement of buckling, power peaking and power distribution.
4. Neutron spectrum unfolding; differential measurements for reaction rates.
5. Dynamic methods of reactivity evaluation Reactor Period measurements-Measurement of reactivity-control Rod Calibration-power run-down experiments-reactivity coefficients measurements –Temperature and void coefficients measurements. Dose and shielding experiments-cross-section measurements.
6. Reactor noise methods- Process parameter measurements using neutronics-coolant flow measurement with N-16 gamma signals- failed fuel detection using delayed neutrons and noble gas fission products.
7. **Critical Facilities:**

   Thermal – ZERLINA, AHWR-CF, PURNIMA (1,2,3) ZED-2

   Fast – GODIVA (US), ZEBRA (UK), ZPPR (US), MASURCA (France), BFS (Russian).
8. **Subcritical Facilities with source:** MUSE, YELINA, PURNIMA-SCF, AHWR-C with source.

II. Operational Reactor Physics (20 hrs)

1. First Approach to Criticality; low power physics experiments; control requirements; general control schemes (auto or manual control as the case may be); spatial power control; nominal operation, power rise schemes; set-back and step back (as applicable); Reactivity balance in operating reactors.
2. Thermal power estimation using secondary and primary parameters – station heat balance. Assembly/ Bundle power, channel power, Linear Heat Rating (LHR): operational and safety limits; Bundle power envelops in PHWRs.
3. Failed fuel detection – delayed neutron monitoring; Fission Product (FP) gammas and volatile-gaseous FPs Back ground activities in the coolant.
4. Research Reactors: APSARA/CIRUS/DHRUVA – application. FBTR operation and applications. KAMINI operation and applications
5. Power Reactors: Operation of 220 and 540 MWe PHWRs : Incore flux mapping system BWR (TAPS- 1&2), PWR / VVER , PFBR

Books Suggested:

1. Experimental Reactor Physics, A.Edward Profio, John Wiley and Sons.

15. Design Methods in Thermal and Fast Reactors including Computer Codes (PY15): (35 lectures)

S.No **Course content**

I. Thermal Reactors

1. Popular multigroup nuclear data libraries and their group structure.
2. Spatial heterogeneity in different thermal reactors. Wigner-Seitz cell approximation. Self shielding effects in space and energy. Neutron transport treatment. Computer codes MURLI and CLUCOP.
3. Fuel assembly heterogeneity and supercell concept. Neutron transport treatment. Computer codes –SUPERB, CLUB, CASMO. Analysis of plate fuel assemblies. Special treatment of burnable absorbers and control rods.
4. Treatment of hexagonal lattices, EXCEL, TRIHEX.
5. WIMS Methodology ; HELIOS Computer code
6. Generation of cell and assembly parameters as a function of burnup and boron concentration in moderator.
7. Core computations. Core follow up and refueling. Computer codes DIF3D, VENTURE and COMESH. Core simulation codes TRIVENI and COMETG.

II. Fast Reactors

1. Popular multigroup libraries and their group structure.
2. Treatment of slowing down and energy self shielding. Heterogeneity effects in absorber rods. Computer code COHINT.
3. Breeding ratio and its variation with core material geometry. Radial and axial heterogeneous designs. Oxide, carbide and metal fuel and their effect on core safety parameters.
4. Hexagonal geometry effects. Optimisation of blanket thickness. Sodium void reactivity effects. Fuel burnup modeling.
5. Fuel management schemes in FBTR and PFBR. Effects on breeding ratio and power distribution. Computation of peak linear heat rating from measured outlet temperature distribution.
6. Computer code FARCOB. Code system ERANOS.

Books suggested:

1. R.J.J. Stammler and M.J.Abbate, Methods of Steady State Reactor Physics Nuclear Design, Academic Press (1983).
2. Handbook of nuclear reactor calculations: Vols I-III, Yigel Ronen Ed. CRC Press, West Palm Beach, Florida (1986).

16. In Core Fuel Management (PY16): (25 lectures)

S.No **Course content**

1. General in-core fuel management schemes. Advantages and dis-advantages of on-line and batch fuelling. Initial and equilibrium core concepts.

   PHWR: Online fueling; refueling strategies; core burnup - power distribution optimization; time average and snap shot evaluations; theory of computer code TAQUIL. Average exit burnup. Core followup; theory of TRIVENI code. Channel Power Peaking Factor (CPPF). Rules of channel selection. Fuelling in PHWRs: (220 & 540) Discharged bundle data – Pu production & Pu-vector.

2. **BWR:** Initial fuel loading; equilibrium cycle Batch fueling concepts; different core loading concepts – checker board, out-in, sector symmetric. Cycle length and Haling principle. SDM demonstration. Control rod pattern. Power distribution optimization. Core followup computer code COMETG. Minimum Critical Heat Flux Ratio (MCHFR).
3. **PWR and VVER:** Initial loading, equilibrium loading. Boron poison management. Fuel enrichment change and use of burnable absorber. Departure from Nucleate Boiling Ratio (DNBR).
4. **AHWR:** Basic principles of fuelling
5. **HTR:** Basic principles of fuelling

suggested:

1. P. Silvennoinen, Reactor Core Fuel Management, Pergamon Press (1976).
2. R.G. Cochran and N. Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

Homi Bhabha National Institute, RRCAT, Indore

M.Phil. in PHYSICAL SCIENCES
(Program Code: PHYS02)

Raja Ramanna Centre for Advanced Technology, Indore

Courses offered at HBNI, RRCAT for
Ph. D. in Physics
M.Tech. in Engineering Physics
(Specialization in Accelerators and Lasers)

- Total credit requirement for Ph. D. (Physics) : 60

Core courses	28 credits
Elective courses	20 credits
Laboratory experiments	04 credits
Two reading courses	08 credits

- Total credit requirement for M.Tech. (Engineering Physics) : 60*

Core courses	38 credits
Elective courses	12 credits
Laboratory experiments	04 credits
Short term project	06 credits

* An additional course (Foundation course) of 5 credits is offered to M.Tech. students as a bridge course.

Contents

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Syllabus for Ph. D. (Physics) and M.Tech. (Engineering Physics) courses

A : Core Courses

03PHYS02-001-C: Engineering Mathematics Credit (3)

Complex Analysis: Analytic functions, Cauchy-Reimann conditions, Cauchy integral theorem, Laurent expansion, conformal mapping, singularities, calculus of residues, evaluation of definite integrals.

Vector Calculus: Gradient, divergence and curl operations and their physical interpretations, vector integrations, Gauss theorem, Stokes theorem.

Matrix: Basic concept of matrix algebra, symmetric, skew-symmetric and orthogonal matrices, eigenvalues and eigenvectors of a matrix, hermitian, skew-hermitian and unitary matrices, illustration of symplectic matrices in particle transporting accelerator.

Integral Transform: Fourier integral, Fourier transform and inversion theorem, Fourier transform of derivative, convolution theorem, transfer function, Laplace transform, Laplace transform of derivatives, convolution theorem, inverse Laplace theorem.

Ordinary and Partial Differential Equations: Review of ordinary differential equations, introductions to partial differential equations, classification of partial differential equations, boundary and types of partial differential equations, solutions of one dimensional diffusion equation, two-dimensional Laplace equation, use of integral transform in solving partial differential equations. Introduction to difference equations.

Probability and Statistics: Bayes' formula, random variables, expected value and variance, discrete and continuous distributions, location parameters, joint distributions, conditional distributions and independence, covariance and correlation, bivariate normal distribution, Poisson process, the central limit theorem, statistical inference (with an aim to better understand and analyze experimental data), point estimators, estimating variance, confidence intervals, comparing two samples, estimation methods, hypothesis testing, goodness of a fit.

References:

1. "Mathematical Methods for Physicist", G. Arfken
2. "Mathematical Methods for Scientists and Engineers", Donald A. McQuarrie
3. "An Introduction to Probability: Theory and its Applications- Vol.1 and Vol 2", William Feller
4. "Ordinary Differential Equations" V.I. Arnold
5. "Advance Engineering Mathematics", Erwin Kreyszig

03PHYS02-002-C: Magnet Physics and Technology: Credit (4)

Origin of Magnetism: Classical and quantum concepts, magnetic moments, angular momentum and quantization of angular momentum.

Classification of Magnetism: Diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetism.

Role of Magnets in Accelerators: Dipole, quadrupole, sextupole, and combined function magnets, DC and fast cyclic magnets, septum magnets, and kicker magnets.

Fundamentals of Magnet Design: Magnetic circuit, dipole, quadrupole, sextupole and higher order multipole magnets and coil design, B-H curve.

Application of Magnetic Materials in Accelerators: Materials for DC magnets: low field magnets, high field magnets, permanent magnets, and shielding.

Materials for AC Magnets: Silicon steels, laminated Ni-Fe alloys, and Ferrites. Numerical methods for magnet simulation: computer code and related mathematical formalism, methods of optimization, multipole expansion, Fourier representation of magnetic field.

Magnet Technology: Fabrication procedures, tolerances, and economic issues.
Methods of magnetic field measurements: magnetic induction, search Coil, Hall probe, and nuclear magnetic resonance.

Superconducting Magnets: Basic concept of superconducting magnets, magnet geometries for dipole magnets, superconducting materials, need for twisted composite conductors, hot spot temperature, current densities, quench, training of magnets and persistent switch.

Geodesy and Alignment of Accelerators: Introduction, survey and alignment as applicable to accelerators and its requirement. Position sensitive elements and their typical tolerances for alignment, fiducial references and adjustment system, fiducial posts and targets, and techniques of fiducialsation. Features of support elements and their adjustments during alignment.

Network and Alignment Procedure: Defining coordinate systems, control networks-types, survey procedure, data adjustment and error analysis.

Survey and Alignment Instruments and Toolings: Electronic theodolite, optical level, laser Interferometer, distinvar, inclinometer, offsetmeter etc. Different types of targets and sensors.

References:

1. "Iron Dominated Magnets", Jack T. Tanabe
2. "Synchrotron Radiation Sources - A Primer," Herman Winick
3. "Iron Dominated Electromagnets, Design, Fabrication, Assembly Measurements", Jack T. Tanabe
4. "Conventional Magnets,Proceedings of CAT- CERN Accelerator School, Nov. 1993, Page 23," Neil Marks
5. "Classical Electrodynamics," J. D. Jackson
6. "Superconducting Magnet Systems," H. Brechna
7. "Physics of Magnetism," S. Chikazumi
8. "Soft Ferrite its Applications", E.C Snelling
9. "Permanent Magnet Materials Their Applications," Peter
10. "Modern Ferrite Technology", Alex Goldman

03PHYS02-003-C: Laser Physics and Technology: Credit (4)

Basic Formalism: Spontaneous and induced transitions, Einstein's approach, A and B coefficients, conditions for light amplification and oscillations, and characteristics of laser light. Homogeneous and inhomogeneous broadening of the transitions, spectral narrowing in a laser, gain saturation, spatial and spectral hole burning and their consequences, Lamb dip spectroscopy and its applications.

Propagation of optical beams in free space and in dielectric slab waveguides, Hermite-Gaussian beam modes, and ABCD law for Gaussian beam propagation.

Optical resonators, concept of cavity modes, resonators with spherical mirrors, resonance frequencies of optical resonators, losses in optical resonators, stable/ unstable resonators, Kirchoff's diffraction treatment for transverse modes.

Methods For Obtaining Population Inversion: Optical pumping, coherent and incoherent pumping, one- and two-photon processes, pumping geometries, pump sources, electrical pumping by discharge in gases, excitation mechanisms, self sustained and e-beam sustained operation, chemical pumping, and gas dynamic pumping.

Laser Dynamics: Laser oscillation, three and four level lasers, rate equation modeling, power in laser oscillators, optimum output coupling low- and high-loss regimes, multimode laser oscillation and mode locking. Different techniques of mode locking. Relaxation oscillations, cavity dumping and Q-switching. Techniques of Q-switching. Pulse compression techniques for ultrashort pulse generation. Spectral control of laser output, tunability of output frequency, single frequency operation, and frequency stabilization.

Physics and Technology of Specific Laser Systems: Solid state lasers, vibronic lasers, semiconductor diode lasers, diode pumped solid state lasers, fiber lasers, dye lasers, atomic and molecular gas lasers, chemical lasers, excimer lasers, free electron lasers. Measurement of parameters of a laser system.

Nonlinear Optics: Crystal optics, electro-optic effect, wave propagation in nonlinear media, phase matched second harmonic generation, optical parametric oscillator, two-photon absorption, stimulated Raman scattering, frequency mixing in gases and vapours, self-focusing, optical bistability and optical phase conjugation. Quantum optics: second quantization, non-classical effects.

References:

1. "Laser Fundamentals", W. T. Silfvast
2. "Laser Electronics", J. T. Verdeyen
3. "Lasers", A. E. Siegman
4. "Quantum Electronics", A. Yariv
5. "Laser Physics and Technology, Proc. of the school on Laser Physics and Tech." Eds. P. K Gupta, R. Khare
6. "Nonlinear Optics", R. W. Boyd
7. "Elements of Nonlinear optics", P. N Butcher and D Cotter

03PHYS02-004-C: Electromagnetic Theory: Credit (3)

Electrostatics: Laplace equation and the uniqueness theorems, variational approach to solutions of the Laplace and Poisson equations. Formal solutions of electrostatic boundary value problems with Green function. Method of relaxation for 2D electrostatic problems, method of images, separation of variables and special functions, finite element method, and multipole expansions. Electrostatic field in matter.

Magnetostatics: Maxwell equations of magnetostatic, macroscopic Maxwell equations in magnetic material and boundary conditions on B and H, and solution of boundary value problems in magnetostatics.

Electromagnetic Wave: Wave equation, solutions in free space, plane waves, Gaussian beams, equations in material media, dispersion relations, Fresnel's laws of reflection and refraction, total internal reflection and evanescent waves. Lorentz transformation of electromagnetic fields.

Wave-guides, Resonant Cavities and Optical Fibers: Hollow metallic waveguides, dielectric waveguides, optical fibers, resonant cavities, and elements of microwave transport line.

Radiation by Moving Charges: Lienard-Wiechert potentials and fields, power radiated by an accelerated charge, Larmor's formula, and angular distribution of emitted radiation.

References:

1. "Electromagnetic Theory", D. J. Griffith
2. "Classical Electrodynamics", J. D. Jackson
3. "Electrodynamics: An introduction including quantum effects", H. J. W. Muller-Kirsten
4. "Microwave Devices and Circuits", S. Y. Liao.

03PHYS02-005-C: Accelerator Physics and Beam Diagnostics: Credit (4)

Introduction: Motion under electric and magnetic fields. DC and RF acceleration. Relativistic kinematics, Brief history and review of particle accelerators.

Synchrotron/Storage Rings: Accelerator magnets - dipole, quadrupole and sextupole magnets. Multipole expansion method. Equation of motion, betatron oscillations, weak and strong focusing, transfer matrices, beam stability, twiss parameters, motion of particles with momentum deviation, momentum compaction, and chromaticity. Magnetic field errors, closed orbit distortion and its correction, resonances - integer and half integer, beam acceleration, synchrotron oscillations, phase stability, transition energy, beam emittance, Liouville's theorem, single turn injection, H-injection, and fast extraction.

Beam Transfer Lines: FODO cells, quadrupole triplet, phase space matching, emittance dilution.

Synchrotron Radiation Sources: Synchrotron radiation, Radiation damping, quantum excitations, equilibrium beam emittance, and beam lifetime.

Linear Accelerators: DC accelerators, various types of RF accelerators, EM mode in a simple structure, Q-factor, shunt impedance, transit time factor, filling time, energy gain, dispersion curve, TW and SW accelerators, and beam dynamics in LINACS.

Cyclotrons: Basic principle of cyclotron, resonance condition, orbit stability, limitations of classical cyclotrons, AVF cyclotrons, injection, central region, extraction, time structure, energy resolution, and beam emittance.

Microtrons: Classical microtrons, basic equations, and Racetrack microtrons.

Beam Diagnostics: Physical principles, charge collection, secondary emission, Ionization, fluorescence, scintillation, capacitive pick up, magnetic pick up, wall current, synchrotron radiation detection, and optical transition radiation.

Instrumentation: Faraday cup, secondary emission wire monitor, beam loss monitor, beam profile monitor, beam position monitor, DC beam current transformer, fast current transformer, wall current monitor, photomultiplier, photo diode, image dissector, and streak camera.

References:

1. "Particle Accelerator Physics", Helmut Wiedemann, Springer
2. "Introduction to Accelerator Physics", Arvind Jain, Macmillan India
3. "CERN Accelerator School Proceedings, Fifth General Accelerator Physics Course, 1992 (Available online)"
4. "The principles of circular accelerators and storage rings", P.J. Bryant and K. Johnsen, Cambridge University Press
5. "Principles of RF linear accelerators", T. Wangler, John Wiley and Sons
6. "Collective phenomenon in synchrotron radiation sources", S. Khan, springer
7. "Physics of collective beam instabilities in high energy accelerators", A. Chao, John Wiley and Sons

03PHYS02-006-C: Reactor Physics, Radiation Physics, and Safety Issues of Credit (3)

Health Physics: Radiation sources - radioisotopes, natural and manmade sources, radioactive series, reactors, accelerators, radiation facilities, solid, liquid and gaseous activity. Control measures - time, distance, decay, shielding, administrative control, radioactive discharge, waste disposal, and exposure control.

Interaction of Radiation with Matter: Interaction of light and heavy charged particles, photons, and neutrons. Interaction of high energy charged particles, electromagnetic cascade, and Hardronic cascade.

Radiation Quantities, Units, and Regulatory Recommendations: Dosimetric quantities, exposure, absorbed dose, equivalent and effective dose, committed dose, ALI, DAC, ICRP, AERB, and dose limits.

Biological Effects of Radiation: Somatic and genetic effects, stochastic and deterministic effects, and LD30/50.

Detection of Radiation: Ionisation chamber, proportional counters, GM tubes, scintillation detectors, semiconductor detectors, thermoluminiscent dosimeters, direct reading dosimeters neutron detectors, BF3 and He3 tubes, Rem-meters, CR-39-foils, pulsed radiation detection. Low and high energy radiation detection.

Reactor Physics: Introduction to nuclear energy - fission and fusion, interaction of neutrons with matter; fission process and energy release, fission cross-section, fissile and fertile materials. Chain reaction, neutron cycle and lifetime, criticality and classical four-factor formula. Thermal and fast systems, slowing down of neutrons, conversion and breeding of fissile materials, concept of neutron flux and current, neutron diffusion theory, critical size and mass, reflected systems and reflector saving, heterogeneous systems. Reactor kinetics, reactivity and importance of delayed neutrons, reactivity changes and coefficients, fission product poisoning, control devices, uranium and thorium fuel cycles and enrichment processes.

Accelerator Safety: Types of accelerators, prompt and residual radiation, source terms, radiation hazards, radiation safety systems, shielding, radiation monitoring, non-ionizing radiation safety, RF and MW safety, magnetic field safety; ozone safety, safety at synchrotron radiation beam lines, spallation neutron sources, and accelerator driven sub-critical systems.

References:

1. "Nuclear Reactor Engineering Vol-1", Samuel Glasstone and Sesonske
2. "Health Physics", Herman Cember
3. "Radiation Detection & Measurement", G. F. Knoll
4. "Atoms, Radiation & Radiation Protection", James Turner
5. "Physics for Radiation Protection", James Martin
6. "Radiological Safety Aspects of the Operation of Electron Accelerators, IAEA Technical Report Series. 188", W.P. Swanson
7. "Radiation Protection for Particle Accelerator Facilities NCRP Report No.144"
8. "Radiological Safety Aspects of the Operation of Proton Accelerators. IAEA Technical Report Series. 283", R. H.Thomas.
9. "A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators Nuclear Technology", A. Sullivan

03PHYS02-007-C: Numerical and Mathematical Techniques and Scientific — Credit (5)

Numerical Methods

System of Linear Algebraic Equations: Direct methods - Gauss elimination and Gauss Jordan methods. Iterative methods - Jacobi, Gauss-Seidel and Successive over relaxation (SOR) methods. Eigenvalue problem .

System of Nonlinear Equations: Newton-Raphson and Secant methods. Roots of polynomials, synthetic division of polynomials, and Baristow method.

Interpolation, Extrapolation, Error and Regression Analysis: Types of errors their analysis.

Numerical Integration: Newton-Cotes, Gauss quadratures, trapezoidal, Simpson's 1/3 and 3/8 rule. Numerical differentiation - forward, backward and central difference quotient.

Differential Equation: Solution of ordinary differential equations. Solution of partial differential equations. Fast Fourier transformation.

Statistical Distributions: Poisson and Gaussian distributions. Monte Carlo simulation, pseudo random numbers, and central limit theorem.

Finite Element Method (FEM)

Introduction: Basic concepts of finite element method, application of finite element method, finite element method versus classical methods, finite element method versus finite difference method, and advantage of finite element method.

Integral Formulations for Numerical Solutions: Variational method, collocation method; subdomain method, weighted residual methods, Rayleigh-Ritz method, Galarkin's method, and least square method

Elements, Nodes, and Co-ordinate Systems: Introduction, element shapes, nodes, nodal unknowns, and coordinate systems

Shape Functions: Introduction, polynomial shape functions, convergence requirement of shape function, and derivation of shape functions.

Introduction to Stiffness (Displacement) Method: Definition of the stiffness matrix, derivation of the stiffness, matrix, assembly of the total stiffness matrix, properties of the global stiffness matrix.

Application of Finite Element Method in Heat Transfer Problem: Fundamentals, one dimensional finite element formulation, and problems.

Fundamentals of Computers: Computer architecture, application of computers, input and output devices, latest processors, desktop PC and servers.

Networking Basic: TCP/IP, DNS, Internet, and Intranet.

Operating System Basic: Linux, windows, shell programming, and CLI, vi, multithreading, multiuser, multitasking, hyper threading, file permissions, and ssh.

Fundamentals of programming: Algorithm, flow charts, high-level languages like Fortran and C, and steps for creating a simple program.

Introduction to C Programming Language: Program structure, header files, basic data types, variables, and declarations.

Operators and Declarations in C: Relational, logical, increment, and decrement operators. Expressions and precedence of operators. Input and output operations, control statements, iterative loops, arrays, and pointer;

Overview of Scientific Computing: Languages and compilers and scientific libraries.

Overview of Trends and Techniques: Sequential, parallel computing, cluster and grid computing.

Architecture Taxonomy: Traditional architecture, Flynn's classical taxonomy, SISD, SIMD, MISD, and MIMD Models.

Steps for Creating a Parallel Program: Decomposition of the program, communication, computations, and composing the results. Parallel example-array processing.

References:

1. "Numerical Methods for Engineers with Personal Computer", S.C Chapra and R. P. Canale
2. "Numerical Analysis", R. L. Burden and J. Douglas Faires
3. "An Introduction to Numerical Analysis", K.E. Atkinson
4. "Numerical Method", E. Balagurusamy
5. "Numerical Methods for Engineers", D. V. Griffiths and I. M. Smith
6. "Data Reduction and Error Analysis for the Physical Sciences", P. R. Bevington and D. K. Robinson
7. "Finite Element Analysis", S. Krishnamurthy
8. "Introduction to the Finite Element Method", Desai and Abel
9. "An Introduction to the Finite Element Method", J. N. Reddy
10. "Concepts and Applications of Finite Element Analysis", R. D. Cook
11. "Finite Element Modeling for Stress Analysis", R. D. Cook
12. "Finite Elements and Approximation", O. C. Zienkiewicz and K. Morgan

03PHYS02-008-C: Materials Science and Technology- I: Credit (4)

The structure of materials (metals and alloys, ceramics and glasses, polymers, composites, low dimensional materials, smart materials). Defects in materials, transport properties of materials, mechanical and thermal properties of materials, electrical, magnetic, galvanometric properties, superconductivity. Optical, nonlinear properties of optical materials, quantum size effects. Electronic materials (like spintronics, and other functional materials). Introduction to symmetry and ferroelectric materials.

References:

1. "Solid State Physics", N. W. Ashcroft N. D. Mermin

2. "Principles of the Theory of Solids", J. M. Ziman
3. "Introduction to the Physics of Electrons in Solids", B. K. Tanner
4. "Introduction to the Electron Theory of Metals", U. Mizutani
5. "Introduction to Superconductivity", A. C. Rose-innes E. H. Rhoderick
6. "Physics of Superconductors: Introduction to Fundamentals Applications", V. V. Schmidt; edited by P. Mueller A. V. Ustinov
7. "Superconductivity", Charles P. Poole, Horacio A. Farach Richard J. Creswic
8. "Shape Memory Materials", Ed. K. Otsuka C.M. Wayman.
9. "Phase Transformations in Materials", Ed. Gernot Kostorz.
10. "Magnetocaloric Effect its Applications", A. M. Tishin Y. I. Spichkin.
11. "Callister's Materials Science Engineering", R. Balasubramaniam.
12. "Engineering Materials 1: An Introduction to Properties, Applications Design", Michael F. Ashby David R. H. Jones.
13. "The Physics of Solids", R. Turton
14. "Dielectric Phenomena in Solids", Kwan Chi Kao.

03PHYS02-009-C: Applications of Lasers in Nuclear Science, Industry and Medicine Credit (3)

Laser Applications: High resolution spectroscopy, ultra-fast spectroscopy, laser cooling, laser metrology, holography and its applications in NDT, optical data storage information processing, and optical communication. Laser photochemistry, laser application in biology and medicine

Laser Isotope Separation: Principles of selective photonic action, selective photonic action on atoms or molecules, atomic and molecular schemes for laser isotope separation, lasers for isotope separation, and uranium isotope separation technology employing lasers.

Laser Material Processing: Laser material interaction, Laser cutting, welding, surface hardening, laser surface re-solidification, laser surface alloying, and cladding, laser shock-hardening, laser rapid manufacturing, laser application in decontamination and decommissioning of nuclear installations.

03PHYS02-010-C: Applications of Accelerators in Nuclear Science,Industry and Medicine Credit (3)

Synchrotron Radiation and its Applications: Properties of synchrotron radiation, various types of sources like BM, wavelength shifter, wiggler, and undulators. Beamline design and

synchrotron optics. Applications of synchrotron radiation to condense matter physics, surface physics, biology and Industries

Industrial and Medical Applications of Accelerators: Accelerators for industrial and medical applications. Beam characteristics for medical and industrial applications.

Radiation Processing Using Accelerators: Radiation cross-linking, radiation curing, polymerization, de-polymerization, and radiation grafting. Dose distribution in the irradiated products.

Typical applications: Treatment of wire and cables, viscose rayon sheets, rubber products, heat shrinkable tubes, and sheets. Flue-gas treatment, waste water treatment, electron beam applications in food irradiation and sterilization.

Accelerator Based Radiotherapy: Clinical requirements of an accelerator for radiotherapy. Various components of radiotherapy machine. Photon beam therapy and electron beam therapy. Quality assurance in radiotherapy accelerator.

Applications of Accelerators in Nuclear and Particle Physics: Evolution of nuclear physics with energy of the incident beam. Nuclear physics and related phenomena at incident beam energy less than 10 MeV/nucleon, between 10 and 100 MeV/nucleon, and more than 100 MeV/nucleon. Nuclear physics with radioactive ion beams (RIB).

Spallation Source: General introduction, applications to condense matter, and nuclear physics.

03PHYS02-011-C: Vacuum Physics and Technology: Credit (2)

Vacuum Theory: Definitions - throughput, conductance, pumping speed etc. Pressure equations, mean free path, monolayer formation time. Units of vacuum, pressure regions in vacuum.

Vacuum Systems and Components: Vacuum pumps - rotary pumps, dry pumps, turbomolecular pump, titanium sublimation pump, non-evaporable getters, and sputter ion pump. Vacuum gauges - capacitance gauge, Pirani, thermocouple gauges, BA gauge, penning gauge, partial pressure gauge. flanges and seals, vacuum valves and leed throughs.

Vacuum System Design and Development: Design considerations, sources of gas load (vaporization, thermal desorption, diffusion, permeation, electron and ion stimulated desorption etc). Materials, fabrication techniques and leak detection. Processing to achieve ultra high vacuum.

References:

1. "Handbook of Vacuum Science and Technology", Ed. Dorothy M. Hoffman, Bawa Singh, John H. Thomas III and John H. Thomas III
2. "Vacuum Technology -3rd edition", A. Roth
3. "A User's Guide to Vacuum Technology - July 4, 2003", John F. O'Hanlon
4. "Vacuum Engineering Calculations, Formulas", Armand Berman
5. "Vacuum Technology-CERN Accelerator School", CERN

03PHYS02-012-C: Quantum Mechanics: Credit (6)

For Ph. D. (Physics) only

Mathematical Background and Postulates: Illustrations and application of postulates by using simple two-level systems and two-slit interference experiment.

Quantum Mechanics of Composite Systems: N-particle system, identical particles, symmetrization and antisymmetrization postulates, concept of density matrix, properties of density matrix, pure and mixed states.

Symmetry: Symmetries in quantum mechanics, space and time translation, time reversal symmetry and parity invariance. Rotational invariance, angular momentum, spin, and addition of angularmomenta.

Approximate Methods: Variational methods, Wentzel-Kramers-Brillouin (WKB) method, time-independent perturbation theory, time dependent perturbation theory, adiabatic and sudden approximations, Fermi-Golden rule.

Scattering Theory: Born approximation, partial wave analysis, two particle scattering.

Relativistic Quantum Mechanics: Klein-Gordon equation, Dirac equation, electron spin, and positron.

Advanced Topics: Quantization of electromagnetic field, coherent, and squeezed states, interaction of radiation with matter, spontaneous emission and Lamb shift, entangled state, EPR paradox and Bell's inequality.

References:

1. "Principle of Quantum mechanics", Ramamurthy Shankar
2. "Quantum Mechanics, Vol. I and II", C. Cohen-Tannoudji, B. Liu, F. Laloe
3. "Modern Quantum Mechanics", J. J. Sakurai

03PHYS02-013-C: Research Methodology: Credit (0)

(Lecture: 20, Credit: 0)

Research Methodology: Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

Documentation: Preparing scientific papers/reports, scientific presentations.

Laboratory safety: Safe practices in laboratory.

Research ethics*:* Ethical conduct in science, ethical issues in scientific publication, awareness of plagiarism and other scientific misconducts.

Probability and Statistics: Bayes formula, random variable, expected value and variance, discrete and continuous distributions, joint distributions, conditional distributions, covariance and correlation, normal distribution, Poisson process, central limit theorem and its applications,
definition of precision, accuracy, systematic and random errors**,** propagation of errors in experimental data and their estimation, estimation of variance and confidence intervals.

Mathematical modeling: Measurement of functional relationships, order of magnitude analysis, dimensional analysis, goodness of a fit, linear regression and data fitting.

Data Security: Introduction to Data Security, Data security requirements, Different Cyber threats to Data & possible Solutions, Basic concepts of Cryptography & Data encryption algorithms, Research opportunities in Data Security.

Data management: Data planning, handling, modelling, analysis, visualization, Different Data Models, Data Management Software, Data Backup & Storage

References:

1) Research Methods for Science, M. P. Marder (Cambridge University Press
2) The Ethics of Science, An Introduction, David Resnick (Taylor and Francis, 2005)
3) Avoiding plagiarism, self-plagiarism, and other questionable writing practices: A guide to ethical writing, Miguel Roig
4) Advance Engineering Mathematics, E. Kreyzwig (Wiley, 2006)
5) An Introduction to Probability: Theory and Applications Vol. 1 and 2, W. Feller (Wiley)

B : Physics Based Elective Courses

03PHYS02-001-E: Statistical Physics: Credit (4)

Classical and Quantum Statistical Mechanics: Introduction, postulates, microcanonical, canonical and grand canonical ensembles, partition and grand partition functions and their properties.

Ideal Bose Gas: Introduction, chemical potential, equation of state and thermodynamic properties, system of phonons, system of photons, Bose-Einstein condensation, Bose-Einstein condensation in dilute atomic gases, and superfluidity.

Ideal Fermi Gas: Introduction, equation of state and thermodynamic properties of degenerate Fermi gas. Neutron stars, conduction electrons in metals, and cold Fermi atomic gases.

Phase Transition: Mean-field theories, symmetry, order parameters, break-down of mean-field theories, critical phenomena and renormalization group.

Non-equilibrium Phenomena: Elementary ideas, irreversibility, study of Brownian motion, random walk model, Langevin force equation, fluctuation-dissipation theorem, Fokker-Planck equation, Glauberdynamics.

References:

1. "Fundamental of Statistical and Thermal Physics", F. Reif
2. "Statistical Mechanics", R. Pathria
3. "Statistical Mechanics", K. Huang

03PHYS02-002-E: Modern Optics: Credit (4)

Geometrical and Physical Optics: Wave front, phase, image formation, resolution, optical path, monochromatic and chromatic aberrations, wave front aberrations, complex representation of EM wave.

Optical Elements: Lens, effective and back focal lengths, shape factor and controlling of aberrations by bending, centering errors. Autocollimator and its applications. Prisms, right angle, penta, dove, corner cube, rhomb, Parallel plate, beam splitters (plane, cube and penta). Polarizers (wire grid, sheet, glan, and Wollaston prisms), Polarization beam splitters, wave plates (quarter and half wave plates).

Interferometers and Optical Measurements: Two and multi-beam interference, Intensity equation for two beam interference, contrast/visibility of interference fringes, temporal and spatial coherences.

Important Interferometric Configurations: Fizeau, Twyman Green, Mach-Zehnder, Jamin, lateral shearing, and Sagnac/ cyclic path interferometers.

Surface Imperfections: Surface flatness, form/figure error, surface roughness, and scratches and digs

Interferometric Testing: Surface form, parallelism, inhomogeneity differential interference contrast. Working principle and applications of Nomarski microscope.

Phase Shifting Interferometry: Principle, phase shifting techniques, and phase unwrapping.

Measuring Micro-scale Devices: Scanning white light interferometers (SWLI).

Overcoming Diffraction Barriers: Scanning near field optical microscope (SNOM).

Metamaterials

Introduction: Maxwell's equations, dispersion, reflection refraction, phase group velocities, photonic band gap crystals, electromagnetic metamaterials.

Negative Refractive Index: Introduction, designing negative refractive index materials, periodic structures, negative refractive index for various frequency regions, anisotropic isotropic materials, double negative metamaterials, nonlinear metamaterials.

Applications: Subwavelength imaging, concept of perfect lens, Veselago-Pendry lens, plasmonic cloaking invisibility.

Optics of Metals Nanomaterials: Electromagnetic waves in metals, skin depth, plasma frequencies, local field enhancements, focusing light beyond diffraction limit.

Optics of Nanoparticles: Optics at subwavelength regimes, dispersion in nanocomposite materials, effective medium theories, Clausius-Mosotti Maxwell-Garnett theories, extraordinary transmission through very small apertures.

Plasmonics: Introduction, electronics versus plasmonics, plasmonic components, manipulating light with plasmonic nanostructures.

Fiber Optics: Basics, Components Systems

Optical Fiber Geometry: Step index fiber, graded index fiber, double-cladded fiber, microstructured fiber. Modes in optical fiber, dielectric slab wave guide, propagating modes of the symmetric slab waveguide, even odd TE modes, characteristic equations, mode cutoff conditions, TM modes, ray optics explanation of modes in a dielectric slab waveguide. Basic equations physical constraints in round optical fibers, the fields in the core cladding, boundary conditions characteristic equation, characterization of modes, mode cut-off conditions, TE, TM hybrid modes, single mode optical fiber, linearly polarized modes, power distribution in optical fiber.

Characteristics of Optical Fiber: Losses in optical fiber: intrinsic impurity absorption loss, waveguide scattering loss, microbending macrobending loss, coupling splicing loss. Dispersion in optical fiber, group velocity dispersion, material dispersion, waveguide dispersion, polarization mode dispersion, dispersion management in optical fiber. Birefringence in optical fiber.

Nonlinear Fiber Optics: Nonlinearities in optical fiber, Kerr nonlinearity, self phase modulation, self focusing, cross phase modulation, four wave mixing, stimulated Brillouin scattering, stimulated Raman scattering. Ultra short pulse propagation, derivation of nonlinear Schrödinger equation (NLSE), ultra-short pulse propagation through fiber, soliton, similariton Gaussian pulse. Effect of gain loss on pulse propagation, interplay of dispersion, nonlinearity gain.

Fiber Optic Components Devices: Directional couplers, coupled mode equations, power transfer characteristics, transfer matrix of a coupler, super modes of a coupler, effect of fiber dispersion. Fiber gratings, Bragg diffraction, photosensitivity, fabrication techniques, grating characteristics, grating as an optical filter, nonuniform (chirped) grating. Fiber interferometer, fiber-ring resonator, Febry-perot resonator, Sagnac interferometers, Mach-Zehndar interferometers. Isolators circulators, Faraday effect, optical isolator, optical circulators. Fiber based system, fiber based sensors, temperature pressure sensors. Fiber laser amplifier, doped fiber, gain in doped fiber, basic construction of fiber laser amplifier. Mode-locked fiber laser: basics of mode-locking dynamics, nonlinear polarization rotation, saturable absorber, basic construction of a mode-locked fiber laser with a highlight of different mode-locking regimes, all-fiber integration.

References:

1. "Applications of Nonlinear Fiber Optics", G.P. Agrawal
2. "Erbium Doped Fiber Amplifiers", P.C. Becker, N A Olsson, and J R Simpson
3. "Introduction to Fiber Optics", Ajoy Ghatak, K Thyagarajan
4. "Lightwave Technology", G. P. Agrawal
5. "Plasmonics: Fundamentals and Applications", Stefan A. Maier (Springer)
6. "Plasmonics and Plasmonic Metamaterials - Analysis and Applications", Ed. Gennady Shvets , Igor Tsukerman (World Scientific)
7. "Metamaterials-Theory, Design, and Applications", Ed. Tie Jun Cui, David R. Smith and Ruopeng Liu (Springer)
8. "Optical Metamaterials: Fundamentals and Applications", Wenshan Cai, Vladimir Shalaev (Springer)

03PHYS02-003-E: Advanced Accelerator Physics: Credit (4)

Ion Sources: Emission processes and Child Langmuir Law, positive and negative ion sources, atomic and molecular phenomena in ion sources, beam extraction and transport.

Proton and Heavy Ion Accelerators: Introduction to acceleration of protons and heavy ions, RFQ, different type of cavities/accelerating structures, including SCRF, and introductory beam transport.

Instabilities in Linear Accelerators: Basics of beam instabilities, short and long range instabilities.

Other topics: FEL, Linac based synchrotron sources, laser plasma acceleration, and ADS.

03PHYS02-004-E: Plasma Physics and Technology: Credit (4)

Basic Plasma Physics: Definition of plasma, concept of temperature, Debye shielding, plasma parameter, criterion for plasma, variety of plasmas.

Plasma Behaviour: Single particle motion in electric and magnetic fields, collisions, plasma as fluid, kinetic approach.

Waves in Plasmas: Dielectric function, plasma oscillations, electromagnetic equations, dispersion relations.

Methods of Plasma Production: Electrical discharge, ohmic heating, RF heating, plasma production by lasers and particle beams, Tokamak plasma, Z-pinch, Theta pinch

Plasma Processes: Ionization, recombination, plasma equilibrium.

Radiation from Plasmas: Emission processes, spectral characteristics.

Plasma Diagnostic Methods: Density and temperature diagnostics using plasma radiation

Plasma Heating by Laser Beams: Propagation of laser beam in plasmas, inverse Bremsstrahlung, resonance absorption, parametric processes, second harmonic generation, filamentation, self-focusing.

Laser Plasma Interaction at Ultrahigh Intensities: Ultrahigh intensity parameters, multi-photon ionization, tunnel ionization, above threshold ionization, high harmonic generation.

Applications of Laser-plasma: Electron acceleration, x-ray lasing, inertial confinement fusion and fast ignition.

References:

1. "Introduction to Plasma Physics and Controlled Fusion Volume 1: Plasma Physics", Francis F. Chen
2. "Fundamentals of Plasma Physics, 3rd Ed.", J. A. Bittencourt Springer
3. "Principles of Plasma Spectroscopy", Hans R. Griem
4. "Principles of Plasma Diagnostics", I H Hutchinson
5. "The Physics of Laser Plasma Interactions", W. L. Kruer
6. "Short Pulse Laser Interaction with Matters: An Introduction", P. Gibbon

03PHYS02-005-E: Materials Science and Technology-II: Credit (4)

Methods for Growth and Synthesis of Materials: Introduction to phase diagrams and phase transitions. Methods of crystal growth: Solution growth, Czochralski method, Bridgman method, zone refining and other novel techniques. Methods for thin films preparation: Thermal vapor deposition, electron beam evaporation, chemical vapour deposition, MOCVD, sputtering, molecular beam epitaxy, sol-gel etc. Methods for ceramic synthesis: Powder preparation, consolidation and sintering. Nanomaterials: Top down and bottom up approaches.

Characterization Techniques: UV-VIS-NIR spectroscopy, FTIR and Raman spectroscopy. X-ray and neutron diffraction techniques. Polarized light microscopy, scanning electron microscopy, transmission electron microscopy, scanning probe microcopy, confocal microscopy. Thermal methods: Differential scanning calorimetry, differential thermal analysis and thermo gravimetric analysis.

References:

1. "Crystallization", J. W. Mullin
2. "Introduction to Phase Equilibria in Ceramics", Clifton G. Bergeron, Subash H. Risbud
3. "Crystal Growth Technology" Hans J. Scheel, Tsuguo Fukuda
4. "Etching of Crystals. Theory, Experiment, and Application", K. Sangwal
5. "A Guide to Materials Characterization and Chemical Analysis", John P. Sibila
6. "UV Spectroscopy: Techniques, Instrumentation and Data Handling (Vol. 4)" B.J. Clark, T. Frost, M.A. Russell
7. "Infrared and Raman Spectra of Inorganic and Coordination Compounds, Part A: Theory and Applications in Inorganic Chemistry", K. Nakamoto
8. "Infrared Spectral Interpretation: A Systematic Approach", Brian Smith
9. "Electron Microscopy and Analysis", Peter J. Goodhew, John Humphreys and Richard Beanland
10. "Transmission Electron Microscopy: A Textbook for Materials Science", David B Williams, C. Barry Carter,
11. "Scanning Probe Microscopy: The Lab on a Tip", Ernst Meyer
12. "Thermal Methods of Analysis: Principles, Applications and Problems", Peter J Haines
13. "Fundamental of Ceramics", Micheal W. Barsoum
14. "Introduction to the Principles of Ceramic Processing", James S. Reed
15. "Thin Film Deposition", Donals L. Smith

03PHYS02-006-E: Advanced Course on Atom-Photon Interactions:

Interaction of Light with Matter: Hamiltonian description, multipolar approximation, review of the time dependent perturbation theory, concept of transition amplitude, semiclassical theory of a two level atom coupled to a single mode radiation field, density matrix, optical Bloch equations, semi-classical laser theory.

Coherent Effects: Coherent population trapping (CPT), electromagnetically induced transparency, laser without population inversion, mechanical effects of light and its application in laser cooling and trapping.

Quantum Field: Quantization of electromagnetic field, interaction of quantized radiation with matter, Jaynes-Cummings model, quantum dissipative processes, atom in the vacuum field and spontaneous emission, resonance fluorescence.

Elementary of Theory of Coherence: Quasi-probability distribution functions, classical light and Non-classical light, coherent state, squeezed state and its experimental realization, atom-photon and atom-atom entanglement, multiparticle Entanglement, Entanglement in Quantum Information Processing.

Interaction of Atom with Intense Light Field: Virtual absorption and multiphoton ionization, generalized Fermi-Golden Rule, above threshold ionization, Volkov state and KFR theory, high harmonic generation, Floquet theory, many-body correlation effects and non-perturbative field effects, and S-Matrix theory.

References:

1. "Quantum Optics", Marlan O Scully and M Suhail Zubairy
2. "Elements of Quantum Optics", Pierre Meystre and Murray Sargent
3. "Laser Physics", Murray Sargent, Marlan O Scully and Willis E Lamb
4. "Photon and Atoms: Introduction to Quantum Electrodynamics", C. Cohen-Tannoudji, J. Dupont-Roc, G.Grynberg

03PHYS02-007-E: Advanced Beam Dynamics: Credit (4)

RMS envelope equation, beam matrix approach, concept of stationary states for beam distribution functions.

Transverse beam dynamics in a solenoid, Busch emittance, transverse and longitudinal beam dynamics in RF field, Panofsky-Wenzel theorem and its applications, wakefields and impedances in linear accelerators.

Emittance growth mechanisms and approximate techniques to estimate the emittance growth, beam halo. Bunch compressors and coherent synchrotron radiation (CSR), emittance growth due to CSR.

Beam dynamics with ion trapping and electron clouds

Coupling of electromagnetic power to RF cavities, beam loading and its implications, Slater perturbation theorem and its applications.

Computational methods in accelerator physics, symplectic integration, Lie Algebraic methods.

References:

1. "Theory and Design of Charged Particle Beams", Martin Reiser.
2. "RF Linear Accelerators", Thomas P. Wangler.
3. "Advanced Beam Dynamics", Bruce Carlsten and Steve Russell, a course offered at US Particle Accelerator School, Univ. of California, 2005.
4. "Computational Methods in Beam Dynamics", Robert Ryne, a course offered at US Particle Accelerator School, Univ. of California, 2005.
5. "Advanced Accelerator Physics Course", CERN Accelerator School Proceedings", CERN-95-06-V1-V2.
6. "Neutralization of Accelerator Beam by Ionization of the Residual Gas", Y. Baconneir, A. Poncet and P. F. Tavares, Lecture notes, CERN.

03PHYS02-008-E: Course on Bio-Photonics: Credit (4)

Introduction: Scope of bio-photonics, interaction of light with cells and tissues: absorption, scattering and depolarization of light .

Basics of Biology: Cell structure and organization, structure and function of biomolecules, metabolism and energetics. General methods for biophysical and biochemical analysis, mechanism of cell death.

Light Propagation in Tissues: Rayleigh and Mie scattering, multiple scattering and propagation of light in tissues, Radiative transport and diffusion approximation, effect of boundary conditions, numerical approaches for determining irradiance at surface and interior of scattering objects, techniques for determination of optical properties of biological samples.

Optical Imaging Through Turbid Medium: Trade-off between resolution and depth of imaging, use of spatial filtering, polarization gating and time-gating for optical imaging, high resolution imaging using coherence gating, Optical coherence tomography (OCT) and diffuse optical tomography.

Optical Spectroscopy for Biomedical Diagnosis: Elastic scattering spectroscopy for disease diagnosis, Fluorescence and Raman spectroscopy for diagnosis.

Optical Techniques for Micro-manipulation: Optical tweezers and micro-beams, radiation pressure and force on microscopic objects, gradient and scattering force, applications of optical tweezer.

Optical Microscopy: Recent Developments: Contrast methods in optical microscopy, techniques for single molecule imaging, scanning laser microscopy, multi-photon microscopy and near-field techniques.

Optical Methods for Bio-sensing Applications: Surface plasmon resonance based sensors, quantum dots and functionalized nanoparticles as biosensors approaches for label-free sensing, opto fluidics and lab-on-a-chip approach.

Effect of Light on Biological Tissue: Basic principals of photobiology, photo-acceptors, action spectra and light induced signaling mechanism, Ligh effect based on endogenous photosensitizers, use of exogenous photosensitizers for photodynamic therapy and photo anti-microbial therapy, biological effects of narrow bandwidth light.

References:

1. "Biomedical Photonics Handbook", Editor-in-Chief Tuan Vo-Dinh
2. "Optical Tweezers: Methods and Applications", Ed. Miles J. Padgett, Justin Molloy, David McGloin
3. "Introduction to Biophotonics", Paras N. Prasad

03PHYS02-009-E: Concepts in X-Ray Physics: Credit (4)

X-ray and Their Interaction With Matter: X-ray waves and photons, sources of X-rays, X-ray scattering from an electron and atom, refractive index including absorption, coherence, Kramer-Kroning relationship.

Refraction and Reflection of X-rays: Refraction and phase shifting in scattering, Snell's law and Fresnel equation in X-ray region, reflection from homogeneous slab and multilayers, rough interfaces and surfaces, examples of refractive and reflective X-ray optics and curved mirrors.

Kinematical Diffraction and Resonant Scattering: Laue condition and reciprocal space, Ewald sphere, lattice vibration, the Debye-Waller factor, Lorenz factor, application of kinematical diffraction, structure factor and basics of structure solving, phase problem in crystallography, anomalous diffraction and some examples, introduction to Rietveld refinement method.

Diffraction by Perfect Crystals: Kinematical reflection from few layers, basics of dynamical theory, Darwin's theory of extinction depth, integrated intensity, standing waves, higher order reflection, effect of absorption, asymmetric Bragg geometry, DuMond diagrams, applications in synchrotron X-ray monochromators, X-ray Topography.

X-Ray Absorption: X-ray absorption from isolated atoms, extended X-ray absorption fine structure (EXAFS), near edge X-ray absorption (XANES), EXAFS equation, basics of EXAFS data acquisition and sample preparation, Transmission versus fluorescence modes of EXAFS.

X-Ray Fluorescence: Theoretical details and data analysis, details of the experimental technique, sample preparation, trace element quantification and related issues.

Photo Emission Spectroscopy and X-Ray Magnetic Circular Dichroism: Basics of photoemission and inverse photoemission, experimental setup, photoelectron and Auger electrons, core level binding energies, chemical shifts, lineshapes and background, valence band structure determination, resonant photoemission, angle resolved photoemission and band structure determination, spin polarized photoemission, basics of XMCD

References:

1. "Elements of Modern Optics", Jens Als-Nielsen & Des McMorrow

2. "Dynamical Theory of X-ray Diffraction", Andre Authier
3. "Soft X-Rays and Extreme Ultraviolet Radiation", David Attwood

03PHYS02-010-E: Physics of Semiconductor Quantum Structures:

For Ph. D. (Physics) only

Introduction to Semiconductor Nanostructures: Review of condensed matter and semiconductor physics, scientific and technological significance of nanostructures and mesoscopic structures, characteristic length scales for quantum phenomena, energy states of carriers in free space of different dimensionality, effect of quantum confinement on carrier energy states, density of states for semiconductors of reduced dimensionality, key ideas on effect of quantum confinement in electronic properties, transport phenomenon and interaction of photons with materials, and applications of nanostructured semiconductors.

Growth of Semiconductor Nanostructures: Homo and hetero epitaxial growth, nucleation and nucleation kinetics, strain in lattice mismatched systems, psudomorphic growth and critical thickness, growth modes: Volmer-Weber (VW) or planer growth, Frank-van der Merwe (FM) or island growth and Stranski-Krastinov (SK) nucleation and growth, fundamental and principle of physical and chemical vapor deposition methods: Pulsed laser deposition, molecular beam epitaxy, chemical vapor deposition, atomic layer deposition, sputtering. Bandgap engineering and growth of quantum well structures, key issues in growth of quantum wires, quantum dots and super lattices, Fundamental characteristics of semiconductor nanostructures.

Properties and Characterizations of Semiconductor nanostructures: Optical processes in low dimensional semiconductors: Excitons, free carriers and defect level induced optical transitions, optical phonons and polaritrons, Basic principles and key issues of optical spectroscopy techniques for nanostructured semiconductors; absorption, reflection, photoluminescence, photoluminescence excitation and surface photovoltage spectroscopy. Transport in semiconductor nanostructures: conductance, resonant tunneling, hot electrons; transport in magnetic field, semi-classical and quantum approach, Aharonov-Bohm effect, Shubnikov-de Haas effect, introduction to quantum Hall effect. Principles of application of devices based on Semiconductor nanostructures: photodetectors, lasers, resonant tunneling diodes and solar cells etc.

References:

1. "Material Science of Thin Films: Deposition Structures", Milton Ohring
2. "Solid State Electronic Devices", Jaspreet Singh
3. "Physics of Low-Dimensional Semiconductors", Davies John H
4. "Semiconductor Devices Design", Jaspreet Singh and Umesh K Mishra
5. "Semiconductor Materials", B. G. Yacobi
6. "Semiconductor Nanostructures", Ed. D. Bimberg
7. "Semiconductor Optoelectronics: Physics Technology", J. Singh

C : Engineering Based Elective Courses

for M.Tech (Engineering Physics) only

03ENGG01-001-E: Power Supplies: Credit (4)

AC-DC Converters: Single phase and three phase diode and controlled rectifiers, effect of source inductance, ripple and harmonic analysis, 12-pulse rectifier, firing angle control schemes, THD and power factor, filters - passive and active, passive and active damping of filters.

Power factor Correction: Effects and limiting standards for line current harmonics, Passive PFC techniques, ActivePFC.

DC-DC Converters: Principle of operation, steady-state analysis of buck, boost, buck-boost converters, Isolated dc-dc converters- forward, flyback and bridge converters, pulse width modulator and control of dc-dc converters.

Principles of Feedback Control System: Negative feedback, Stability criteria- gain and phase margin, steady state errors, transient response, current loop and voltage loop acting together.

Magnet power supplies in Accelerators: Requirements, Load characterisation, DC and ramping type power supplies, Pulsed power supplies.

High current magnet power supplies: Stability requirements, current cycling, Field stabilization.

Power supplies for superconducting magnets : Load requirements, quench detection, protection and training.

Laser and Plasma power supplies: Load characterisation, Gas discharge, Ballast requirements, CW/Pulsed operation, Current stabilisation, Power coupling schemes to gas discharges.

Thermal Management: Heat transfer, Heat sink design, Water- cooled heat sinks.

03ENGG01-002-E: Power Electronics: Credit (4)

Power Semiconductor Devices: Diode, SCR, MOSFET, IGBT, Static and switching characteristics, Safe operating areas, Drive requirements and circuits, Introduction to the properties of emerging materials and devices, High voltage switches, Turn-on and turn-off snubbers.

Modelling and Analysis : Introduction to modelling and analysis techniques for dc-dc converters, Averaged equivalent circuit modelling and analysis, small-signal analysis with an illustrative converter, Feedback control of power converters: Feedback controller design, voltage- mode control and current- mode control.

Soft-switching Converters: Concept of soft-switching, Load resonant converters: concept and

definition, ac analysis of converters and modes of operation, Full bridge zero voltage switching converter: Phase shifted PWM, Operation and analysis of converter in steady state.

High frequency Magnetics: Ferrites- characteristics and types, skin effect, proximity effect, parasitic components- origin, minimisation and characterisation, design of high frequency magnetic components, introduction to planar magnetics.

Electromagnetic Interference: Measurement techniques, LISN, separation of common mode and differential mode noise, limiting standards and mitigation techniques, design of high frequency filters.

03ENGG01-003-E: Advanced Course on RF and Microwaves: Credit (4)

Microwave Networks: S-parameters, Matrix representation of Microwave networks and its properties, cascade networks, periodic network system and application, mixed mode S parameters and their applications.

Generation of RF power for accelerators: Design requirements, RF power amplifiers using tetrode & triodes and solid state devices, klystrons, IOT, Gyrotron, Cooling and protection, Grounding and shielding.

High Power RF transmission: design aspect of high power RF transmission, directional couplers, dividers, combiners, high power waveguide and coaxial transmission lines, circulators, bends, magic-T, microwave windows, dummy loads, RF couplers.

Accelerator cavities: Characterizing RF cavity, determination of important cavity parameters, Fundamentals of beam-cavity interactions. RF power coupling to cavity.

Low level RF components and systems: Planar circuits, microstrips, substrate materials, lumped and distributed circuits, mixer circuits, phase shifters, filters, switches, couplers, dividers/combiners, Low level RF signal processing and RF feedback systems.

RF systems for accelerators: Design and configuration of typical RF system, Safety interlocks and operation of RF system.

RF/Microwave measurements: Specialty of high frequency measurements, Measurement of RF power, impedance, VSWR, frequency and phase. Measuring instruments used in RF/microwaves, passive and active detectors, spectrum analyzer, VNA calibration systems, Vector measurement with VNA, peak and average power meters, impedance analyzer, frequency counter.

03ENGG01-004-E: Advanced Data Acquisition and Control Systems:

Components of data acquisition system and their selection, signal conditioning modules, polling, hand-shaking, interrupt and event driven, DMA, data sampling methods.

Embedded system software concepts and development tools assembly and HLL, assembler,

compilers, linker, librarian, resident monitors, source level debuggers, in-circuit & in application programming (ICP/IAP) and logic analyzer. In circuit emulator (ICE), object code and HEX file formats, FPGA & CPLD architectures, logic cell structures, programmable interconnect and I/O ports, programming technologies and VHDL, implementation of combinational and sequential circuits, timing issues in FPGA synchronous circuits.

Centralized v/s distributed control system, PAC and PLCs, PC software issues and virtual instrumentation, VISA, image acquisition, data logging, online and offline data processing, data presentation and reporting, BUSES for digital data communication.

PC buses: PCI & PCI Express specifications mechanical, electrical functional.

Back plane buses: VME, CPCI, PXI, VXI mechanical electrical functional specification.

Buses for instrument network: Asynchronous & synchronous communication standards, bus, ring, net topologies, RS-232, RS-485, USB, LAN-Hub, GPIB, Ethernet, field bus serial port expansion cards on PCI, Converters: USB-GPIB, USB-Serial.

Real-time system concepts, timeliness vs speed, hard vs soft real time, scheduling method, concurrency, process & thread concepts, inter process communication and synchronization.

Software reliability: Software implemented fault tolerance, reliability and availability, safety issues. Software reliability standards and practice.

Process control elements, Set point, disturbance, servo system, regulatory system, analog vs digital control systems, Z - transform for digital control systems, feedback control system, continuous time domain PID controllers. Feed forward and cascade controls, digital controllers, digital form of PID controller, Z-transform based dead beat and Dahlin's algorithms, programmable logic controllers and applications, compensator design and stability criterion.

References:

1. "Process Control Systems: Application Design and Tuning", F.G. Shinskey.
2. "Modern Control Systems", K. Ogata, Prentice Hall (India)
3. "Chemical Process Control", G. Stephanopoulos.
4. "Digital System Design with VHDL and Synthesis: An Integrated Approach", K C. Chang.
5. "Digital System Design and Prototyping Using Field Programmable Logic and Hardware Description Language", Zoran Salcic.
6. "VHDL Made Easy", David Pallerin.

03ENGG01-005-E: Reliability Engineering: Credit (4)

Basic engineering statistics: Basic probability, random variables, probability density and cumulative distribution functions of engineering importance such as the binomial, poisson, normal, exponential, weibull, etc. Random sampling and sampling statistics and distribution of sampling statistics, such as the Chi-Square and Students test, point and interval parameter estimation, test of hypothesis, examples to solve on continuous and discrete distributions, mathematical equations relating to hazard rate, reliability, cumulative failure probability and

failure probability (density) function, Bath-tub curve - explanation of different parts of the life characteristic curve and corresponding failure distributions.

Quality and reliability, QA/QC concepts - Acceptance sampling plans, quality measurement, quality improvement and control methods with applications in design, development, and manufacturing, modern quality management philosophies, engineering/statistical methods including process control, control charts, process capability studies, loss functions, design of experiments, and total quality management (TQM) topics.

Reliability, availability and maintainability concepts and principles, reliability statistical analysis concept overview and application, accelerated life testing concepts, principles and application, qualitative and quantitative accelerated life testing principles, life-stress relationships and application to electronic components and semiconductor devices, software reliability issues, reliability prediction for electronic systems, system reliability concepts and case studies, role of redundancy in system reliability, design for reliability concepts and case studies, degradation analysis and case studies, reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software, hardware reliability analysis of electronic and computer based C&I systems based on MIL-STD-217, methods of measuring the reliability effectiveness of complex engineering systems, optimization theory, preventive maintenance models, and statistical analysis.

03ENGG01-006-E: Advanced Course in High Voltage Engineering: Credit (4)

High Voltage Technology: Introduction, classification of voltage levels, high voltage in electric supply network, major components of a high voltage network.

Electrostatic Fields and their Control: Electric field intensity, electric strength, classification of electric fields, degree of uniformity of electric fields, control of electric field intensity.

Dielectric Materials and their Behavior in Electric Fields:

a. Insulating Behavior of Air and other Gaseous Dielectrics: Generation of charge carriers: impact ionization, thermal ionization and photo-ionization, Negative ion formation, Breakdown by avalanche discharge (Townsend Mechanism); Breakdown voltage characteristics in uniform fields (Paschen's Law) Practical factors affecting the breakdown voltage: Corona, Fields non-uniform, high pressure and vacuum.
b. Liquid Dielectrics in High Voltage applications: Mineral insulating oils, Dielectric properties of insulating liquids, Dielectric power losses in insulating materials, Breakdown in liquid dielectrics, Aging of mineral insulating oils.
c. Solid Dielectrics and their Behavior in Electric Fields: Classification of solid insulating materials, Breakdown and pre-breakdown phenomena in solid dielectrics, Partial discharge and its effects on dielectrics.

Generation of High Voltages:

a. Alternating voltages: single step-up transformer, Transformers in cascade, Voltage control

of testing transformers, Series resonant circuits.

b. Direct Voltages: Half wave and full wave rectification, Voltage doublers and cascade circuits.

c. Impulse Voltages: Single stage impulse generator, Multistage Marx generator, Practical Impulse Generators.

High Voltage Test & Measurement: Types of tests, Power frequency tests, DC voltage test and Impulse withstand test, Peak voltage measurements by spark gaps, Sphere gaps and uniform field gaps, Voltage measurement using ammeter in series with high impedance, Voltage measurement using potential dividers, Generating voltmeter, Voltage and current transformers.

High Voltage Design and Applications: Design considerations of high voltage bushings, power cables, transformers and switchgears; high voltage applications and electrostatic hazards.

High Voltage Safety and Protection.

References:

1. "High Voltage Engineering", E. Kuffel and W S Zaengl.
2. "High Voltage Measurement, Testing and Design", T J Gallagher and A J Pearmain
3. "High Voltage Insulation Engineering", Prof. Ravindra Arora and Prof. Wolfgang Mosch
4. "High Voltage Technology", L. L. Alston

03ENGG01-007-E: Digital Signal, Image Processing and Applications:

Introduction: Digital image, steps of digital image processing systems, elements of visual perception, connectivity and relations between pixels. Image acquisition: Frame grabber, optics and illumination Simple Operations - Arithmetic, Logical, geometric operations.

Mathematical Preliminaries: 2D LTI systems, 2D convolution, correlation, 2D random sequence, 2D spectrum.

Image Transforms: 2D orthogonal and unitary transforms- properties and examples. 2D DFT, histogram, image smoothening, image filtering, Sharpening, thresholding.

Image Segmentation and Analysis: Edge detection, line detection, curve detection, Edge linking and boundary extraction, boundary representation, region representation and segmentation, morphology-dilation, erosion, opening and closing.

Image understanding and recognition: Matching by templates, classifiers models, statistical, matching shapes by contour and texture.

Review of LTI systems: Fourier transform for discrete-time signals and its properties, comparison with continuous-time Fourier transform. Discrete time signals, sequences, representation of signals on orthogonal basis, sampling and reconstruction of signals.

Signal analysis using the Fourier transform, impulse function and complex exponential signal, modulation and frequency translation, duality, Fourier transform of periodic signals,

correlation, energy and power spectral density, Hilbert transform, Fourier transform of finite-duration discrete - time sequences.

Z-transform, Discrete Fourier Transform (DFT), Fast Fourier Transform algorithm and applications. Design of FIR & IIR digital filters, effect of finite register length in FIR filter design. Overview of DSP processors, FPGAs.

Typical applications in Lasers and Accelerators.

Reference:

1. "Digital Image Processing", Rafel C Gonzalez, and Richard E Woods.
2. "Fundamental of Digital image processing", A K Jain.
3. "Fundamentals of Electronic Image Processing", A R Weeks Jr.
4. "Practical Image Processing in C; Wiley professional Computing", Dr. Craig A Lindsey.
5. "Digital image processing: concepts, algorithms, and scientific applications", Jaehne, Bernd.
6. "Digital Imaging: Theory and applications", Burdick Howard E.
7. "Two dimensional signal and Image processing", Lim Jae S, V Oppenheim Allan.
8. "Discrete-Time Signal Processing", A. Oppenheim, R. Schafer and J. Buck.
9. "Signals and Systems", Oppenheim, Willsky and Nawab.
10. "Discrete Time Signal Processing", A.V. Oppenheim and Schafer.
11. "Digital Signal Processing: Principle, Algorithms and Applications", John G. Proakis and D.G. Manolakis.
12. "Theory and Application of Digital Signal Processing", L.R. Rabiner and B. Gold.
13. "Introduction to Digital Signal Processing", J.R. Johnson.
14. "Digital Signal Processing", D. J. DeFatta, J. G. Lucas and W. S. Hodgkiss.

D : Laboratory Experiments (Credit :4)

Experiments relating to lasers, accelerators and general electronics techniques will be offered. A student needs to carry out twelve experiments (4 each from laser, accelerator and electronics related areas) in two phases with a total working time of 72 hours which will carry 4 credits.

03PHYS02-001-L Lasers and Applications

1. Measurement of spectrum and spectral width of diode laser and their dependence on current.
2. Study of characteristics of a Q- switched Nd:YAG laser.
3. Second harmonic generation: phase matching and maker fringes.
4. Saturated absorption in atomic vapour: Doppler broadening, natural line width, power broadening.

5. Study of light propagation through fiber: coupling efficiency, bending losses, splicing and connecting fiber.
6. Studies on Nitrogen laser pumped dye laser.
7. Parametric study of a XeCl Excimer laser.
8. Output power characteristics of a diffusion-cooled CO_2 laser.
9. Determination of severance energy for cutting mild steel with CO_2 laser.
10. Determination of laser power coupling efficiency in Nd-YAG/CO_2 laser welding of stainless steel.

03PHYS02-002-L Accelerators Related Areas

1. Electrical resistivity measurement on metallic samples at low temperature.
2. Parametric studies of magnetic materials and operating point of magnets.
3. Outgassing of materials, discharge cleaning and ESD studies.
4. Estimation of radioactivity and shielding attenuation coefficient measurements.
5. Determination of cooling power of a cryocooler.
6. Electron gun: Operation and experimental studies.
7. Proton ion source: Operation and experimental studies.
8. X-ray fluorescence studies using radioactive source.
9. Calibration of cryogenic sensors.

03PHYS02-003-L Electronics

1. Study of stepper motor, dc motor drive and position feed-back.
2. Study of different transducers and their interfacing.
3. Communication buses and protocols, buses for distributed embedded processing.
4. G.U.I. software familiarization and applications.
5. Digital image processing and their applications.
6. Current and voltage regulated power supplies and change from one another.
7. Study of flash lamp and measurement of flash lamp current and K0 factor.
8. Characterization of RF components.
9. Fast current transformers: Study and measurement of response.

<u>03PHYS02-001-R</u> E : Reading Courses (Credit : 8)

Ph. D. scholars will work on two reading courses each of four credit worth. For each reading course, a Ph. D. scholar is expected to do self reading (under the guidance of his/her Ph. D. supervisor) of a review paper or book(s)/monograph(s) of specialized subjects related to the

area of his/her proposed area of research. Alternatively he/she may also work out and comprehend a research paper or a part of research paper relevant to his/her Ph. D. work. The topic and the structure/contents of the two reading courses should be decided by the guide in consultation with the respective doctoral committee and the Ph. D. scholar. The two reading courses should be approved by the respective doctoral committee.

The two reading courses will be evaluated on the basis of the detailed reports that will be prepared by the scholar and presentations, which will be held at the end of first year (in the month of August). The total marks for each reading course is 150 with 100 and 50 for report and presentation respectively.

BACK TO MAIN

GOVERNMENT OF INDIA

BHABHA ATOMIC RESEARCH CENTRE

M.Sc in ENGINEERING SCIENCES (PROGRAM CODE: ENGG03)

SYLLABUS

BARC Training School, Mumbai

HUMAN RESOURCE DEVELOPMENT DIVISION

MUMBAI 400085

PREFACE

The Department of Atomic Energy (DAE) has the multi pronged mandate of the utilisation of the power of the atom towards generation of power, development of advanced technologies, directed research in various scientific and engineering disciplines, production of radioisotopes for societal applications in medicine and agriculture and towards national security. In order to become self reliant and self sustaining in this high technology area, the need for generating highly skilled manpower and ensuring its continuous availability was indispensable. Thus in 1957, the BARC Training School (BARCTS) was established as a centre for in house training of professionals. These professionals today form the backbone of the Nuclear Power Programme. More than 9000 trainees have graduated from BARC TS over the last 61 years and provide the technological leadership in DAE for all its important programmes. Over the last five and a half decades, the BARCTS has grown into a model institute, recognised internationally as a school of excellence.

The academic activities of BARCTS are carried out by the Human Resource Development Division (HRDD) from its campus situated at Anushakti Nagar, well away from the hustle and bustle of Mumbai, nestling between wooded hills and sylvan surroundings, close to the BARC premises. This crucible of learning has been a focus of attraction to many a bright young talent, eager and willing to learn, guided and mentored by an academia drawn from the pool of experts available within DAE. Hailing from some of the best universities in India, they are nurtured with care and concern, by means of a holistic approach to training and personality development. A judicious mix of academics, practical training and soft skills training is imparted at the Training School and at the state of the art laboratories of BARC. A well equipped hostel with sports, recreation, and internet facilities provides the right environment needed for wholesome development. The lure of a professionally challenging career with opportunities for upgradation of skills, an objective merit recognition based career growth pattern and attractive compensation packages have attracted the best talents to BARCTS.

The BARCTS has two principle programmes, the One-Year **Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)** and the **DAE Graduate Fellowship Scheme (DGFS)**

Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)

OCES is the flagship programme of the BARC Training School and its affiliates. Under this scheme, engineering graduates from eight engineering disciplines- Mechanical, Chemical, Metallurgy, Civil, Electrical, Electronics, Instrumentation & Computer Science and Science Post-Graduates from Physics, Chemistry & Biological Sciences are selected and imparted a

rigorous one year training in the field of Nuclear Science and Technology. In addition to the above 11 disciplines, selected post graduate candidates from the Physics and Chemistry disciplines are also inducted into a course specifically designed for the purpose of providing a holistic training in all aspects of radiological safety. This course has been named as “Radiological Safety Engineering’ course.

The curriculum provides multidisciplinary training in topics relevant to the nuclear industry, frontier areas of science and technology and some super specialized areas. Training is imparted by adjunct faculty comprising the scientists and engineers working in various projects of DAE. In this manner, not only the objective of training but also the greater task of seamless and effective knowledge transfer from the expert to the acolyte is carried out successfully. The scheme also ensures the retention of the trained manpower within the Department thereby maximising the benefits of the training programme to the Department.

A total of about 150 courses in the above disciplines comprising more than 4000 lectures are delivered by more than 500 adjunct faculty members from BARC and other educational institutes during this period.

OCES Training Objectives: It involves one year of academic and training programme at the BARC Training School. The training programme aims to ensure that the selected candidates are provided with the necessary facilities and opportunities to acquire knowledge and develop skills for meeting the challenging technological goals of the country in the field of nuclear S&T. The training courses are organized in a structured manner as detailed below

- Foundation courses impart multidisciplinary training in the topics relevant to the nuclear industry.
- Core courses bring all selected candidates from different universities to the same or common level of understanding in the core subjects of the respective disciplines.
- Elective courses impart training in few specialized areas in respective disciplines.

OCES graduates are also eligible for the award of Post Graduate Diploma in Nuclear Science/Engineering & Technology of HBNI. After joining the DAE, the eligible OCES graduates can undertake one year project work leading to the award of M.Tech./M.Phil. Degree of the HBNI.

DAE Graduate Fellowship Scheme (DGFS)

In order to meet the requirement of highly specialised professionals in specific areas, DAE initiated the DGFS Programme for inducting engineers at MTech level in collaboration with the six IITs viz. Bombay, Delhi, Kanpur, Kharagpur, Madras, Roorkee and BHU in addition to some other elite institutes such as NIT Rourkela and ICT, Mumbai. The scheme strengthens the research-education linkage with premier institutes of the country in the areas of interest to DAE and provides useful synergy between the nuclear sector and the academia

Under this scheme, trainees selected for the OCES programme as well as one of the above institutes pursue the M.Tech degree under the sponsorship of DAE. On completion of the MTech degree, the candidates are absorbed into DAE as a Scientific Officer with advance increments. These Fellows then undergo a 4-month Orientation Course for DGFS Fellows (OCDF) after successful completion of M.Tech.

Orientation Course for DGFS Fellows (OCDF)

Several topics of interest to the Department do not form part of the MTech curriculum. To provide an exposure to such topics, the DGFS Fellows undertake a four months orientation course in the BARC Training School **(Orientation Course for DGFS Fellows- OCDF)** after successful completion of their MTech. Programme.

This document furnishes the course structures of all disciplines and syllabi of the courses conducted by the BARC Training School under each discipline.

CONTENTS

SYLLABUS

ENGINEERING SCIENCES

Annexure-I

REVISED CREDITS
FOR
COURSES IN ENGINEERING
SCIENCES

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (MECHANICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for PVP	EN610	60	6	250
2	Computational fluid Dynamics and Heat Transfer	EN611	50	6	200
3	Finite Element Method	EN621	30	4	125
4	Fracture Mechanics	EN622	40	4	150
5	Mechanics of Solids	EN624	40	4	150
		Core Total	**220**	**24**	**875**

ELECTIVES (MECHANICAL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Machine Design	EN711	25	2	100
4	Material Science in Nuclear Engineering	EN712	25	2	100
5	Multi-scale material modelling	EN715	30	4	125
6	Nuclear Emergencies	EN716	35	4	150
7	Reliability Engineering	EN718	25	2	100
8	Vibration	EN721	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CHEMICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25	2	100
2	Advanced Mass Transfer	EN604	25	2	100
3	Code design for PVP	EN610	30	4	125
4	Computational Fluid Dynamics and Heat Transfer	EN611	50	6	200
5	Nuclear Chemical Engineering	EN628	35	4	150
6	Process Dynamics and Control	EN634	45	6	200
7	Process Modeling, Simulation and Optimization	EN635	45	6	200
	CORE TOTAL		**225**	**30**	**950**

ELECTIVES (CHEMICAL) – Any 3 Courses - 9 CREDITS

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Material Science in Nuclear Engineering	EN712	20	2	75
4	Membrane Technology	EN714	35	4	150
	ELECTIVES TOTAL (APPROX)		**90**	**8-10**	**350**

	THEORY TOTAL	**535**	**62-64**	**2175**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 535; Total Credits: 106-108; Total Marks: 2775

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - METALLURGY

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (METALLURGY)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	2	75
2	Extractive Metallurgy	EN620	40	4	150
3	Mechanical Metallurgy	EN623	30	4	125
4	Nuclear Materials	EN628	50	6	200
5	Nuclear Metallurgy	EN629	30	4	125
6	Physical Metallurgy	EN630	40	4	150
7	Process Control & Instrumentation	EN631	25	2	100
		CORE TOTAL	**230**	**26**	**925**

ELECTIVES (METALLURGY) Any 3 Courses- 9 Credits

S.No.	Subject Title		Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Image processing and Machine Vision	EN710	30	4	125
4	Materials Characterization	EN713	20	2	75
5	Multi scale Material Modeling	EN715	30	4	125
6	Nuclear Chemical Engineering	EN628	35	4	150
7	Nuclear Emergencies	EN716	35	4	150
8	Welding Science & Technology	EN723	25	2	100
		ELECTIVES TOTAL (APPROX)	**90**	**8-12**	**350**

	THEORY TOTAL	**540**	**58-62**	**2150**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 540; Total Credits: 102-106; Total Marks: 2750

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CIVIL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1	30	4	125
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2	30	4	125
3	Design Basis Hazards & Geotechnical Engg	EN621	40	4	150
4	Earthquake Engineeing & Structural Dyanmics	EN609	45	6	200
5	Finite Element Method	EN626	30	4	125
6	Mechanics of Solids	EN624	40	4	150
	Core Total		**215**	**26**	**875**

ELECTIVES (CIVIL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Struct Dynamics & Earthquake Engg	EN724	30	4	100
2	Construction Materials, Management & Quality	EN614	30	4	100
3	Safety & Reliability of Civil Engineering	EN722	25	2	100
4	Project Management	EN717	25	2	100
	ELECTIVES TOTAL (APPROX)		**80**	**8-10**	**300**

	THEORY TOTAL	**515**	**58-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 520; Total Credits: 102-104; Total Marks: 2600

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECRICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	20	2	75
2	Computer Based System Design I	EN612	25	2	100
3	Electrical Systems for Nuclear Power Plants	EN618	30	4	125
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**195**	**22**	**800**

ELECTIVES (ELECTRICAL) Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design II	EN702	25	2	100
2	Artificial Intelligence and its Applications	EN703	30	4	125
3	Computer Based System Design II	EN704	25	2	100
4	Digital Signal Processing & Image Processing	EN706	30	4	125
5	Image Processing & Machine Vision	EN710	30	4	125
6	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
7	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**525**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECTRONICS)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	4	125
2	Advanced Nuclear Instrumentation	EN605	40	4	150
3	Embedded & Computer Based Sys. Design	EN619	45	6	200
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**200**	**28**	**825**

ELECTIVES (ELECTRONICS) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Embedded Electronics Software	EN707	25	2	100
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**60-66**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 104-110; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
		FOUNDATION TOTAL	**240**	**26**	**950**

CORE ENGINEERING (INSTRUMENTATION)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40	4	150
2	Computer Based System Design I	EN612	25	2	100
3	Modern Control Systems Design and Simulation	EN625	35	4	150
4	Reactor C&I and Human Machine Interface	EN636	40	4	150
5	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
6	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		EN639	**20**	**775**

ELECTIVES (INSTRUMENTATION) Any 3 Courses-- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	125
2	Computer Based System Design II	EN706	25	2	100
3	Digital Signal Processing & Image Processing	EN707	30	4	125
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**8-12**	**350**

	THEORY TOTAL	**525**	**54-58**	**2075**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-102; Total Marks: 2675

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25	2	100
2	Computer Graphics & Visualisation	EN613	35	4	150
3	Distributed Computing	EN616	45	6	200
4	Networking & Information Security	EN6627	40	4	150
5	Reactor Control Engineering	EN637	15	2	75
6	Software Engineering and Formal Methods	EN640	40	4	150
	CORE TOTAL		**200**	**22**	**825**

ELECTIVES (COMP. SCIENCE AND ENGINEERING) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Data Base Management System & Web Technology	EN705	30	4	100
3	Digital Signal Processing & Image Processing	EN706	30	4	125
4	Embedded Electronics Software	EN707	25	2	100
5	Feedback Control System	EN708	25	2	100
6	Image Processing & Machine Vision	EN710	30	4	125
	3 ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

FOUNDATION COURSES

EN501: Accelerator Physics and Technology

Basic Accelerator Physics (5)

- Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons;
- Ion sources.
- General equations of motion in a combined electric and magnetic field, beam rigidity; relativistic expressions, weak and strong focusing principle; condition for strong focusing.
- Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.
- General design of a cyclic accelerator.
- Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;
- Matrix techniques in beam optics; first order transfer matrix of dipole, quadrupole, transfer matrix of a drift space; quadrupole doublet;
- Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters
- Introduction of normal (room temperature) DC and pulsed magnets, construction features. Superconducting coils, magnets and their construction features.
- Momentum compaction; Phase stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.
- Synchrotron radiation sources; spectrum of emitted radiation; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators.

RF Linacs (12)

Introduction to Linacs

- Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.
- Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac
- Transit time factor and the energy gained in a linac.
- Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.
- General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature RF structures.

Proton Linac

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.
- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
- Introduction to Space charge effects.
- Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Accelerator Driven Systems & RF electron accelerators

Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.

Accelerator Technology (13)

General

- Material selection for Accelerator components
- Mechanical Design and fabrication issues; tolerances, surface finish, etc
- Thermal management in accelerator systems
- Alignment requirements of accelerator magnets and RF structures, methods and instruments for alignment and surveying in accelerators.

Ultra High Vacuum Systems

Basic concepts in Vacuum

- The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
- Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
- Basics of low pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, Sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.

Cryogenics Systems

Introduction to Cryogenic Engineering

- General and basics, Cryogenic properties, Basic cycles
- Large Cryogenic Systems for Accelerators

Cryogenic Equipments

- Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

References

1. Principles of RF Linear Accelerators, T. P. Wangler, (John Wiley & Sons Inc., 1998)
2. Introduction to Accelerator physics – Arvind Jain
3. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer, (John Wiley & Sons Inc., 1982)
4. An Introduction to the Physics of Particle Accelerators - M. Conte, W.W. Mac Kay.
5. Handbook of Accelerator Physics and Engineering - A. Chao, M. Tigner.
6. Particle Accelerator Physics (Vol 1 and Vol 2) - Helmut Widemann.
7. Principles of Charged Particle Acceleration – Stanley Humphries.
8. Fundamentals of Beam Physics - James Rosenzweig.
9. An Introduction to Particle Accelerators - E. J. N. Wilson.
10. Accelerator Physics - S. Y. Lee.
11. The Physics of Particle Accelerators, An Introduction - Klaus Wille.
12. The Principles of Circular Accelerators and Storage Rings - Philip Byrant.
13. Introduction to Vacuum Technology-Compiled by K.G. Bhushan, BARC

EN 502:Engineering Maths-I (15) (All Engg)

- Overview of arithmetic errors in computations
- Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
- Linear systems solutions by direct methods, iterative methods and acceleration techniques.
- Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
- Linear systems: Eigen values.
- Non -Linear systems: Newton-Rapson & Successive Approximation methods
- Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
- Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
- Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and
 Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 503: Engineering Maths-II (20) (ME Group)

- Introduction to discretization methods and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations, wave equation
- Formulation of the matrix methods by equilibrium concepts (1D-heat conduction, 2D-truss and 1D-hydraulic flow examples).
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's methods, Piecewise approximations. Basis of Finite Element Method, energy principles in structural mechanics and principles of minimum potential energy, assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit methods.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.
- Finite element formulation for laminar and turbulent flows.
- Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
- Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
- Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
- Response Surface Method 2K+1, factorial design, 3k factorial design
- Monte Carlo Method
- Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Artificial Intelligence and Genetic Algorithm
- Artificial Neural Network
- Gram-Schmidtt Orthogonalization
- Transformation of matrix

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
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10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 504:Engineering Maths-II (20) (MT)

Applications in Materials Science:

- Use of matrix in crystallography. Stereographic analysis, lattice correspondence, orientational relationship, applications to twinning and martensitic. transformations,
- Tensor analysis in phase transformation and deformation studies
- Analysis of diffusion data, Solutions of diffusion equations - error function and Eigen value analysis, Polynomial fitting of diffusion profiles.

Application in thermodynamics of metallurgical systems:

- Temperature dependence of thermodynamic quantities, graphical and analytical integration of Gibbs-Duhem equation. Introduction to database for thermodynamic tables
- Analysis and synthesis of phase diagrams, introduction to first principles calculations of phase diagrams with computer demonstration, cluster variation and Monte Carlo methods

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wilev, 1966.
2. Todd R.J. "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods.
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McCraw-Hill Book Co. 1983.
6. Rajaraman V,, "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C. "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis

1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B,, "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers. 1968.
11. Conte S.D,, "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo,McGraw Hill. 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G,, "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis". Addison Wesley, 1984.
15. Rajsekaran S,, "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987; •
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation' Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.-• •
19. Acton, "Numerical Methods That Work"
20. Forsythe et. al,, "Computer Methods for Mathematical Computations"
21. Forsythe et. al,, "Computer Solution for Linear Algebraic Systems"
22. Golub Gene H., "Matrix Computations"
23. Griffiths D. V., "Numerical Methods Engineers: A Programming Approach"
24. Williams P. W,, "Numerical Computation.
25. Strang G,, "Applied Mathematics"
26. Crank J,, "Mathematics of Diffusion"
27. Worked Examples in the Geometry of Crystals: MKDH Bhadesh
28. Materials Science & Technology, Vol.4; Rudman.

EN 505: Engineering Maths-II (20)(EE Group)

- Transforms: Laplace & solution to ODE, Bilinear & Z transforms, Discrete cosine transforms & compression, Entropy & Haufman coding for compression
- Solution of Matrix Differential Equation: Existence & uniqueness of solutions, Solution of Non-Linear continuous time state equation, Solution of Linear time varying continuous time state equation, Solution of linear time invariant continuous time state equations
- Basic Procedure for Designing Conservational Logic: Quine McCluskey method, Iterative consensus method, Design example
- Design of Sequential Circuit Using Sequential Machine Flow Chart: Sequential machine flow chart, Reading reduced dimension maps, Output function synthesis, Next state function synthesis, State assignment & design examples
- Counting Statistics and Error Prediction: Statistical models -Binomial, Poisson and Gaussian distributions, Application of statistical models: Error propagation, Optimization of counting experiments, Limits of detectability, Distribution of time intervals

References:

1. F R Grantmacher, "The Theory of Matrices", New York: Chelsea Publishing Co., 1960.
2. R Bellman, "Introduction to Matrix Analysis", II ed., New York, McGraw Hill, 1970.
3. E Kreyszig, "Advanced Engineering Mathematics, 5th ed., Wiley Eastern Ltd., 1985.
4. Paul R Halmos, "Finite Dimensional Vector Spaces", and New York: D Van Nostrand Co. Inc., 1965
5. Bajpei et.al, "Numerical Methods for Engineers and Scientists"
6. Dahlquist et.al, "Numerical Methods"
7. G Strang, "Applied Mathematics"
8. Golub Gene H, "Matrix Computations"
9. Numerical Methods for Scientists and Engineers, By H.M.Antia, Hindustan Book Agency,New Delhi.
10. Numerical Methods for Mathematics, Science and Engineering, Mathews(IInd Ed), Prentice Hall of India.

EN 506:Health Physics and Radiological & Industrial Safety (20)

Health Physics

Introduction

- Radiation sources, its interaction with matter and units**:** Natural and Induced radioactive sources,
- Units of radioactivity, half-life and decay constant, specific activity.
- Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter.
- Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given).
- Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given),
- Exposure-dose relationship, Bragg-Gray principle.

Biological effects, Radiation Protection and Regulation:

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Importance of radiation protection programme in DAE.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.

- Radiation protection philosophy,
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Principles of radiation detection and monitoring

- Basic operating principles ofa) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type ofRadiation monitors/Radioactivity measurement methods adopted for radiation protection should be taught.

Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management.
- Personal monitoring, area-monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures:

- Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper),
- Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation, Protective equipments

Nuclear Accidents, Emergency Preparedness and Management:

- Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

INDUSTRIAL SAFETY ASPECTS

Introduction:

- Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques

Hazards due to physical agents:

- UV and IR radiation, Lasers, Microwave radiation; noise, heat

Chemicals hazards:

- Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals

Evaluation:

- Instrumental methods, air sampling methods, liquid effluent monitoring

Occupational exposure limits:

- Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50

Handling, storage and control:

- Engineering control measures and safety features,
- Safety management techniques such as safety audit, Personal/ administrative control, and Medical control

Fire and explosion hazards:

- Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits,
- USNFPA Classification of Flammable/combustible liquids: flammable gases;
- Engineering safety for prevention of fire and explosion,
- Hazard area classification, selection of equipment, detection and extinguishing systems.

Hazard identification, assessment and control:

- Hazard identification: Concept of risk and Risk management
- Formal methods of hazard identification and assessment:
- Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies
- Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation.

Management of major hazard Installations:

- Plant Layout and Engineering Design Consideration
- Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic Releases,
- Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment,
- Emergency Planning Guidelines, Development of Emergency Plan

Health and safety regulatory aspects:

- Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate.
- EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

References:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute Of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment And Control; Vol-1, 1996 2 Edition, Frank P Lees.

EN 507:Material Science in Nuclear Engineering (EE) (20)

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction methods --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices.
- Material characterization techniques --- XRD, RBS, SEM, TEM, EDAX, XPS, IR and Raman Spectroscopy.
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials, mechanical properties and measurement techniques, strength and ductility, creep, fatigue and wear testing
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Reactor core materials, Zircalloys, Zr-Nb alloys --- fabrication, properties and applications in reactors
- Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels) --- fabrication, properties and applications.
- Chemistry of fuel materials: Production of Uranium, Plutonium and Thorium.
- Heavy water: Production process, purification, properties and applications.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)

2\. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)

3\. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)

4\. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)

EN 508: Nuclear Fuel Cycle Technology(35)

An overview (1)

FRONT END

Mining, Milling and Associated Processing of Indian Uranium Resources(1)

- General Introduction
- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.

Case Studies (1)

- Jaduguda and Turamdih Uranium Ore Processing
- Tummalapalle Uranium

Metal Purification using Hydro-Metallurgical Processes (1)

- Process, Equipment, Quality control

Metal Production by Metallothermic Reduction Processes (1)

- Process, Equipment, Quality control

WasteManagement and Safety (1)

- Associated wastes, characterisation and management

BACK END

Reprocessing (4)

- Nuclear fuels and generation of Pu239 & U233
- Spent fuel management options.
- Characteristics of spent fuel (RR, PHWR, AHWR ,FBR&LWR).
- Reprocessing by PUREX -Head end operations, solvent extraction cycles including the conversion of nitrates to oxides.
- Reprocessing of AHWR and FBR spent fuels.
- Prevention of criticality in reprocessing plants.

Waste Management (3)

- Waste sources.
- Radioactive waste classification.
- Management of low and intermediate level wastes.
- Vitrification of high level liquid waste.
- Schemes for partitioning of high level waste including recovery of valuable fission products.
- Storage and disposal of radioactive wastes.
- Various decontamination techniques to address alpha bearing materials.

Instrumentation & Control (3)

- Measurement techniques for level, pressure, temperature, interface density and flow Instrumentation and control associated with transfer devices—steam jets, pumps and air lift pots
- Interlocks related to major equipments like pulse column, dissolver, evaporator, joule melter and ion exchange column
- Computerised data acquisition and control system

Radiation Monitoring System (2)

- Area monitoring instruments, stack monitors, criticality alarm systems, effluent monitors,PCW & steam condensate monitors
- Single line diagram for Class-4, Class-3 and UPS
- Earthing, cabling, lightening protection system, VF drives

Civil (1)

Design aspects of back end technology facilities- Design classification and seismic categorization, considerations for external events, Standards/codes for design

Metallurgy (2)

- Corrosion aspects and material of construction for reprocessing and waste management plants.
- Degradation modes of SS 304L in nitric acid.
- Welding techniques, quality assurance and special requirement for in cell equipment.

Mechanical (7)

- Spent fuel transportation- shipping cask design and regulatory requirement.
- Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
- Remote handling system in reprocessing.
- Automation in plutonium powder handling.
- Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
- Sampling system. Transfer devices and valves for radiochemical plants.

Features of Radiochemical Plant (7)

- Layout considerations and design philosophy for back end operation.
- Control of radiation exposure including shielding and barriers.
- Ventilation aspects and Off gas handling and treatment.
- Utilities requirement for back end.
- Mechanical design aspects of metallic and joule melter.
- Radiation shielding windows.
- Remotisation and remote handling in vitrification plants

EN 509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40)

Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulas gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

1. Wakil M.EI, "Nuclear Power Engineering", McGraw- Hill.
2. Strosal and Vapet, "Power Plant Engineering & Economics".
3. Lewis E.E., "Nuclear Power Reactor Safety", Wiley Inter Science.
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von-Nostrand, 1981.

Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time.Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
  - Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio, blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly
  - Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
  - Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination

References:

1. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors", Pergamon Press
2. Yevick J.G., "Fast Reactor Technology", Plant Design, M.I.T, Press.

Module 3:Advanced Reactor Concepts (6)

Introduction(1)

- Need for Advanced Reactors and in what way these are different from conventional reactor
- International initiatives – INPRO, GIF etc.
- Definition of sustainability and INPRO areas of sustainability
- Brief Description of the INPRO Guidelines and Methodology to Evaluate INES
- Basic principles, User requirements, Key Indicators, Allowable parameters etc.

Directions of Development in the World(1)

- GIF and other advanced reactor concepts

Indian Programme on Advanced Reactors and Associated Challenges (2)

- AHWR
- AHWR-LEU
- CHTR, IHTR, MSBR etc.

Reactor Physics Design Challenges(1) ADS and applications(1)

EN 510:Reactor Physics & Engineering (55)

Module 1 :Nuclear Reactor Physics (33)

Properties of Nuclei

Binding energy-formula and interpretation, nuclear forces, nuclear structure.

Fission Process

- Fission rate and reactor power
- Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
- Fissile, fertile and fissionable materials
- Fission product activity after shut down –decay heat.

Interaction of Neutrons with Matter

- Production of neutrons

Concept of microscopic cross section:

- Inelastic and elastic scattering

Variation of cross-section with energy

- Fast, resonance and thermal ranges
- 1/v law of neuron cross-section
- Resonance absorption, Doppler effect.
- Eta vs E curve conversion & breeding concept
- Thorium utilization

Diffusion of Neutrons
- Fick's law and its validity
- Steady state neutron diffusion equation
- Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.

Chain Reaction
- Four Factor formula
- Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
- Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,

Slowing Down Process
- Neutron slowing down
- Slowing down power/ moderating ratio of moderators
- Slowing down with spatial migration
- Fermi age concepts, migration length
- Multi zone reactors
- Ideas of reflectors/blankets, reflector savings, form factor.

Heterogeneous Reactors
- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

Reactor Kinetics
- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

Core Burn Up
- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

Neutron Poisons
- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

Reactivity Coefficients
- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Module 2: Reactor Engineering & Radiation Shielding (22)

Reactor Engineering (14)
- Introduction to reactor system & Indian Nuclear power programme
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems
- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR),
- Fast reactors;
- Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
- Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.

Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.
- Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
- Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.

Nuclear Fuel Cycle (2)
- Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
- Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
- Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
- Advanced fuel cycles

Radiation Shielding (6)
- Source of various neutron & Gamma radiation within the reactor system
- Attenuation of neutrons & gamma rays

- Dose rates for gamma rays for various source geometries
- Buildup factors for homogeneous & multiple layer shields
- Removal diffusion theory for neutron attenuation
- Coolant activation, heat generation
- Streaming of radiation through gaps & void in the shield

CORE COURSES

E601: Advanced Chemical Reaction Engineering (25)

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
- Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
- Reactor design: counter-current moving bed reactors, fluidized bed reactors.
- Advanced topics in reaction engineering- three phase reactors, photochemical reactors, integral reactor-separators, complex systems.
- Examples from nuclear chemical engineering.

References:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

EN602: Advanced Electrical Engineering Design-I (20)

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Methods, Finite Element Methods, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Methods: MFL Technique, Eddy current Technique, Remote Field eddy current Methods. (5)

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronics Circuit Design Techniques (30)

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Programmable Logic Devices: PLD, CPLD and FPGA, Technology architecture (4)
- Hardware Description Languages: VHDL – language details (6)
- Digital Circuit Design using VHDL: Design methodology and optimization, Design of a multiplexer, counter, finite state machine etc., test bench (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. Actel HDL Coding Style Guide, 2009 edition, Published by Actel Corporation, Mountain View, CA 94043. Free softcopy available on Actel website (www.actel.com).
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles

10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25)

- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Rate based approaches for design.
- Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors.
- Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors.
- Adsorption and ion exchange equipment.
- Membrane separation and other advanced mass transfer processes.
- Process intensification approaches.

References:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)

EN605: Advanced Nuclear Instrumentation (40)

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and methods of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems ,Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.

Reactor Instrumentation:

- Fundamental Considerations / Philosophies, requirements, and scope.
- Measurement ranges of reactor neutron flux and considerations
- Types of neutron detectors FC,10B, BF3, CIC and SPND for in-core and out-of-core use.
- Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR,LR, Lin, LinR and ρ)
- Noise reduction techniques, considerations and practice: EMI Interference, Grounding and shielding.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma Monitors, Neutron Monitors, Contamination Monitors, including networking and RADAS.

References

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

EN606: Advanced Operating Systems (25)

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Processs Subsystem : Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem : Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Interprocess Communication : Message Queues, Shared Memory, Semaphores, Mailboxes, Sockets, Fundamentals of Socket Programming, Remote Procedure Calls [1][6]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing, Features of distributed Unix, Logical time, Concurrency Control [1][5]
- Unix Shells: Unix Shell Commands & Fundamentals of Shell Programming [1][2]

- Linux: Packaging and Distribution, Loaders, Virtual Terminals, Internal and External Drivers, Threads, Interfaces, X Window System, Hard Disk Partitions, File System Enhancements, Extended File Systems, Virtual File System, System Tuning. [3, 9, 10]

References:

1. The Design of Unix Operating Systems : Maurice J. Bach, Prentice Hall
2. Unix Programming Environment : Kerninghan & Pike, Prentice Hall
3. Linux Internals : Rubini, O'Reilly & Associates
4. Operating Systems Concepts: Silberschatz, Galvin, John Wiley
5. Distributed Operating Systems : Tanenbaum, Prentice Hall
6. Unix Network Programming : W. Richard Stevens, Prentice Hall
7. Xlib Programming : Adrian Nye, O'Reilly & Associates
8. Inside Windows NT , David A. Solomon, Microsoft Press
9. Demblon & Spitzner, http://learnlinux.tsf.org.za/courses/build/internals/internals-all.html
10. Tigran Aivazian, http://www.faqs.org/docs/kernel_2_4/lki.html or http://students.mimuw.edu.pl/SO/Linux-doc/LinuxKernel-2.4.pdf

EN607: Applied Process Instrumentation (40)

- Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables:
- **Flow**: Differential pressure flow elements: Orifices , venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters. Applications and limitations of various flowmeters. Two phase flow measurements.
- **Pressure**: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.
- **Level**: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
- **Temperature**: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
- **Temperature transmitters**- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
- **Analytical Instrumentation**: Conductivity, pH, ORP and Turbidity measurement.
- **Other Measurements**: Relative humidity; viscosity and density measurement
- **Control valves:** Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
- **Instrument Impulse lines and instrument fittings**: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
- **P & I Diagrams, loop and hook up diagrams:** P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

EN 608 Civil Engineering Design of Concrete and Steel Structures

EN 608.1Civil Engineering Design of Concrete and Steel Structures-I (30)

Introduction to various structures of nuclear facilities Classification of structure and design basis

Radiation protection objectives, defense in depth, safety functions, safety classification, seismicclassification, quality classification, design classification, design for natural and man induced events.

Design Loads:
- Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
- Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
- Severe Environmental Loads: operating basis earthquake,severe windincluding gust effect and aerodynamic instability, design basis flood load,tsunami.
- Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind- induced missile

Design of RC structures:
- DesignofRC structures as per IS456,AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 ,designloadcombinations,design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies

Design for shrinkage, creep & heat of hydration:

Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies..

Foundation design
- Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
- Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
- Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

EN 608.2 Civil Engineering Design of Concrete and Steel Structures-II (30)

Introduction to Prestressed Concrete structures

Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.

Design of lined and unlined containment structures

Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.

Design of steel structures of nuclear facility

Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections,design of embedded parts and anchor boltsas per AERB and ACI standards, case studies.

Design of water-retaining structures

Design of overhead and underground tanksusingun-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.

Design of cooling towers

Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

References

1. IS 456 (2000) "Plain and Reinforced Concrete – Code of Practice ".
2. ACI 318 (2014) "Building code requirements for structural concrete".
3. ACI 349 (2013) "Code requirements for Nuclear Safety related concrete structures".
4. RCC-G "Code of Practice for Design of Prestressed Nuclear Containment Structures". 5. ISO 14000
6. Raju, N. K. (2006), "Prestressed concrete", Tata McGraw-Hill Education.
7. ACI 207 (1995) "Effect of restraint, volume change and reinforcement on cracking of massive structures".
8. Bowles, J. E. (2001) "Foundation analysis and design", Tata McGraw-Hill Education.
9. Rao, N.S.V.K. (1988),"Vibration analysis & foundations dynamics", Wheeler publishing.
10. IS 2974-1, 1984,"Code of practice for design and construction of machine foundations".
11. Arya, S.C., Oneill, M.W. and Pincus, G. (1979), "Design of structures and foundations for vibrating machines", Gulf Publishing Co.
12. Manohar, S. N. (1984) "Tall Chimneys design and construction", Mcgraw-Hill Book Comp.
13. ANSI/AISC N690 (1984), American and National Standard – Nuclear facilities, "Steel safety related structures for design fabrication and erection".

EN 609 Earthquake Engineering and Structural Dynamics(45)

Introduction to Seismology
- Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA),Design Basis Earthquake,Concept of

Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra
- Seismic instrumentation for micro-earthquake and strong motions.

Structural Dynamics
- Introduction to dynamic loading, different types of dynamic loadings, concept of damping,derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
- Single degree of freedom of system (SDOF)–undamped& damped system, free & forced vibration; Response to harmonic and impulse loading,concept of transmissibility and vibration isolation,estimation of damping of structural system using free & forced vibration approach;response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
- Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
- Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies)& eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
- Introduction to dynamics of continuous system

Seismic Response Analysis of Structures
- Seismic response analysis using response spectrum and time history approach
- Modal superposition method, Modal combinations and spatial combinations, missing mass correction
- Time history analysis using direct time integration,
- Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction

Random vibrations
- Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.

Special Seismic Design Considerations

Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain, curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures;Seismic Design Optimization, Principles of performance based design, dynamic response control techniques such as base isolation, dampers etc.

Seismic Requalification of Existing Installations

Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection, review basis ground motion, evaluation of seismic margin capacity, retrofitting.

Case Studies

Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear installments.

References

1. Chopra, A.K. (2007), "Dynamics of structures: Theory and application to earthquake engineering", Prentice Hall.
2. Clough, R. W. and Penzien, J. (1993). "Dynamics of structures", McGraw Hill, Inc.
3. Mario Paz and William Leigh (2006), "Structural Dynamics-Theory and Computation", Springer.
4. Thompson, W. T. (1972),"Theory of Vibrations with Applications" Prentice-Hall, Englewood Cliffs.
5. ASCE 4-98 (1998), "Seismic Analysis of Safety related Nuclear Structures and Commentary on standard for seismic analysis of safety related nuclear structures".
6. AERB/SG/S-11, "Seismic Studies and Design Basis Ground Motion for NPP Sites".
7. IAEA SAFETY STANDARDS SERIES No. NS-G-3.3 (2002), "Evaluation of Seismic Hazards For Nuclear Power Plants".
8. IS 1893-1 (2002), "Criteria for Earthquake Resistant Design of Structures".
9. IS 13920 (1993),"Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces".
10. Dowrick D.J., "Earthquake Resistant Design"
11. Park and Pauley, "Reinforced Concrete Structures"
12. Pankaj Agrawal, Manish Shrikhande, (2006), Earthquake Resistant Design Of Structures
13. AERB monograph, (2008), SEISMIC SAFETY OF NUCLEAR POWER PLANTS

EN 610: Code Design for PVP (60)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin- walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
- Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material

and allowable stresses. Design of saddle supports.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 and Div.2.
- Difference between metallic pressure vessel and FRP pressure vessels

Nuclear Pressure Vessels and Piping (30)
- Monotonic and Cyclic Stress-Strain Curve, Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Failure modes of pressure vessels, Ratchetting and shakedown.
- Organization of Boiler and Pressure vessel Sec. Ill code. Safety classification and Criterion for selection of ASME sec. Ill classes. Design loadings and service loadings as per NCA 2140.
- Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Definition of B, C and K stress indices.
- Design of Nuclear piping as per Sec. Ill div.1. Design rules for standard support as per NF 3400, Design rule for piping support - NF 3600.
- ASME code rule for component support
- Design rule for Plate and shell- Type support as per NF 3200, Design rule for Linear-type support - NF 3300.
- Design rule for component support - NF 3500, Core support structure Design - NG 3300.
- Fracture Toughness requirements for materials for pressure vessels, pipings and boltings.
- Failure Analysis Diagram.
- Protection against Nonductile Failure - Appendix G, Basis of Low Cycle fatigue Design. Fatigue evaluation of vessels.
- Strain concentration factor ' Ke', Local strain approach: Neubar and Zarka rule, Elastic and elastic-plastic fatigue analysis of nuclear pipings, Leak-Before-Break Design Concept.
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec. Ill.
- NDE requirements, Examination of welds, Acceptance standard.

References:

1. Harvey J.F., “Pressure Vessel Design”, CBS Publication
2. Brownell L.E., and Young E.D., “Process Equipment Design” Wiley Eastern Ltd., India
3. ASME” Pressure Vessel and BoilerCode”, Sec. VIII, Div. I and Div. II, 1985
4. American StandardCode for Pressure Piping”, - B31.1, 1972
5. American Standard Code for Pressure Piping”, - Petroleum, Refinery Piping, B31.3, 1972
6. “Standard of Tubular Exchanger Manufactures Association”, 7th Edition, 1988.

EN 611: Computational Fluid Dynamics & Heat Transfer (50)

Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):
- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme
- Laminar Boundary Layer and Forced Convective Heat (5):
- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
- Convective heat transfer for internal and external flows
- Low and high Prandtl number limits and different thermal boundary conditions
- Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer (5):
- Reynolds decomposition for turbulence
- Prandtl's mixing length theory, Mixing length models
- Structure of turbulent boundary layer over flat plate and through circular cylinder
- Calculation of friction factor and drag coefficient
- Analytical and semi-analytical correlations for calculating heat transfer coefficients
- Analogy between heat and momentum transfer

- Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
- Turbulence Modeling:
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
- Reynolds stress models: algebraic and differential models
- Low Reynolds number models
- Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
- **Natural Convection (3):**
- Basic Equations of natural convection
- Boussinesq approximation
- Derivation of Dimensionless groups from basic equations
- Analytical approximations
- Numerical solution of approximate equations

Numerical Solution of Complete Fluid Flow and Energy Equation (10):

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation
- Streamfunction-vorticity-temperature formulation
- Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
- Primitive-Variable (P-V-T) formulation
- Pressure velocity coupling for incompressible flow:
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
- Simple grid generation techniques for structured grid:
- Elliptic, parabolic and hyperbolic equation method
- Grid adaptation
- Domain decompositions in CFD and heat transfer
- SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer (12):

- Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
- Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.
- Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
- low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
- Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
- Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.
- **Heat Transfer With Phase Change (10):**
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
- Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model)
- Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)
- Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
- Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
- Critical Flow: Models for single – phase and two-phase critical flow.

References for CFD:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.

14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor &Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

EN 612: Computer Based System Design- I (25)

Hardware Design

- Overview of microprocessors and peripherals: 8086, 68000, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications
- Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL)
- Case Study: Design of a single board computer with shared memory interface, I/O board design using ADC, DAC etc with emphasis on signal conditioning and isolation
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues

EN 613: Computer Graphics and Visualization (35)

- Introduction overview, Graphics software/hardware and types of graphics applications (1)
- 2D/3D Geometric Transformations, Affined transformations-Translation, Rotation, Scaling, Shear and reflection. (3)
- Homogeneous coordinates, composite transformations, rotation with qutenion, current transformations and matrix stacks. (3)
- Two dimensional viewing 2D viewing – window, viewport, viewport transformations, clipping operations, line clipping algorithms – Cohen-Sutherland, Liang-Barsky, polygon clippimg algorithm – Sutherland-Hodgman. (4)
- Three dimensional graphics – Planer geometric projections – parallel and perspective, Mathematics for projections, classical three-dimensional viewing, specifying views, viewing transformations, 3D clipping operations. (4)
- Hidden surface removal, object space and image space approach, back face culling, z-buffer algorithm, LOD.(2)
- Illumination and shading – Basic illumination models, light sources, material properties, polygon shading methods – flat, gouraud and phong shading, ray tracing methods. (2)
- Color - Color perception, color models – RGB,CMY,HSV (1)
- Visual Realism – Depth cuing, texture mapping, transparency, shadow, steropsis. (2)
- Curves and surfaces – Representation of curves and surfaces, Algebric and geometric form, Blending functions, interpolation, Hermite, Bezier, B-spline curves and surfaces, Rational polynomials, NURBS (5)
- Modern Graphics Architecture – Graphics Pipeline, GPU, PCI Express (2)
- Case Study – Using OpenGL (3)
- Scientific Visualization – Introduction, Geometry (Structured & Unstructured Grids), Data Representation (Scalar, Vectors), Volume Rendering (Marching Cubes, Ray Casting) (3)

EN 614 Construction Materials, Management and Quality Assurance (30)

Construction Materials

- Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
- Reinforcement: Passive and active (Prestressing)
- Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
- Paints
- Water-proofing materials & membranes

Shuttering/Formwork

Design philosophy, different design requirements, climbing shutter design, slip form work.

Prestressing system

Cable ducts, anchorage and grouting, qualification of Prestressing system

Quality Assurance (QA)

- QA in Civil Engineering design
- QA in materials
- QA in construction
- QA in operation & maintenance
- Inspection during construction, Regulatory inspection

Construction Procedure & Construction Safety

- Dewatering, rock excavation, consolidation grouting

- Construction safety, Job Hazard Analysis.

Contract Management

Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication

References:

1. Singh, K. A. N."ISO 9000-Quality Systems", Dolphin books, New Delhi.
2. Quality systems requirements (QS 9000) – Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 3rd edition
3. Quality system assessment (QSA) Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 2nd edition
4. CPWD Works Manual (2012), Central Public Works Department, Government of India, Published by DIRECTOR GENERAL, CPWD, NIRMAN BHAWAN, NEW DELHI-110 011.
5. Manual of Internal Inspection/DAE Works Procedure (2010), Department of Atomic Energy, Government of India.
6. ATOMIC ENERGY (FACTORIES) RULES (1996), Atomic Energy Regulatory Board, Government of India.

EN 615: Corrosion (15)

- Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables, composition and heat treatment. (3 Lectures)
- Forms of corrosion: uniform attack; corrosion rate measurements, Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion, low temperature sensitization, corrosion of weldments; stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen embrittlement, hydrogen attack, corrosion fatigue; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, failure analysis, specification tests, advanced methods for on-line corrosion monitoring. (7 Lectures)
- General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification. (1 Lecture)
- Corrosion in the nuclear industry – Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. corrosion in fluoride and ammonia containing environments; liquid metal corrosion. low alloy steels, stainless steels and Ni and Cu base alloys, protective magnetite formation on carbon steel, stress corrosion cracking of stainless steels and nickel base alloys. high temperature oxidation and hydriding of zirconium alloys, materials for fast breeder reactor system. Effects of radiation on corrosion (4 Lectures).

References:

1. Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. Corrosion – L.L. Shrier (Ed.) Vol.I & II, 1963.
5. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
6. Modern Electrochemistry, Vol. 1 & 2 – J. O.M. Bockris and A.K. Reddy
7. Corrosion of Stainless Steels – A.J. Sedricks.
8. Stress Corrosion Cracking – Materials Performance and Evaluation – Ed. Russel H. Jones, ASM Int., 1993
9. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN 616: Distributed Computing (45)

Advanced Computer Architecture

- Advances in CPU Architecture
  a. Advancements in CPU architecture – Dynamic Instruction level parallelism, Branch prediction, register renaming
  b. Static instruction level parallelism - EPIC, VLIW
  c. Hyperthreading
- Multi core architectureAdvances in Memory
  a. SDRAM, DDR, DDR-2
  b. Registered ECC, FB-DIMM
  c. CPU – Memory Interfacing techniques - FSB, Hypertransport, Quickpath
- Advances in I/O interfaces
  a. Shared I/O bus
  b. Switched I/O fabric
  c. Serial and parallel I/O bus
  d. Case studies - PCI, PCI-X, PCI-Express, PCI-Express Gen2
- Advances in Interconnect techniques
  a. Shared and switched networks
  b. Interconnect fabrics

  c. Approaches for improving interconnect performance
  d. Case studies – Ethernet, Infiniband, SCI
- Cache
  a. Associative, Direct mapped
  b. Write through, Write back
  c. MESI
  d. Shared caches
- Advances in storage systems
  a. Direct attached storage, Network attached storage, Storage Area Networks
  b. File level and block level accesses
  c. Storage protocols
  d. Case studies - ATA, SATA, SCSI, SAS, Fiber channel
  e. Case studies - FC, iSCSI, iSER, SRP

Parallel Computing

- Introduction to High Performance Computing
  a. Need for HPC
  b. Applications of HPC
  c. HPC Overview – Conventional Supercomputers, Parallel Computers, Classification (SISD, SIMD, MIMD)
- Pipelining, Vector processing, SIMD
  a. Pipeline, Speedup and Efficiency of pipeline
  b. Pipeline stalls, out of order execution
  c. Techniques to improve pipeline efficiency
  d. Superscalar, Superpipelined, VLIW, EPIC architecture
  e. Vector processors, vector instruction sets, registers
- MIMD Architecture
  a. Classification of MIMD machines
  b. UMA, NUMA, CC-NUMA, COMA, NORMA
- Interconnection networks and topologies
  a. Interconnection Concepts – Bandwidth, Latency, Network Diameter, Bisection Width, Node degree, Static and Dynamic Networks
  b. Various topologies – Ring, Hypercube, Torus, Mesh, CLOS, Fat tree etc.
- Current Parallel Architectures
  a. Parallel Vector processor
  b. Symmetric Multiprocessors
  c. CC-NUMA
  d. Massively Parallel Computers
  e. Clusters of workstations
- Clusters
  a. Classification of clusters
  b. Cluster software
  c. File systems for clusters
- Software concepts of High Performance Computing
  a. Parallelism – Algorithmic, Geometric, Event, Data
  b. Granularity – Coarse and Fine grains
  c. Speedup, Efficiency, Amdahl's and Gustaffson's Laws
- Parallel Programming Models
  a. Shared Variable Model
  b. Message Passing Model
  c. Threads Model
  d. Data parallel Model
- Design of parallel algorithms
  a. Data dependencies
  b. Data partitioning
  c. Communication patterns
  d. Synchronization
  e. Load balancing
- Parallel Programming Environments
  a. Parallel Languages
  b. Parallel Extensions to Sequential Languages
  c. Parallel APIs – MPI, OpenMP
- Parallelization of example programs – Dot product, Matrix Multiply, etc. at the pseudo code level
- Message Passing Interface (MPI)
  a. Introduction to MPI
  b. MPI constructs
  c. Example programs in MPI
- Benchmarking
- Case studies – ANUPAM series of parallel computers

Grid Computing

- Introduction to Grid Computing
  a. Evolution of Grid Technology comparison with contemporary technologies,
  b. Issues of virtualization, events that have lead to grid computing, client-server, peer-peer, operating system perspective,
  c. Overview of Grids: Formal definition of Grids - how do they work?
  d. How are they different from clusters? Computational Grids, Data Grids, Production Grids worldwide - Applications of Grid.
- Components of Grid
  a. Grid Security- concepts of single sign on, How the security requirements are met?
  b. Concept of Digital certificate- How RSA works? - Working of Kerberos
  c. Concepts of Myproxy services
- Grid Resource management
  a. Issues in Grid Resource management
  b. Abstract model for Grid Resource Management
- Grid Scheduling
  a. Issues in Grid Scheduling
  b. Taxonomy Of Grid Schedulers
  c. Resource Discovery issues
- Visualization and interactivity in Grids, High Performance Computing in Grids- Grid enabled MPI – MPI-G2
- Grids Services
  a. How are they different from Web services?
  b. Concepts and their implementation
- Data Management in Grids
- Information services- Building information services in Grids
- Grid Portals, Their Purpose, Issues in Portal design, discussion on portlets
- Grid Workflow
  a. Concepts
  b. Taxonomy of Grid Workflow
- Semantic Grids
- Virtualization
  a. Concept
  b. Its utility in Grid Computing
- Grid Enabling Applications
  a. Issues
  b. Implementations
- Discussion about GRID standards
  a. OGSA
  b. OGSA-DAI
- Comparative study of different Grid Middlewares
  a. Lacuna in current Grid Architectures
  b. Grid as operating system of operating systems
- Case study of Middlewares:
  a. GT4,
  b. Glite
  c. DAE Grid
- Future of Grids - Concepts of Cloud Computing

References

1. Advanced Computer Architecture, Kai Hwang
2. Scalable Parallel Computing, Kai Hwang, Zhiwei Xu
3. Introduction to Parallel Computing, Ananth Grama, George Karypis, Vipin Kumar and Anshul Gupta
4. High Performance Computing – Paradigm and Infrastructure, Laurence T.Yang, Minyi Guo
5. Storage Networks Explained, Ulf Troppens, Rainer Erkens, Wolfgang Muller
6. Computer Organization and Architecture: Designing for Performance, William Stallings
7. Grid Computing – Making the Global Infrastructure a Reality, Fran Berman, Geoffery Fox, Anthony J. Hey
8. The Grid2 Blueprint for a new Computing Infrastructure, Ian Foster, Carl Kesselman
9. Grid Computing for developers, Silva
10. Current Journal Articles in the area of Parallel Computing, Computer Architecture and Grid Computing

~~**EN 617**~~

EN 618: Electrical Systems for Nuclear Power Plants (30)

- Interaction of Nuclear Power Station With The Grid Number of evacuation lines; Optimum size of NPP in grid; Brief introduction to Power System Analysis - Short circuit, load-flow and stability studies, Tariff and Capacity factor.
- Ehv Switchyard Design Switching schemes; Clearances; Com parison between types of svvitchyards; Brief introduction to equipments in switchyard and their functions; Lightning arresters and insulation co-ordination; Lightning protection.

- Protection Line protection; Generator protection; Transformer protection; Motor protection.
- Selection of Transformers Accessories; Types; Specifications and testing; Voltage regulation calculations.
- Selection of MV & LV Switchgear Types; specifications and testing, MCCS; Distribution boards; Generator circuit breaker; ELCB.
- Motors In NPP Types of motors; Radiation withstand requirements; Performance requirements.
- Station Auxiliary Systems of NPP Class 1, 11, Ill and IV systems classifications; Nature of electrical loads and supply voltages; Effect of voltage variation on Electrical equipments and remedial measures; Emergency transfer system; Load shedding scheme; Auto transfer schemes; synchronizing schemes.
- Class 1 e requirements Cabling, lighting & grounding Specific requirements for safety related electrical equipments & systems in NPR Cabling, Lighting, Grounding systems in NPP; Bus ducts. Introduction to seismic qualification of electrical equipments., Electrical system control from Control Room. Introduction to []G sets, UPS & Batteries.
- Billing and metering scheme for a typical NPP. Introduction to brushiess and static excitation systems for Generators. Introduction to SCADA systems.

References:

1. Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity :.CBProblems and Remedial Measures. IAEA Report - Technical Reports Series No. 271.
2. Elements of Power System Analysis - W.D. Stevenson
3. Electrical Transmission & Distribution Hand Book - Westinghouse Electrical Co., USA
4. Protective Relays - Application Guide, GEC Measurements.
5. Manual on Layout of Substations - CBIP, New Delhi
6. The J & P - Transformer Book
7. The J & P - Switchgear Book
8. Utilization of Electrical Energy - E. Openshaw Taylor
9. Cabling - Siemens Hand Book
10. Illumination Engineering Society - IES Lighting Hand Book
11. Modern Power Station Practice - Volume D - Electrical System & Equipment, British Electrical International.
12. Standard Hand Book for Electrical Engineers - Donald G. Fink and H. Wayne Beaty
13. IEEE-80 - IEEE Guide for Safety in AC Substation Grounding
14. IEEE-308 - Criteria for class 1E Equipments for Nuclear Power Generating Stations
15. IEEE-323 - Qualifying class 1E Equipments for Nuclear Power Generating Stations
16. Indian Nuclear Power Programme with PHWR - Published by Directorate of E & P A, NPCIL, Bombay
17. IS-3716 - Application Guide for Insulation Coordination
18. IS-2309 - Code of Practice for the Protection of Buildings and Allied Structures Against Lightning
19. Handbook of Batteries and Fuel Cells - McGraw Hill Book Company

EN 619: Embedded & Computer Based System Design (45)

Module I [22]

Part A - Microprocessor based Design [10]

- 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
- Introduction to Microcontrollers and comparison with Microprocessors
- Introduction to DSP Processors

Part B [12]

- ARM processor: architecture details and introduction to programming
- Board level buses: I2C and SPI
- Introduction to USB

Module II [23]

Part A – Computer based hardware design [8]

- Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
- Industry standard bus systems: ISA, PCI, VME: Mechanical, electrical, functional and procedural specifications
- Multi processing, bus arbitration and Plug and Play
- System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
- Design Case Study:
- I/O Board design, bus interface (ISA, PCI) FIFO and shared memory interfaces.

Part B - Computer Communication and Networks [7]

- Overview of asynchronous and synchronous communication standards
- Encoding (NRZ, Manchester),
- Ethernet, Industrial networks, Field Bus, CAN bus
- Networking hardware: Cables, Hubs, switch and routers.

Part C - Software development for embedded and PC based systems (8)

- Basic RTOS concepts
- C programming for ARM based applications
- Programming for PC based systems:
  - Interface between applications & device drivers
  - Windows: Programming of I/O, ISR, DMA

References:

1. Computer Networks. By: A.Tanenbaum

2. Principles of Communication. By: Taub and Schilling.
3. Microprocessors and Interfacing. By: D.V.Hall
4. CAN Application Note: Robert Bosch GmBH
5. Microcomputer System 8086/8088 family- Architecture, Programming and Design.
Yi -Cheng Liu & Glenn.A.Gibson.
6. The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486 and Pentium series: Architecture, Programming and Interfacing. By: Barry.B.Brey.
7. The Scientist and Engineer's guide to DSP. By: Steven.W.Smith
8. High speed digital design: A handbook of black magic. By: Howard Johnson & Martin Graham
9. Interference control in computer and microprocessor based equipment. By: Michel Mardiguian
10. Interfacing to the IBM Personal Computer. By: Lewis C. Eggebrecht
11. PCI bus system architecture – Mindshare publication
12. VME bus standard document
13. USB complete. By: Jan Axelson
14. ARM System Developer's Guide. By: Andrew Sloss, Dominic Symes, Chris Wright
15. Designing Embedded Hardware. By: John Catsoulis

EN 620: Extractive Metallurgy (40)

Principles of Metallurgical Thermodynamics (15)

- Thermodynamic Functions: Enthalpy, Entropy, Free Energy, Chemical Equilibria
- Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Phase Diagrams
- Solution Thermodynamics, Integral and Partial Molar Thermodynamic Properties
- Experimental Methods- Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.
- Computation of predominance area diagram and Phase diagrams

Kinetics(5)

- Principles of Chemical Kinetics, Homogeneous Reactions, Effect of Concentration, Effect of Temperature
- Theory of Reaction Rates, Heterogeneous Reactions, Reaction Models, Mass Transport Phenomena, Heat Transport Phenomena.

Process Metallurgy (25)

- Methods of attaining High Temperatures,Measurement of Temperature,
- Vacuum Metallurgy Principles and Equipments,
- Process Metallurgy of Rare and Refractory Metals,
- Resources of Special Metals, Beneficiation Methods, Physical, Chemical, Separation Methods, Halide Metallurgy, Vacuum Metallurgy, Electro Metallurgy, Reduction Processes, Refining Processes, Ultrapurification Processes,
- Preparative aspects of Special Materials and Alloys,
- Advanced Materials Processing Techniques,
- Reprocessing of irradiated nuclear fuels, Process Metallurgy of - Uranium, Thorium, Plutonium, Beryllium, Zirconium, Hafnium, Niobium, Tantalum, Rare Earths.

EN 621: Finite Element Techniques (35)

- **Introduction to FEM:** Weighted residual method, Galerkin's methods, Weak form formulation, Piecewise approximations. Basis of Finite Element Method, Variational principles, energy principles in structural mechanics, Element libraries 5
- **Element shape functions**: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements. 15
- **Bar element:** Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss
- **Beam element:** Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- **2D plane elements** – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- **2D isoparametric formulation** – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature.
- **Incompatible displacement model**: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements.
- **Introduction and Application to 3D elements:** Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Plate bending elements: Thin and Thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration

- **Shell element**: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking.
- **Introduction to Nonlinear problems:** Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method
- **Finite element applications for design**:Finite element modelling and discretization criterion, h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

References:

1. **Bathe K.J., Finite elemen**t procedures in engineering Analysis, Prentice Hall of India, 1990
2. Cook R.D., D.S. Malkus and M.E. Plesha, Concepts and Applications of finite element analysis, John Wiley, 2000.
3. Reddy J.N., An Introductions to Finite Element Method, 4th Edition, McGraw Hill, 1993.
4. Seshu P., Finite Element Method, Prentice Hall of India, New Delhi, Fourth printing, 2006.
5. Zeinkiewicz, O.C., and K. Morgan, Finite elements and approximation, John Wiley, 1983.
6. Zeinkiewicz, O.C., and R.L. Taylor, The Finite Element Method, Vol. 1 & 2, Tata McGraw Hill.
7. M. Asghar Bhatti, Advanced Topics in Finite Element analysis of Structures, John Wiley, 2006.

EN 622: Fracture Mechanics (40)

Linear Elastic Fracture Mechanics (5)

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks and concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture
- Superposition of K
- Plastic zone correction - Irwin's approach
- Basic design principles in LEFM
- **Plane stress vs. plane strain - Variation of toughness (KIc and Kc)**

Elastic-plastic Fracture Mechanics (5)

- J-integral as energy release rate
- J-integral as amplitude of HRR singularity
- J-integral as contour integral
- Laboratory measurement of J-integral - η factor approach
- Fracture resistance of materials – J-R curve and JIc and possible explanation for shape of J-R curve
- Stable and unstable crack growth – Tearing Modulus approach
- J-controlled fracture
- Basic design principles in EPFM
- **J-estimation schemes**

Laboratory measurements of material fracture properties (2)

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- KIc testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of JIc from J-R curve – blunting line equation and SZW

Limit load (2)

- Definitions of limit load
- Global and local limit load
- Basic expressions of limit load of some common geometries

R6 method (2)

- Basic principles of R6 method
- Sensitivity analysis

Fatigue (7)

- Conventional high and low cycle fatigue – S-N diagram, Coffin-mansion relation
- Fatigue crack growth under constant and variable amplitude loading
- Rainflow algorithm
- Environmental effects on fatigue crack growth
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- **Experimental determination of Paris law constants as per ASTM procedure Fracture assessments of welds (2)**
- Basic aspects of fracture assessment of welds – residual stress effect
- Special considerations in fracture toughness determination of welds

PTS and ASME reference/Master curve (6)

- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Warm pre-stress effect

- Reference ASME curve in assessment of PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Computational Fracture Mechanics(4)
- Barsoum's crack tip element and showing the singularity from shape function
- Evaluation of SIF by displacement correlation technique from FEM
- Evaluation of 2-D J-integral by contour integral technique
- Evaluation of 3-D J-integral by domain integral technique

Fracture Mechanism (4)
- Basic mechanism of ductile fracture – Void nucleation, void growth and coalescence
- Cleavage fracture- Mechanism of cleavage initiation
- Mathematical model of cleavage fracture toughness, explanation for scatter in cleavage fracture toughness, RKR model

Application of Fracture Mechanics Principles to Leak-Before-Break (1)
- History of LBB
- Basic concepts of LBB – three levels
- Application to Indian reactors

EN 623: Mechanical Metallurgy (30)

Elasticity and Plasticity
- Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
- Equations of equilibrium.
- Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria

Dislocations:
- Elastic stress field of edge and screw dislocation.
- Self energy of dislocations.
- Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP

Deformation Behaviour
- Single crystal deformation, critical resolved shear stress, Schmidt's factor, Thermally activated deformation, Strengthening mechanisms.

Creep of Metals and alloys
- Various stages of creep and creep laws
- Types of creep tests, evaluation of parameters of a creep test and its use
- Factors influencing creep resistance
- Deformation mechanism map and identification of creep mechanisms, Irradiation creep

Fracture Mechanics
- Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
- Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
- Concepts of R-curves, Evaluation of various fracture parameters, fracture control

Fatigue of Metals:
- High cycle and low cycle fatigue
- Factors contributing to fatigue failure and its mitigation
- Various stages of fatigue damage and Fatigue life improvement
- Fracture mechanics approach to characterize crack growth behavior

References:
1. Engineering Fracture Mechanics - S. A. Meguid.
2. Mechanical Metallurgy - G. E. Dieter
3. Mechanical Behaviour of Materials - T. H. Courtney
4. Elementary Dislocation Theory - J. Weertman & J. R. Weertman
5. Introduction to Dislocations - D. Hull
6. Mechanical Metallurgy : Principles and Applications - M. A. Meyers & K. K. Chawla
7. Deformation and Fracture Mechanics of Engineering Materials - R. W. Hertzberg

EN 624: Mechanics of Solids (40)

Introduction to Theory of Elasticity Mathematical Frame Work (2)
- Illustration of concepts of elasticity, Stress-strain curve, Isotropy, Homogeneity
- Illustration of equilibrium equation, Cauchy equation and stress strain relation in 1-D
- Solution of 1-D boundary value problems using theory of elasticity equations: (a) Natural frequency determination. (b) Solution under external excitation force to show resonance condition, stress wave etc.
- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Kronecker Delta, Permutation symbol ; Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of Stress (3)
- Description / Notations of Forces
- Description / Notations of Stress
- Component of stress
- Reciprocity of shear stress in 3D

- Stresses Transformation using direction cosines
- Stress Traction Vectors or Traction Vectors
- Stress component on an arbitrary plane
- Principal stresses
- Stress Invariants
- Mohr's Diagram for 3D state of stress
- Hydrostatic and Deviator components of stress
- Principle planes and their orthogonally
- Octahedral plane, Octahedral stresses
- State of pure shear

Analysis of Strain (2)

- Description / Notation of Strain in 3D
- Components of strain
- Strain Transformation using direction cosines
- Principle Strains, Strain Invariants
- Cubical Dilation
- Strain Deviator Tensor
- Maximum and Octahedral Shear Strains

Principles and Fundamental Equations of Elasticity (8)

- Strain and displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Stress and strain relationship
- Equations of equilibrium (Navier's Equations , Lame's equations)
- Strain Energy
- Uniqueness theorem
- Bounds on elastic constants
- Superposition Principles
- Saint-Venant's Principle
- General Solution Procedures for a elasticity problem

Two and Three Dimensional Formulation (8)

- Elasticity equation for Plane strain
- Elasticity equation for Plane stress
- Biharmonic equations
- Airy's Stress Functions
- Solution for beam bending problems
  a) Special cases by use of polynomials
  b) General solutions using fourier series method
- Solution in polar co-ordinates
  a) Tube subjected to internal and external pressure (Lame's problem) ; shrink fit
  b) Stress Concentration due to a circular hole in stressed plate (Kirsch's problem)
- Stress in spherical shell under internal and external pressure

Thermal Stresses (4)

- Thermal stress definition and their significance
- Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
- 2D thermal stress analysis
  a) The problem of circular disk
  b) The problem of circular cylinder
- 3D thermal stress analysis : The problem of sphere
- Transient thermal stress

Introduction to Plasticity (4)

- Stress-strain curve, Examples of Multiracial stress
- Different Yielding Criteria and their significance
- Yield Surface , Tresca and von-Mises
- Path dependence of Plastic Strains
- Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
- Prandtl-Reuss Equations
- Incremental or flow theory
- Deformation theory of plasticity, Hencky equations
- Plasticity Relations (plastic strain and total strain)

Theory of Plates

- Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
- Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.

- Introduction to analysis of Thick Plates

Theory of Shells

- Introduction to shell theory.
- Classification of shells, Membrane theory of shells of revolution and translation.
- Application to spherical, conical and cylindrical shells.
- Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
- Application to cylindrical shells, spherical and conical shells.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Piblications, Inc.
6. Plasticity Theory and Application, Alexander Mendalson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K .Chandrasekhara, University Press
9. Stresses in shell- W.Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN 625: Modern Control Systems Design and Simulation (35)

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analyti- cal methods of modeling.
- State Space Characterization State 5PaCe representation, solution of state equation, state Transition matrix, properties of STM, computation methods, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kaiman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Control- lability and observability of Discrete data systems.
- Stability liapunov,s stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design Guillemin-Truxal design Procedure, pole placement by state feedback. H,' meth- od, Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kaiman filter as OPtimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency re- sponse methods, Recurise Least square Identification technique.
- Introduction to Adaptive and Robust control.

References:

(Reference materials will be provided during the course)

EN 626 Design Basis Hazards and Geotechnical Engineering (40)

<u>Design Basis Hazards (Natural)</u>

Role of civil engineering in achieving overall nuclear safety: Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.

Introduction to hazard evaluation:

Hazard due to internal and external events, case studies.

Seismic Hazard

Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum

Flood hazard

- Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
- Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
- Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding

Wind hazard

Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India,Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.),

Solar radiation

Temperature map(Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)

Snow hazard

Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides

Design Basis Hazards (Human-Induced)

Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)

Geotechnical Engineering

Soil Mechanics

- Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
- Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
- Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability; Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.
- Bearing capacity – Determination of bearing capacity for soils and Rock.

Geotechnical and Geophysical investigations:

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

Soil Dynamics and Liquefaction

Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

References:

1. Kramer . S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. **IS** 875(Part 3) (1987) " Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. **IS** 875(Part 4) (1987) " Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance"
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – "Basic and applied soil mechanics".
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities'
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN 627: Networking and Information Security (40)

Networking

General Issues in the transport of data traffic over networks of digital transmission media.

- V.24, V.35, Modems, xDSL, Multiplexing

Circuit switching & Packet switching

- ISDN (BRI), PRI.

Datalink Layer

- Data link layer protocols, Medium access method, Flow control, Error Control
- Ethernet technologies, Bridge, Switching, Analysis of collision domain, Layer 2-based network attacks

Introduction to Satellite communication

- Satellite orbits, VSATs, VSAT network Topologies

Network Layer

- IP, IP Fragmentation, ARP, DHCP, Classes of IP address, CIDR, Layer 3 based network attacks, ICMP
- IP Routing algorithms, RIP, OSPF, BGP.

Transport Layer

- TCP & UDP, TCP Call establishment & Call termination, Sockets, TCP state machine, TCP timers
- RTP, Layer 4 based network attacks

Firewall
- Layer 3 firewall, Layer 4 firewall, Application based firewall

Network Applications
- FTP, DNS, Mail, application based attacks

Network Security
- Data security, type of possible attacks on data etc?
- Ecurity services for secure data communication?
- Like Identification, Authentication, Authorization, Data Integrity, Confidentiality, Non-repudiation, Replay, Availability etc.
- Cryptography and its services Cryptology, cryptanalysis.
- Components of cryptology like algorithms, Keys, Message Digest, Digital signature, Digital Certificates etc. with block diagram.

Types of Algorithms
- Symmetric and Asymmetric.

Symmetric Algorithm
- stream cipher algorithms
- Type of stream ciphers, Unconditional security with stream ciphers, one time pad, LFSRs, Linear complexity in LFSRs, Shanon's concept of perfect secrecy
- Type of possible attacks, Conversion of block ciphers onto stream ciphers etc.

Asymmetric Algorithms
- Diffie-Hellman, RSA with detail mathematics and applications.
- Key management methods for symmetric and asymmetric keys.
- PKI infrastructure, Digital certificates, digital signatures for asymmetric key managements. CRL (certification revocation list)
- Symmetric key certificates. Difference between symmetric and asymmetric key certificates etc.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN 628: Nuclear Chemical Engineering (35)

Intoduction

Role of chemical engineering in the nuclear industry

Recovery & processing of nuclear materials from ores / intermediates (5)
- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources , New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths : Occurrence, importance and separation.

Uranium Conversion / reconversion (6)
- Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF6: choice and problems, Fluorination of UF4, Purification and collection process for UF6, Conversion to UO2.

Isotope Separation (9)
- Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical- exchange: H2S-H20, NH3-H2, monothermal and bithermal process, salient features of equipment like contacting towers, tower internals. Heavy water plants in India. Final enrichment and upgradation plants. Distillation and electrolysis, Tritium removal.
- Laser based separation and new processes (2)
- A brief description of laser based isotopic separation processes.
- Fuel Reprocessing (6)
- Fuel Reprocessing: Introduction to Radiochemistry; Differences between a conventional chemical plant and radio chemical plant- Process and equipment limitations, criticality, safety and other hazards, numerical examples, ventilation, shielding, Typical compositions and burn-up of irradiated nuclear fuels.
- Thermal Reactor Fuel Reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements. Evolution of solvent extraction process fore reprocessing, 'PUREX' and 'THOREX' processes in detail; Head-end process, flow sheet, co-decontamination and partitioning cycles.
- Fast Reactor Fuel Reprocessing and Introduction to reprocessing of Thorium based fuels.

Nuclear Waste Management (7)

- Sources, characteristics and classification of radioactive wastes; general philosophies of management.
- Method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Discussion of the various chemical engineering operations involved. Use of desalination and membrane separation techniques in waste management.
- Conditioning of radioactive waste- cementation, bituminisation, use of polymers and vitrification methods.
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical Engineering in Decommissioning of nuclear facilities.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series,IAEA,Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)

EN 629: Nuclear Materials (50)

Melting & Casting (10)

- Introduction to vacuum measurement units and types of vacuum pumpsincluding diffusion pump & turbo- molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and methods to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits

Mechanical working of Metals (10)

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Methods of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Powder Metallurgy & Advanced Ceramics (30)

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production methods, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.
- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. "Introduction to Ceramics" by Kingery et al.
11. "Ceramics Through Chemistry" by Brinker et al.
12. "Electroceramics" by Buchanan
13. "Ceramics Fabrication Processes" by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman

16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
19. 'Ceramics Fabrication Processes" by Wang.

EN 630: Nuclear Metallurgy (30)

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post- Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradition effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels,definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister fomation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Bengamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brain R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN 631: Physical Metallurgy (40)

- Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor Stereographic projection, X-ray, Electron and Neutron diffraction Common Crystal structures and quasi crystals, Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics
- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation. Ordered omega and Hydride formation.
- Recovery, Recrystalization and Grain Growth

References:

1. Physical Metallurgy Principles - R. E. Reed-Hill
2. Modern Physical Metallurgy - R. E. Smallman
3. Introduction to Metallurgy - A. H. Cottrell
4. Physical Metallurgy - P. Haasen
5. Introduction to Physical Metallurgy - S. H. Avner
6. Structure of Metals - C. S. Barrett & T. B. Massalski
7. Crystallography and Crystal Defects - A. Kelley and G. W. Groves
8. Principles of Phase Diagrams in Materials Systems - P. Gordon
9. Thermodynamics of Alloys - C. Wagner
10. Introduction to Metallurgical Thermodynamics D. R. Gaskel
11. Physical Chemistry of Metals - L. W. Darken and R. W. Gurry
12. Metallurgical Thermochemistry- O.Kubuschewski

13. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering - K. Denbigh
14. Modern Chemical Kinetics - H. Eyring
15. Kinetics of Phase Transformations in Metals - J. Burke
16. Transformation in Metals - P. G. Shewmon
17. Phase Transformations in Metals and Alloys - D. A. Porter and K. E. Easterling
18. Diffusion in Solids - P. G. Shewmon
19. Modern Metallography - R.E. Smallman and K.H.G. Ashbee
20. Electron Optical Applications in Materials Science - L. E. Murr
21. Electron Microscopy and Analysis - P. J. Goodhew and F. J. Humphreys
22. Defect Analysis in Electron Microscopy - M. H. Loretto and R. E. Smallman
23. Thermoanalytical Method of Investigation - P. D. Garn
24. Thermal Analysis - T. Daniels
25. Methods of Surface Analysis - A. W. Czanderna (Ed.)

EN 632: Process Control and Instrumentation (MT)(25)

Principles of Measurement (2)

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.

Sensors, Transducers and Transmission methods for parameters (10)

- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical& Radiation Pyrometers.
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli's Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

Principles of Automatic Control Systems (8)

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doeblin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN 633: Process Control & Instrumentation (EE)(30)

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysterisis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of following process variables
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter, Different types of standard pressure taps for orifices. Variable Area Flowmeters- Glass tube rotameters, armoured rotameters, bypass rotameters,
- Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs- Wire wound and thin film RTDs, self heating error, differential temperature measurement by using RTDs. Thermistors - Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer, two colour pyrometer.
- Pressure and Differential Pressure: Manometers-U tube, well and inclined manometers, mechanical pressure gauges- Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressureTransducers and transmitters, Smart pressure transmitters, Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauges, Mcleod gauge.
- Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass,

Purge system, capacitance probes, displacer type, ultrasonic type, nucleonic type and conductivity type level gauge.

- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- Distributed Control System: Programmable Logic Controllers, Smart Transmitters Control room concepts.
- P & I Diagrams: P &ID symbols, Typical P &ID.
- Class 1E Instruments in nuclear power plant: Definition of Class 1E equipment, various tests for Class 1E equipment qualification.

References:

1. 'Fundamentals of Temperature, Pressure and Flow Measurements" – Bendict
2. "Instrument Technology", Vols. 1 to 5, - E.B. Jones, Butterworth and London
3. "Mechanical and Industrial Measurements" - R.K.Jain, Khanna Publishers, New Delhi
4. "Measurement System, Application and Design", Ernest D. Deophhlin.
5. "Fluid Meters" - ASME Publication
6. "Principles and Practice of Flow meter Engineering" - L.K. Spink, Published by the Foxboro Company
7. "Process Instruments and Control Handbook" - Edited by D.M. Considine, McGraw Hill
8. "Handbook on Applied Instrumentation": Edited by D.M. Considine and S.D. Ross, McGraw Hill
9. "Instrument Engineer's Handbook", Part I & II: Edited by Bela G. Liptak, Chilton Book Company
10. "Instrumentation for Process Measurement and Control", Norman A. Anderson, Hilton Co.
11. "Manual on the use of Thermocouples in Temperature Measurements" (ASME Publication by subcommittee 4).
12. "Process Control Systems: Application Design and Tuning". F.G. Shinskey, Mcgraw Hill.
13. "Fluid Meters - Their theory and Application" Edited by H.S. Bean. ASME Publication

EN 634: Process Dynamics & Control (45)

Instrumentation , Controls & Computers(20)

- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real- time control applications.

Advanced Process Control (25) Background theory

- Introduction to state-space controls, state & measurement equations, general solution **of** the state equation, state- transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.

Introduction to Advanced Process Controls

- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

EN 635: Process Modelling, Simulation & Optimization (45)

Simulation

- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Methods of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent methods.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution methods for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization:

- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies.Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals,evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.

- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

References:

1. Bisio, A and R.L.Kabel, 'Scale-up of Chemical processes', Wiley-Interscience,NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W.Hoffman, A.I.Johnson, D.R.Woods and P.T.Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Methods and Modelling for Chemical Engineers, Winley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain,A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)
6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs,E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Rekliatis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Methods & applications, John Wiley,N.Y (1983)

EN 636: Reactor Control and Instrumentation and Human Machine Interface (40)

Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
- Practical

EN 637: Reactor Control Engineering & Instrumentation -1(15)

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic methods (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant Tav program, constant pressure program, Boiler level and

pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., " Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN 638: Reactor Control Engineering & Instrumentation-2 (20)

- Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.
- Reactor Instrumentation
  - Measurement ranges of reactor neutron flux and considerations
  - Principles of detection and types of neutron detectors: in-core and out – of –core
  - Modes of signal processing: Pulse, Campbell, DC
  - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- Health Physics Instrumentation
  - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
  - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
  - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Contamination Monitors

References:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerl

EN 639: Reliability Engineering (EE)(20)

Introduction: Reliability Engg Applied to C&I Systems

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

Reliability Maths/Statistics

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

Fault Tolerance and Systems Reliability:

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

QA/QC Concepts in Brief:

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.

Environmental Qualification and Reliability Testing:

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

PSA/PRA Concepts in NPPs:

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

Additional safety concepts:

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
- Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc.

References:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
6. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
7. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
8. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
9. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
10. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), ('Formal Methods' has been explained).
11. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
12. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
13. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN 640: Software Engineering and Formal Methods (40)

Software Engineering (20)

- Importance of Software Engineering (1)
- Life cycle, Phases and Work-Products of different Phases, traditional models, agile models, Extreme programming (1)
- Project Management: Relationship to lifecycle, planning, control, Risk Management, Cost Models.(1)
- Requirements: Gathering, Categorization, Analysis, and Specification.(1)
- Software Architecture and Design: Architectural Styles, Design Notation, Design principles. (5)
- Object oriented Design: OOAD, Design Patterns (7)
- Testing: Principles of program Testing, Test Coverage, Static Analysis, and Tools for testing. (2)
- Support Activities: Configuration Management, Verification and Validation, Software Engineering Standards, Documentation formats, Tools and environments for Software Engineering (2)

Formal Methods (20)

- Introduction to Formal Methods, Role of Formal Methods in Software Life Cycle – development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, Statecharts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing - Assertions and their verification (dynamic and Static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)

- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic,, Case study from hardware and software, model cheking tools (SPIN, NuSMV etc.) (4)

References:

1. Software Engineering: Roger S. Pressman McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Adison-Wesley
3. Unified Modeling Language *User Guide*: G. Booch, J. Rumbugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I & II , Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K. McMilan, Kluwer, 1993

ELECTIVE COURSES

EN 701: Advanced Computational Techniques (30)

Programming Language C++

- C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.
- C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initialisers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogona Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions,parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

EN 702: Advanced Electrical Engineering Design-I I (25)

Special Electrical Machines

- Special Electrical Machines and their applications :Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

Pulse Power Technology

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

EN 703: Artificial Intelligence Methods & Applications (30)

- **AI Basics**Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert

Systems.

- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence **theorem,** Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification methods, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig
2. Genetic Algorithms in Search, Optimization, and Machine Learning, by David E. Goldberg
3. Neural Networks: A Comprehensive Foundation, by Simon Haykin
4. Reinforcement Learning: An Introduction, by Richard S. Sutton and Andrew G. Barto

EN 704: Computer Based System Design- II (25)

Communication, Networking, Realtime systems, RTOS and Software

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- USB
- Encoding schemes
- Local Area Networks
- OSI 7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Networking hardware – cables, hub, switch, router, etc
- Role of fibre optics in communication
- Fieldbus standards
- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking
- Realtime Systems, their characteristics and applications
- Realtime Operating Systems:
- Concepts of
- Process and threads
- Concurrency
- Latency, context switching
- Scheduling policies
- Inter process communication
- Semaphores
- Priority inversion
- Shared memory
- Common systems calls, Communication features in RTOS
- Comparative study of various RTOSs
- Integrated S/W development environment

EN 705: Data Base Management System and Web Technology(30)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

EN 706: Digital Signal Processing and Image Processing (30)

Digital Signal Processing

- **Introduction**

Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**

  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
- Fast Fourier Transform

Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- Digital filters

FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- DSP Applications

  Applications of digital signal processing in nuclear and other fields.

Image Processing

- **Introduction**

  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- **Image Enhancement**

  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- **Image Segmentation andAnalysis**

  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation; Boundary extraction and representation;
- **Morphological operations**

  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy- based methods;

  Image Compression Models, Error free compression, Lossy compression, Standards;

References:

1 Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
1. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles,
2. Algorithms and Applications, Prentice- Hall of India,1995.
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.
4. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine
6. Vision,Vikas Publishing House,2003.
7. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004

EN 707: Embedded Electronics Software(25)

Programmable Digital System Design, Representation & Synthesis [8]

- Introduction to HDLs, Introduction to PLD, FPGA, ASIC. Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Handel-C, VHDL. Introduction to Design Flows and EDA Design Tools.

Real-time Software [11]

- Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion,

Priority Inheritance

- Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development

Introduction to Microprocessors / Microcontroller and Interfaces [6]

- Introduction to Microprocessor and microcontroller, Synchronous and Asynchronous Standards, RS232C, RS485, FieldBus (Profibus, Foundation FieldBus, CAN, Ethernet , MIL-STD-1553B), TTP

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P.Singh & Renu Singh
3. Fieldbus Technology: by N.P.Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN 708: Feedback Control Systems (25)

- Introduction: The control systems, Basic elements of FIB control systems, Types of FIB control systems.
- Transfer Function: Transfer function of linear systems, Impulse response, Block diagrams, Signal flow graphs, Mason's gain formula, Polar plots, Bode plot.
- State Variable Characterization: State concept, State equation, Standard representation, State transition matrix and solution of state equations, relationship between state equations and transfer functions, Characteristic equation, Illus- trative examples of some electrical, mechanical, electromechanical systems.
- Time Domain Analysis: Test input signals, Time domain perform- ance characteristics, Transient response of a typical second order system, PID controllers
- Stability: Definition, Routh-Hurwitz criterion, Nyquist criterion. Relative stability, Gain and Phase margins.

EN 709:Fluid Power Technology (25)

Basic Fluid Power & Components

Basic principles of Hydraulics and pneumatics

- Fluid power introduction and fundamentals of fluid mechanics
- principle of pneumatics, basic definitions
- pressure – gauge, vacuum, absolute; flow
- Pressure loss, Power, torque, energy – mechanical, hydraulic etc. , power, force, speed, viscosity, hydraulic terms in fluid power, resistances, bulk modulus, Pascal’s Law, law of conservation of energy
- Transmission and multiplication of force, Momentum theorem, Angular momentum theorem, continuity equation, Euler's equation of motion, Bernoulli’s theorem, laws of compression, forces developed by jets on plates (curved plate, moving plate, etc.) orifice flow formula, flow measurement, pressure measurement, comparison of Pneumatics with Hydraulic power transmissions.

Hydraulic Fluids and pneumatic air

- Basic properties of hydraulic fluids and pneumatic air, compressibility, pour point, flash point, fire point,
- Desirable properties of fluid, undesirable properties of fluids,
- Types of fluid, composition of fluids, effects of additives to hydraulic fluids,
- Advantages of various types of oil.
- Advantages of oil vs. air as working fluid.

Fluid power pumps and compressors

- Function and purposes of pumps and compressors
- Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump. (ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps (iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
- Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
- Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.

Hydraulic and Pneumatic pressure control

Pressure Control Valves, construction and working principles of relief valves- direct acting and pilot operated relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Hydraulic fuse, pressure switch, Pneumatic Pressure regulating valves.

Flow control valves

Basic two way valves, non-compensated flow control valves, throttle valves, restrictor valve, needle valve, ball tip valve, check valves, control valve circuits, pressure compensated flow control valve, demand-compensated flow control, pressure, temperature-compensated, flow control valve, methods of speed regulation in pneumatics.

Directional control valves

Application of directional control valve (DCVs),, designs, construction and operation of check valves, pilot operated check valves, rotary and spool type valves, two way valves, shuttle valves, three way valves, diversion valves, four way valves, solenoid operated, control valves, operation of directional control valves, mounting interfaces, designation, type of actuation of DCVs, pneumatic direction control valves – two way, three way, four way valves, etc., solenoid operated, push button operated, lever operated pneumatic DCVs.

Actuators

Definitions, linear actuators – Hydraulic cylinders, Plunger type, , piston type, Single acting, double acting cylinders, spring return type, tandem and telescopic cylinder, construction of hydraulic cylinders, cylinder seals – piston seal, rod seal, wipes, wear pads, etc. mounting style of cylinders, Pneumatic reciprocating actuators.

Rotary actuators –motors and limited rotation rotary actuators, their types, construction, advantages, vane type single and double vane rotary actuators, rack and pinion type rotary actuators, gear motors – external and internal, gerotor motors, vane motors, Radial piston motors, non-rotating barrel type axial piston motors, advantages of hydraulic motors. Pneumatic rotary actuator, radial piston, vane, and axial piston type air motors etc.

Seals

Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

Pipes, Tubes and Hoses, fittings

Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.

Accessories

Hydraulic and pneumatic filters, their applications, working principles and designs, beta ratio, absolute filtration, nominal filtration, selection of filters, heat exchangers – types, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, types of pneumatic filters, regulators, lubricators, mufflers, dryers, reservoirs etc.

Hydraulic Circuit Design

- Introduction to fluid Power Symbols, Overview of IS 7513,
- Classification of hydraulic circuits, Criteria for designing open loop hydraulic circuits, Analyzing resistive loads, overrunning loads and inertial loads, Heat generation and control.
- Flow control circuits, Pressure control circuits, Direction control & check valve circuits, Cylinder circuits, Pump circuits, Hydraulic motor circuits, Accumulator circuits, Intensifier circuits, Regeneration circuits.
- Sizing of Hydraulic circuit components :
- Reservoir.
- Heat Exchanger: Oil to air heat exchanger, Oil to water heat exchanger.
- Filters: Sizing of suction filter, return line filter, pressure line filter, Beta ratio, Necessary sizing information for filters.
- Fluid Conductors: Flow v/s Pressure drop, Pressure losses, tube/ hose sizing, Pressure rating, Hose/ Tube designation, Calculation of pressure drop in straight lines, bends, fittings etc.
- Pumps: Fixed displacement, variable displacement pumps, Design of suction side and pressure side of pump
- Hydraulic cylinders and motors.
- Accumulator: Isothermal &Adiabatic charging / discharging of accumulator. Sizing of accumulator for various applications i.e. energy storage, shock absorber etc.
- Valves sizing: Direction, pressure & flow control valves.

- Hydraulic Circuit Dynamics considerations: Bulk modulus, Spring rates, natural frequencies, Transmission line dynamics, Pulses in transmissions, Energy controls, Load energy output interaction, system stability, damping, time constant, system response, hydraulic system parameters i.e. resistance, capacitance, impedance.

Advanced Hydraulic Control Circuits

- Various pilot operated valves, construction features, operation, and advantages.
- Modular valves, Stacked type direction control valves, flow control valves, pressure control valves and

combinations.
- Electrically modulated pressure control valves, flow control valves. Pulse width modulation,
- Proportional controls, Servo controls, construction, Uses, differences, operation, advantages and disadvantages.
- Cartridge Valves: Design and construction features of cartridge valves, Types and Operation of cartridge valves, Advantages of cartridge design.
- Advanced pump controls, load sensing, pressure compensation.
- Integrated Hydraulic Circuit:Construction , Advantages of integrated hydraulic circuit, Case study of PVG32 valve, Various modules of PVG 32 valve block, Features of integrated hydraulic circuit of PVG 32, Electronic control capabilities.
- Pneumatic control circuits, proportional and servo valve, proportional and servo actuators

Water Hydraulics and Component Design
- Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals.
- Case Study-1: Differential Pressure Reducing Valve: Conceptual design and sizing
- Case Study-2: Auto Differential Pressure Control Valve - Conceptual design and sizing.
- Case Study-3: Pressure Compensated Flow Control Valve - Conceptual design and sizing.
- Case Study-4: Pilot Operated Pressure Control Valve - Conceptual design and sizing

Electronics and Instrumentation for Hydraulics:
- Current/ Voltage Sources and its measurements, Electronic components –resistance, capacitor, transistors, Opamps etc. Basic circuits for Addition multiplication, division using Opamps. Digital electronics, Logic gates.
- Analog to Digital converters (ADC) and Digital to analog controllers (DAC), Signal conditioning circuits, filters.
- Sensors-Pressure measurement, pressure switches, Position measurement, limit switches-proximity switches, Velocity measurements, Temperature measurement, temperature switches, Viscosity, density measurement, Force, torque, strain measurements.
- Controllers, Closed loop and open loop controllers, Proportional, Integral, derivative controllers and its uses and characteristics. Analog and digital controllers, comparison between digital and analog controllers. Programmable logic controllers, different I/O modules, wiring sensors to PLC. Introduction to microcontrollers, Applications, programming.
- Data Acquisition, Communication buses RS232,RS485, CAN bus, MODBUS, CANOpen bus uses and applications.

Fluid Logic & Control:
- Need for Fluid Control.
- Building Basic Elements for Control Logic (AND, OR, NOT, NAND, NOR).
- Function Implementations using Control Logic.

Experiments :
1. Tuning of PID controller in rotary actuator test facility.
2. Speed control of hydraulic motor using PLC.
3. Measurement of cleanliness level of hydraulic oil samples using particle counter.
4. Qualitative analysis of oil samples using Ferrograph.
5. Establishing position control using frictionless hydraulic linear actuator.
6. Finding characteristics of Differential Pressure Reducing Valve.
7. Finding characteristics of Auto Differential pressure control valve.
8. Finding characteristics of Pressure Compensated Flow Control Valve.
9. Finding characteristics of Pilot Operated Pressure Control Valve.
10. Study of Rexroth/Bemco oil hydraulic power pack and carrying out pressure setting, flow setting etc. in the same.
11. Experiments on ROHYTAM
12. Testing of oil hydraulic filter using filter test set-up.
13. Dismantling & assembling of various valves and actuators.

EN 710: Image Processing & Machine Vision (30)

Image Processing
- Introduction: Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;
- Boundary extraction and representation;
- Morphological operations;
- Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy-based

methods;
- Image Compression: Models, Error free compression, Lossy compression, Standards;

Machine Vision
- Imaging model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflectance, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, Boundary representation,Mathematical Morphology;
- Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, The Generalized Hough Transform;
- High Level Vision: Scene interpretation;
- Texture – Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, Classification and recognition, Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

References:
1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine , Vision,Vikas Publishing House,2003.
6. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004.
7. Davies E.R., Machine Vision Theory Algorithms Practicalities, Academic Press.
8. D.A. Forsyth & J. Ponce, Computer Vision A Modern Approach, Prentice Hall,2003.
9. Horn B.K.P., Robot Vision, The MIT press, 1987.
10. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
11. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

EN 711: Machine Design (25)

Principles of Machine Design:
- Objectives of machine design, general design rules, design methods
- Lightening of' parts and rational design schemes,
- Rigidity of structures, Cyclical/ Contact/ Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs.
- Introduction to inventive problem solving.

Design and Drawing Practices
- Drawing standards, selection of tolerances, fits, and positional tolerances.
- Introduction to Drawing Practices: (matter from various drafting standards),
- Introduction to CAD (including introduction to various drafting and solid modeling softwares)

Sealing Methods
- Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric 'O' rings, mechanical seals, labyrinth, valve packings.
- Methods of sealing for high and ultra high vacuum.

Special Dimensional Inspection Techniques
- Description of special dimensional inspection techniques, gaging techniques including composite and paper gauging, Advanced inspection tools including co-ordinate measuring machines and form measuring machines.

Advanced Manufacturing Techniques:
- Precision machining, super finishing, advanced manufacturing
- Micro machining.

References:
1. "Mechanical Engineering Design" by Joseph E. Shigley.
2. "Machinery's Hand Book" (24th edition)
3. "ISO Standards Hand Book" 18.
4. "SKF Bearing Catalogue."
5. "Relevant IS standards."
6. "Friction, Wear, Lubrication, Tribology Hand Book" edited by Prof. I.V.Kragelsky & V.V Alisim.

7. "Gear Hand Book by" Dudley.
8. "AGMA Standards 218.01" Dec. 1982.
9. "Industrial Sealing Technology" by H.HUGO BUCHTER

EN 712: Material Science in Nuclear Engineering (ME) (20)

- Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.
- Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X- ray Radiography, etc. for welds.

Corrosion

- Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards

Metallurgy of steels

- Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
- Selection and application of advanced alloys.

Nuclear Materials

- Fabrication, properties and application of Zircaloy, Zr-Nb alloys
- Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications.

Advanced Polymeric materials and Composites

- Physical and Chemical Properties, corrosion, mechanicalproperties
- Equipment design with polymeric materials
- Fabrication principles; standards for design, fabrication and testing.

References:

1. "Introduction to Materials Science for Engineers" - James Shackelford
2. "Physical Metallurgy Principles & Practice" - V.Raghavan
3. "Introduction to Solids" - L.V.Azaroff
4. "Structure and Properties of Materials" - Wulff Series, Wiley Eastern, New Delhi
5. "Materials in Nuclear Application" - C.K.Gupta
6. "Nuclear Chemical Engineering" - Benedict and Pigford

EN 713: Materials Characterisation (20)

Microscopy Techniques

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
    - Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
    - Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High reolution electron microscopy
    - Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, Other modes of operation, Applications in failure analysis, fracture surfaces etc.
    - Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

X-Ray Diffraction and Applications

- Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production and detection of x-rays.
- Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
- Experimental methods in x-ray analysis; Laue methods, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates,

crystal size crystal perfection, crystal orientations:

Chemical Analysis (with applications in materials science).

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

Basics of Analytical Transmission Electron Microscopy,

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, llllcorrections
- Cliff Lorimer factor, thin film correction

Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
- Fundamentals of energy filtering and its uses in life sciences
- Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
- Case studies for metallic bulk samples, life science samples, nano-materials

Physical and Thermal Characterization Techniques

- **Thermal expansion**: Methods and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
- **Thermal Conductivity**: Methods and their principle, advantages and limitations of each method, data of nuclear Fuels
- **TGA/DTA/DSC**: Methods and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
- **Elastic Properties**: Methods and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
- **Hardness**: Different methods and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

EN 714: Membrane Technology (35)

Fundamentals and Overview of Membrane Processes: (5)

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Growth Potential, Classification and description of membrane processes
- Pressure driven membrane processes (MF, UF, NF and RO)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

Novel Membranes

- Features, transport mechanism and application areas
- Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Membrane Bio-reactor, Fuel cell membranes, Membrane sensors, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

Membrane Materials, Preparation and Characterization: (10)

- Material selection
- Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity Molecular weight and molecular architecture
- Membrane preparation techniques- Phase-Inversion, In-situ polymerization, Track-etching, Slip-casting, Sintering
- Membrane Casting Aspects for continuous casting
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of charged membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
- Surface characterization -pore size, roughness, in-homogeneities, and hydrophilicity
- Bulk characterization -porosity, permeation study through flux and solute rejection.

Engineering and Design Aspects of Membrane Technology (10)

- Transport through membranes-Preferential sorption-capillary model,Solution Diffusion model, Irreversible thermodynamics model
- Derivation of basic transport equation for RO membranes

- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants
- Pretreatment considerations, Water chemistry- turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control,Scaling assessment parameters (SDI, MFI)
- Materials of construction
- Process design and system design for water desalination-Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices -pelton wheel, turbo-charger and pressure exchanger
- Effect of operating parameters on membrane performance
- Membrane cleaning and protocols
- Trouble-shooting analysis of operating plants
- Post-treatment techniques
- Membrane autopsy, Reject disposal techniques and brine management.

Membrane Technology Applications (10)

- Techno-economics of membranedesalination plant - seawater / brackish water
- Design aspects of water recovery & recycle from spent streams including sewage Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle
- Hybrid membrane systems, Combo systems -membrane + conventional- for separation application
- Nuclear Desalination
- Membrane based water purification systems-RO/UF application in food processing, pharmaceuticals and Bio-technology
- Fractionation & Value Recovery.
- Zero Liquid Discharge (ZLD)

References

1. Membrane Technology & Applications by Richard W Baker (2008)
2. Membrane Handbook by Ho and Sircar (1992)
3. Transport Phenomena in Membrane by K. Lakshminarayanaiah (1970)

EN 715: Multi-Scale Material Modeling (20)

Introduction

- Spatial and temporal hierarchy of microstructure and dynamics in materials
- Types of models: quantum mechanical, atomistic, mesoscopic, continuum
- Multiscale approaches

Short review and elements of differential equations (numerical solution)

- Differential equations in discrete and continuum simulation methods
- Ordinary differential equations for particle dynamics
- Partial differential equations, conduction/diffusion equation

Atomistic models: Molecular dynamics

- The basics of classical molecular dynamics
- Initial conditions, creating lattice structures, introducing defects
- Defining and maintaining temperature and pressure
- Boundary conditions (periodic, stochastic, conducting, non-reflecting)
- Methods for constant temperature or/and pressure simulations
- Tricks of the trade (neighbor lists, force/energy tables, potential cutoffs, etc.)

Monte Carlo methods

- The basics of Monte Carlo
- Monte Carlo integration, thermodynamic averages
- Importance sampling, Metropolis scheme
- Lattice Monte Carlo, Ising model
- Multi-state Potts models (grain coarsening, recrystallization)
- Kinetic Monte Carlo (surface processes, thin film growth)

Interatomic potentials

- Introduction, Born-Oppenheimer approximation
- Pair potentials and their limitations
- Calculation of elastic constants from potential function

- Potentials for ionic systems, ceramics
- Many-body potentials for metals
- Many-body potentials for covalently bounded systems
- Forces from "first principles"

Analysis of the simulation results

- Equilibrium properties (energy, temperature, pressure, velocity distributions)
- Structural properties (geometrical tessellation, pair correlation functions, atomic level stresses)
- Dynamic properties (diffusion, time correlation functions)

Mesoscopic methods

- Discrete dislocation dynamics
- Strain and stress fields for edge and screw dislocations in an isotropic medium
- The equation of motion in Newtonian Dislocation Dynamics
- Examples from 2D and 3D simulations
- Current problems
- Coarse-grained models

Bridging the scale gaps between different simulation levels

- Simultaneous integration of the models
- Sequential integration of the models (hierarchical approach)
- Examples of combined methods (MD-FEM, MD-MC, etc.)

Modeling at microscale

- Mechanism of ductile fracture and cleavage fracture
- Gurson constitutive law for modeling ductile damage
- Roussiler constitutive law for modeling ductile damage
- Beremin's model for cleavage fracture
- Modeling of material under transition temperature
- Case studies

EN 716: Preparedness & Response to Nuclear Emergencies (35)

- Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
- Radiation Shielding & Study of Criticality parameters and control
- Nuclear Waste Management
- Nuclear Accidents/emergencies
- Transport of Radioactive material
- Radiological accidents/emergencies
- Effects of Hiroshima & Nagasaki bombing
- Detection of Nuclear detonation
- Nuclear weapons: effect (Blast, heat, Radiation and EMP)
- Medical decontamination with demonstration
- Nuclear weapon tests (atmospheric)
- Nuclear & Radiological terrorism (Method to contain and control)
- Chemical warfare & Biological warfare (Method to contain and control it)
- Emergency Response methodology/ Philosophy
- Systems and methodology for Radiological impact assessment
- Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities
- Emergency Monitoring & Shelters
- Civil defence WEB plan for Nuclear attack on major cities
- Monitoring of High radiation field area
- Lab Visits

EN 717: Project Management (25)

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
  - Resources of project.
  - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an

activity, earliest start time EST, latest completion time LCT.
o Scheduling in a project by critical path method, CPM
o Scheduling in a project by Precedence Diagram Method.
o Use of Project Management Software for project planning, scheduling & monitoring.
o Preparation of master control management milestone network, Level-1,2, 3 & 4 network.

- Preparation of Target Plan, updating of progress, monitoring variance & reporting
o Constraints of project and its effective management o
Development of Six Monthly Plan and its review process o Resource
based planning
o Physical & Financial Monitoring of project, Use of S-curve
o Capital Budgeting & expenditure control in a project
o Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis methods, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN 718: Reliability Engineering (ME) (25)

- Reliability Mathematics – Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations,
Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
- Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
- Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
- Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
- System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
- Application of Reliability - PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

References:

1. Mishra, K.B., “ Reliability Analysis and Prediction”, Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M.,Reliability& Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., “Reliability in Engineering Design”, John Wiley & Sons, 1977.
5. Balaguruswamy, E., “Reliability Engineering” Tata Mcgraw-Hill, 1984.
14. Provan, J.W., “Probabilistic Fracture Mechanics & Reliability”, Martinus Nijhoff, 1987.
15. Nowak, A. S. and Collins, K. R., “Reliability of Structures” McGraw Hill, 2000.
16. Ayyub, B. M. and McCuen, R. H., “Probability, Statistics and Reliability for Engineers”, CRC Press, 1997.
17. Haldar, A. and Mahadevan, S., “Probability, Reliability and Statistical Methods in Engineering Design”,
18. John Wiley and Sons, Inc. 2000.

EN 719: Signal Conditioning, Recovery & EMI Aspects (25)

Review of Analog Signal Conditioning & Recovery Techniques

- Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types ofA/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

Theory of Quantization

- Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti- aliasing filters, fast algorithms for implementation.

Theory of Signal Analysis and Reconstruction

- Function space, orthogonal basis functions, Limitation of Shanon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

Review of EMI Aspects

- Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

EMI Modeling

- Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EN 720: Software Engineering (25)

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools.(3)
- Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods Testing principles, unit testing, integration testing, acceptance testing Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

EN 721: Vibrations (25)

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
- Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor;

Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinary.

- Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, aperiodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN 722: Safety and Reliability of Civil Engineering Structures (25)

Introduction to Probability Theory

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, ProbabilityDistributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

Structural Reliability

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment Method, Hasofer Lind Reliability Index, Rackwitz Fiesseler Method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

Probabilistic Safety Assessment

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

Industrial Safety

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

Safety assessment of existing structures:

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

Introduction to decommissioning of structures

References:

1. Hahn, G. J.and Shapiro, S. S. (1994), “Statistical Model in Engineering” Wiley-Interscience.
2. Ranganathan, R. (2000), “Reliability analysis and design of structures”,Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), “A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”, The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety Standard No. AERB/SS/CSE.
6. AERB (1996),“Atomic Energy (Factories) Rules”.

7. AERB (1991), "Safety Guide for Works contract", Safety Guide No. AERB/SG/IS-1
8. AERB (1996), "The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex", Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities".
10. Regulatory Guide 1.165 (1997), "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion", U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (25)

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- BeamWelding Processes
- Arc-Beam Hybrid WeldingProcesses
- Study of welding arc characteristics
- Metal transferduringarcwelding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on themacro-andmicro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high coolingrates
- Phenomena of hot-crackingand coldcracking
- Residualstresses anddistortion duringand afterwelding
- Residual stressmeasurements
- Application ofaboveprinciplesto welding ofcarbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

EN724: Advanced Structural Dynamics and Earthquake Engineering(CE) (30)

I. Introduction to Structural Dynamics and Earthquake Engineering

II. Performance Based Design of structures, systems and components subjected to earthquake loading

Concepts of performance bases, Seismic demand, Capacity of structures, systems and components, performance levels, energy dissipation and damping.

II. Seismic and Vibration Control

Concepts of seismic and vibration control, Passive control using Yielding dampers, friction dampers, tuned mass dampers, Tuned liquid damper, etc., Semi active and active control strategies.

III. Base Isolation Techniques

Concepts of vibration and seismic isolation, laminated rubber bearings, Lead plug bearings, Friction Isolation System etc.

V. Testing and Modal analysis

Need of testing, Methods of testing, qualification of systems by testing, data processing using FFT and Wavelets, modal analysis for frequency, mode shapes and damping. Causes and types of experimental error, statistical analysis of data.

VI. Seismic and Vibration Instrumentation

Measurement Methods and Applications: Measurement of displacement, velocity, acceleration, pressure, forces, strain and optical methods of measurements; Data Acquisition and Processing.

Types of inputs: analog and digital signals, calibration and uncertainty, Measurement System: Performance characteristics, linearity, dynamic range, sensitivity, stability, accuracy, bandwidth, noise, repeatability, hysteresis- threshold- resolution, readability and span.

VII. Fluid-structure interaction techniques

Coupling of fluid with structure, Dimensionless numbers in fluid-structure interactions, Added mass and added stiffness, Fluid sloshing, Flow induced vibration, Flow over bluffed bodies, Vortex shedding.

VIII. Multibody Dynamics

Rigid-Body Kinematics, Kinematics for General Multibody Systems, Modelling of forces in multibody systems, contact forces, friction effect, Equations of Motion of Multibody Systems.

Numerical integration methods for free standing objects, spring-mass system with friction, Runge Kutta methods, error estimation, Computer programs.

Text / Reference Books

1. A. K. Chopra, "Dynamics of structures", Prentice Hall, 4th edition, 2007.
2. S. S. Rao, "Mechanical vibration", Prentice Hall, 5th edition, 2014.
3. Holman, "Experimental Methods for Engineers", 6e, McGraw-Hill, 1994.
4. Doeblin, Engineering Experimentation, McGraw-Hill, 1995.
5. Hans-Joachim Bungartz Michael Schäfer, "Fluid-Structure Interaction Modelling, Simulation, Optimization", Springer-Verlag Berlin Heidelberg 2006.
6. Soong, T.T. and G.F. Dargush, "Passive Energy Dissipation Systems in Structural Engineering", Wiley & Sons, New York, 1997
7. Farid Amirouche, "Fundamentals of Multi Body Dynamics, Theory and Applications", Springer Science, 2006

NON-SUBJECT ASSIGNMENTS

EN 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

EN 592.1: Process Control Trainer (15)

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

Expt 1

Introduction to typical process under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.

Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

Expt 2

Optimisation of process control - using ultimate sensitivity method.

Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.

Optimum gain and integral / differential time constants are calculated using empirical formulae.

Expt 3

Feed forward control configuration - study of process response in comparison with normal feedback control. Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

Expt 4

Smart Differential Pressure transmitter.

Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.

Re range transmitter using HART communicator.

Re configure transmitter for linear and square root characteristics.

Expt 5
Final control element - Linear pneumatic control valve.
Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.
Virtual instrumentation and wireless data communication between controller and PC.

EN 592.2: Nuclear Detectors (15)

A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.

NaI(Tl) γ- Ray Scintillation Detector

This experiments imparts training on the use of NaI(Tl) detector using known γ- Ray sources (Co^{60} & Cs^{137}) , plotting of calibration curves and identification of unknown sources.

α-Particle spectroscopy using a Solid State Detector

This experiment imparts training on the use of the Solid State Detector using known α-Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup. **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter , testing counting statistics of the counter and studying absorption behaviour of β-rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN 593: Mini-Project Work (300)

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.
The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.). Project runs on a part time basis for 11 weeks from mid May to Mid July.

BACK TO MAIN

IGCAR

M.Sc. in ENGINEERING SCIENCES
(PROGRAM CODE: ENGG03)

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
ME1	Code Design for Pressure Vessels and Piping	30	4
ME4	High Temperature Design and Inelastic Analysis	25	2
ME6	Computational Fluid Dynamics	30	4
ME8	Finite Element Method	30	4
ME10	Advanced Heat and Mass Transfer	30	4
ME13	Reliability Engineering	20	2
ME14	Manufacturing Technology	40	4
Total		**205**	**24**

SPECIALISED/ELECTIVE COURSES

(Any three of the seven listed courses)

Course Code	Course Name	Hours	credits
ME3	Machine Design	25	2
	Structural Integrity Assessment Methods and NDE	30	4
	Vibration Engineering and condition Monitoring	20	2
ME5	Seismic Design of Nuclear Reactors and Facilities	20	2
	Plant Dynamics	20	2
	Experimental Mechanics	20	2
ME15	Process Control and Instrumentation	20	2

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-001-P	Project	Duration : 9 Weeks	
2.	02ENGG04-001-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

1. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
2. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
3. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
4. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
5. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
6. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
7. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity

2 **Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor

3 **Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors

4 **Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation

5 **Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions

6 **Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization

B BASIC REACTOR PHYSICS-STATIC

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety
Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down
Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
7. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology (NRST)

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flowmeter: Electromagnetic pumps and flowmeter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6.	Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7.	Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Code Design for Pressure Vessel & Piping (ME1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11.	Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , ‘Pressure vessel design’ CBS publication
2. Brownell. L. E & Young. E. D , ‘Process equipment design’, Wiley Eastern Ltd., India

3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Finite Element Method (ME8) (30 hours)

S.No.	Course content
1.	Introduction to FEM as applied to solid mechanics. Energy principles in structural mechanics and principles of minimum potential energy
2.	Element Shape and Shape Functions: Generalised co-ordinates. General requirements of shape functions; Lagrangian and Hermitian interpolation functions – CO, C1 continuity; Natural coordinate system; Derivation of shape functions for Bar, Beam, Plane, Brick and Plate elements.
3.	Bar Element: Derivation of elemental stiffness matrix and load vector; Transformation from element to global coordinate system; Assembly of Global stiffness matrix and load vector; Solution of typical 2D-plane Truss problems to evaluate Displacements and Member forces/stress; Thermal stress evaluation in Bars/Truss.
4.	Beam Element: Derivation of elemental stiffness matrix and load vector; Solution of simple Beam problems to evaluate Deflections/rotations; BM/SF distribution and determination of stresses, Shear deformation in beams. Curved Beam Element: Derivation of elemental stiffness matrix and load vector; Derivation of stiffness matrix for elbow.
5.	Axisymmetric Thin Shell Element: Strain-displacement and stress-strain relationship; Derivation of stiffness matrix and load vector for 2 noded axisymmetric thin shell element. 2D Plane Elements – 3 Noded Triangular Element: Derivation of elemental stiffness matrix and load vector, Plane Stress/Plane Strain & Axisymmetric elements: Evaluation of Strain/Stress.
6.	2D Isoparametric Element – 4, 8 and 12 noded quadrilateral Element: mapping of parent element to global space; Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of stiffness matrix for plane & axisymmetric elements; Evaluation of strain/stress at Gauss points.
7.	Introduction and Application of 3D Elements: Strain displacement and stress-strain relationship; Tetrahedron, Triangular prism and Hexahedron elements.
8.	Plane Bending Elements: Thin and Thick plate theory; Elements based on Kirchoff's Theory; Elements based on Mindlin Theory; Shear locking and Reduced Integration.
9.	Shell Element: Strain-displacement and stress-strain relationship; Flat plate and curved shell elements; 4 and 8 noded degenerated thick shell Elements, basic assumptions, degree of freedom, shape functions and shear locking.
10.	Incompatible Displacement Model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral element.
11.	Introduction to Nonlinear Problems. Meshing and Errors: Finite Element Modeling and Discritization Criterion, Adaptive meshing, classification of FEM stresses per ASME code, sources of potential error in the finite element solution

Books Suggested:

1.Finite Element Procedures-K.J.Bathe, Prentice Hall, 1996.
2.Concepts and Applications of Finite Element Analysis, R.D.Cook,D.S.Malkus & M.E.Plesha, 4th Ed., Prentice-Hall India, 2003.
3.An introduction to the Finite Element Method-J.N.Reddy, 2nd Ed., McGraw Hill Education (ISE editions)-1993.
4.Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.1, Butterworths-Heinemann,2000.
5. Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.2, Butterworths-Heinemann,2000.

6.The Finite Element Methods: its basics and fundamentals- O.C.Zienkiewicz ,R.L.Taylor &J.Z.Hu, Elsevier,2005.
7.The Finite Element Method: Linear,Static and Dynamic Finite Element analysis-T.J.R.Hughes, Dover Publication,2000.
8.Fundamentals Finite Element Analysis and Applications-M.Ashghar Bhatti, John-Wiley & Sons, NJ,2005.

3. Advanced Heat and Mass Transfer (ME10) (30 hours)

S.No.	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes & Bemoulli equations.
2.	**Laminar Boundary Layer and Forced Convective Heat:** Formulation of differential equation for hydrodynamic and thermal boundary layer. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory. Convective heat transfer for intemal and extemal flows. Low and high Prandtl number limits and different thermal boundary conditions Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method.
3.	**Turbulent Flow and Heat Transfer:** Reynolds decomposition for turbulence**.** Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical. correlations for calculating heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
4.	**Turbulence Modeling:** Eddy diffusivity models: k-£ and k-w) models, RNG based k- £ model. Reynolds stress models: algebraic & differential models. Low Reynolds number models Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
5.	**Natural Convection:** Basic Equations of natural convection. Boussinesq approximation. Derivation of Dimensionless groups from basic equations. Analytical approximations
6.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Moment, porosity, permeability etc.., homogenization method, continuity equation & energy equation, introduction to 2 phase flows & heat transfer in fluid flows.
7.	**Heat Transfer With Phase Change** : Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post dryout heat transfer. Various models available for calculation of heat transfer coefficient.. Critical Flow. Models for single - phase and two-phase critical flow.
8.	**Radiation heat transfer:** Radiation heat transfer. Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Books suggested:

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.

3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

4. Computational Fluid Dynamics (ME6) (30 hours)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme
B.	**Numerical Solution of Complete Fluid Flow and Energy Equation:**
1.	Formulations of governing equations used in numerical simulation:
2.	Stream function-temperature formulation
3.	Stream function-vorticity-temperature formulation
4.	Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5.	Primitive-Variable (P-V-T) formulation
6.	Pressure velocity coupling for incompressible flow.
7.	Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8.	Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9.	Simple grid generation techniques for structured grid:
10.	Elliptic. parabolic and hyperbolic equation method
11.	Grid adaptation
12.	Domain decompositions in CFD and heat transfer
13.	SIP and preconditioned conjugate gradient methods for solution

14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Books suggested:

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9^{th} Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

5. Reliability Engineering (ME13) (20 hours)

S.No.	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.\
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY.

6. Manufacturing Technology (ME14) (40 hours)

S.No. **Course content**

Curriculum for Metal Forming

1. **Uniaxial tensile test**:
   a. Engineering stress, engineering stain, true stress, true strain;
   b. Extraction of plastic stress-plastic strain data from load – elongation data of uniaxial tensile tests; Hollomon type and Voce type constitutive relations;
   c. Tensile instability and significance of strain harkening exponent;
   d. Determination of strain rate sensitivity index and the significance of strain rate sensitivity;
2. Stress matrix and the derivation of the Cauchy relation from the law of conservation of linear momentum; concept of principal stress;
3. Small strain matrix and rotation matrix obtained from the displacement functions;
4. **Elements of the theory of plasticity**:
   a. Decomposition of stress matrix to hydrostatic and deviatoric matrices;
   b. Yield surfaces as a function of the second and third invariants of the deviatoric matrix with von Mises and Tresca criteria being examples; concept of equivalent stess;
   c. Normality flow rule and convexity of the yield surface; concept of equivalent strain

Curriculum for Materials Joining

1. **Welding Processes**
   a. Fusion Welding Processes: Arc Welding Processes like SMAW, GTAW, GMSE, GVSE etc. and Beam welding process like EB welding and Laser Welding
   b. Solid state Welding Process like Friction Welding, Friction Stir Welding, Diffusion bonding, Explosive welding
   c. Resistance Welding Processes
2. **Thermal Cycle during welding**
   a. Weld Thermal Cycle, Dependence of bead shape with welding speed, prediction of weld thermal cycle
3. **Residual Stress and Distortion**
   a. Generation of residual stress, Effect of residual stress on performance, removal of residual stresses, measurement of residual stresses
   b. Origin of Distortion, Control of distortion

7. High Temperature Design & Inelastic Analysis ME4: (25 hours)

S.No. **Course content**

1. Introduction: Modes of failure, material selection, criteria to assess creep effect, creep law, creep-fatigue interaction, thermal striping
2. Design Practice: Loading category, primary, secondary and peak stress intensity, allowable stress intensity (S_m), assessment of basic wall thickness, strain limits

3. Analysis: strain range under multi axial state of stress, Nuber’s rule, triaxiality, elastic followup, fatigue damage, allowable numbers of cycle, creep damage, creep life prediction, creep rupture strength, creep fatigue interaction, ratcheting, efficiency diagrams and creep buckling
4. Fracture mechanics, creep crack growth, introduction to RCC-MR A16
5. In elastic Analysis: General principles for constitutive models, non unified model (plastic + creep), flow rule, creep strain hardening, classified models, viscoplastic material model, non-linear kinematic hardening, isotropic hardening, plastic strain memory, finite element Implementation, automatic time integration

Books Suggested:

1.Creep Analysis – H.Krauss
2.Mechanical Metallurgy-G.E. Dieter
3.Creep in Structures-A.R.S.Ponder and Drkhayhurst
4.Advances in Creep Design-Ed.A.I.Smith and A.M.Nickelson
5.ASME Section3 Subsection NH-1
6.French Design Code-RCCMR-Subsection RB

SPECIALISED/ELECTIVE COURSES

1. Machine Design (25 hours)

S.No.	Course content
1.	Principles of Machine Design: Objectives of machine design, general design rules, design methods, variable loads, Lightening of parts and rational design schemes, Rigidity of structures, Cyclical/Contact/Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs. Introduction to inventive problem solving.
2.	Design and Drawing Practices: Drawing standards, selection of tolerances, fits, and positional tolerances. Introduction to Drawing Practices: (matter from various drafting standards), Introduction to CAD (including introduction to various drafting and solid modelling softwares)
3.	Sealing Methods: Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric `O’ rings, mechanical seals, labyrinth, valve packings. Methods of sealing for high and ultra high vacuum.
4.	Special Dimensional Inspection Techniques: Description of special dimensional inspection techniques, gauging techniques including composite and paper gauging, advanced inspection tools including co-ordinate measuring machines and form measuring machines.
5.	Advanced Manufacturing Techniques: Precision machining, super finishing, advanced manufacturing, Micro machining.

Books suggested:

1) Mechanical engineering design (In SI Units) - Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2) Design Of Machine Elements Edition 7 - Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3) Machine Elements in Mechanical Design - Mott (R L), Columbus, Charles E Merril, 1985.
4) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.

5) Mechanical Engineering Design (In SI Units) – Joseph E Shigley & Charles R. Mischke, New Delhi, Tata Mcgraw Hill, 2001.
6) Design of Machine Elements - Ed. 7 – Spoots M F, Shoup T E, New Jersey, Prentice Hall 1998
7) Machine Elements in Mechanical Desgin – Moot R L, Columbus, Charles E Merril, 1985.
8) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.
9) Fundamentals of machine design – Oriov, Mir Publishers, Moscow.
10) Fluid power applications – Anthony Esposito, Pearson education
11) Precision engineering manufacturing – Murthy R.L., New Age International
12) MEMS and Microsystems design and manufacture – Tai-Ram Hsu, Tata McGraw Hill.

2. Structural Integrity Assessment Methods and NDE (ME3) (30 hours)

S.No.	Course content
1.	Fracture Mechanism in Metals
2.	Linear Elastic Fracture Mechanics
3.	Elastic Plastic Fracture Mechanics
4.	Low Cycle Fatigue
5.	Assessment of Creep damage and creep-fatigue interaction
6.	Creep crack growth models
7.	Experimental determination of fatigue and creep curve CTOD, KIC, KIa, J-R curve and C*
8.	Basis of ASME Sec. XI Reference Curve and its use in Pressurised Thermal Shock
9.	CTOD design method
10.	J-Estimation Schemes and J-based failure assessment diagram
11.	Net Section Collapse Criteria and Reference Stress approach
12.	R-6 method and its application
13.	Thermal background of international assessment procedure
14.	RCCMR code/A-16 method and its application
15.	CEGB codes
16.	Application of R-5/R-6 for design of high temperature components
17.	Failure Assessment Diagram of PD-6493 and BS-7910
18.	J-Estimation Schemes and J-based failure assessment diagram
19.	Leak-Before-Break design method
20.	Analysis of numerical techniques/Computational fatigue, Fracture and creep
21.	Probabilistic Fatigue, Fracture and creep
22.	Bench Mark solutions
23.	Manufacturing and process-induced defects that influence structural integrity -
24.	Principles, capabilities and applications of surface examination NDE techniques
25.	Principles, capabilities and applications of volumetric examination NDE techniques
26.	Quality assurance of nuclear components with relevant codes and standards and quality concepts
27.	Structural integrity, in-service inspection and life assessment of nuclear components using NDE
28.	NDE Lab visit and Practicals

Books Suggested:

1. Practical Non-destructive testing- Baldev Raj, Jayakumar.T. and Thavasimuthu. M., Narosa publishing house, New Delhi, 1997
2. Advances in NDE for structural integrity, - Nichols. R.W., Applied Science Publishers, London, 1982.
3. Non destructive Evaluation: A tool in Design, Manufacturing and Service and Francis – Don E.Bray and Roderick K. Stanley, Taylor, CRC Press, New york, 1996.
4. Non-destructive testing, R. Halmshaw, Edward Arnold, 1991.
5. Electrical and Magnetic Methods for Non-destructive testing, - J. Bllitz, Adam Hilger, Bristol, 1997.
6. Ultrasonic testing of materials, - Josef Krautkramer, Herbert Krautkramer, Springer-Verlag. January 1983.

3. Vibration Engineering and Condition Monitoring (20 hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
7.	Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum,

coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

4. Seismic Design of Nuclear Reactors and Facilities (ME5) (20 hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson’s ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
7.	**Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.

Books Suggested:

1. Chopra, A.K., "Dynamics of Structures, Theory and applications to Earthquake Engineering", Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures", New York, McGraw-Hill Book Company.
3. Mariopaz, "Structural Dynamic (Theory and Computation)", CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., "Numerical Methods in Finite Element Analysis", Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, "Engineering Seismology", IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, "Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites". AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design", BIS, New Delhi.

5. Plant Dynamics (20 hours)

S.No.	Course content
1.	**Pressure drop** in fuel Subassembly, friction, local acceleration and elevation pressure drop in wire-wrap. Flow zoning
2.	**Hot spot factors**: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors. Subchannel analysis of fuel subassemblies, mixing parameters, introduction to computer codes.

3. **Event analysis**: General safety features, General Considerations on Design Basis Events, Thermal and Hydraulic Modeling for Analysis, Safety Criteria, Design Criteria for Selection of SCRAM Parameters, Sympathetic Safety Actions, Primary Sodium Flow Halving Time, Maximum Permissible Absorber Rod Speed.
4. **Results of Analysis of Major DBE:** One Primary Sodium Pump Acceleration, Both Primary Sodium Pumps Acceleration, One Secondary Sodium Pump Acceleration, Both Secondary Sodium Pumps Acceleration, Feed water Flow Increase Events, Continuous Withdrawal of One CSR, One Primary Sodium Pump Trip, One Primary Sodium Pump Seizure, Off-Site Power Failure with Emergency Backup for PSP, Primary Pipe Rupture, One Secondary Sodium Pump Trip, One Secondary Sodium Pump Seizure, One Boiler Feed Pump Trip, Loss of Feed Water Flow to Steam Generator, Intermediate Heat Exchanger Sleeve Valve Closure, Loss of Heating in High Pressure Feed water Heaters, Spurious SCRAM. Reactor start-up, BFP Trip and over speeding at full power, Turbine Generator -Trip and subsequent plant operating actions, power setback.
5. **Decay Heat Removal:** Decay Heat Removal through OGDHRS, Decay Heat Removal through SGDHRS, Need for Forced Convection Core Flow, Decay Heat Removal during Station Blackout Situation, Adequacy of SGDHRS Capacity.
6. **Energy Release In Beyond Design Basis Events:** Local Events: Subassembly Accident, Whole Core Events: Pre – disassembly Phase, Disassembly Phase, Mechanical Energy Release / System Response Phase, Analysis of Transient Over Power Accident, Computer Codes, Analysis of Loss of Flow Accident (LOFA), Sodium Void Worth, Consequences of Fuel - Coolant Interaction

Books Suggested:
Material will be provided during the course

6. Experimental Mechanics (20 hours)

S.No.	Course content
1.	Stress & Strain: State of stress, strain, plane stress, plane strain, Thermal stress, Hydrostatic & Deviatoric Component of stress, Elastic stress-strain relationship, Elastic-Plastic strain relations, Von-mises plasticity criteria, plastic flow rule, strain hardening law, perfectly plastic material, Isotropic strain hardening material, kinematic strain hardening, combined strain hardening stress concentration, cyclic stress, Fatigue, Endurance limit, Creep, Larson Miller parameter.
2.	Photo elasticity: Polarisation, polariscope, diffused light and lense polariscope, stress optics law, plane polariscope, circular polariscope, criteria for model material selection, Isochromatic fringe pattern, Iso fringe pattern, scaling model to prototype stress.
3.	3D photo elasticity: locking of model deformations, scaling model and interpretation of the resulting fringe pattern, effective stresses, Birefringent coating, scattered light and its relation to photo elasticity, scattered light polariscope.
4.	Strain measurement methods: strain gage, basic characteristics, types of strain gages, factors in gage selection, electrical resistance strain gage, potentiometer for strain measurement, strain gage circuit, wheat stone bridge

5. Recording Instrument: galvanometer with oscillograph, transient response galvanometer, frequency response of the wheatstone bridge and galvanometer, cathode ray oscilloscope and potentiometer recorder.

Books Suggested:

1.Mechanical engineering design (In SI Units)', Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2.Design Of Machine Elements Edition 7, Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3.Machine Elements In Mechanical Design, Mott (R L), Columbus, Charles E Merril, 1985.
4.Experimental methods for engineers- J.P.Holman, McGraw Hill.
5.Theories of engineering experimentation-Hilbert Schenck, McGraw Hill.

7. Process Control & Instrumentation (Co-ordinator: A. Venkatesan) (20 hours)

S.No.	Course content
1.	Basic Concepts
2.	Units of measurements, Definitions (accuracy, precision, repeatability, span, range, hysterisis, drift, sensitivity, resolution, lag etc.) -- Sensors, transducers, Transmitters, PI diagrams, Symbols., Digital and analog devices.
3.	Sensing, Transmission, Receiving of the following Process Variables
4.	Temperature: classification, thermocouples, RTD, Thermistors, Pyrometers.
5.	Flow: Direct type, inferential type, constant area sensors, differential pressure meters, variable area meters, magnetic, ultrasonic, vortex type flow meters, and mass flow meters.
6.	Level: Direct type (Float, gauge glass, torque tube, piston tube, reflex etc) indirect type (Pressure gauge, purge, d/p with open/closed tanks, Ultrasonic, nucleonic, capacitance & conductivity).
7.	Pressure: Manometers, Bourdon, bellows, diaphragms, D/P Tx, (electronic & pneumatic), strain gauges, load cells.
8.	Analytical: pH, viscosity, conductivity, humidity, isotopic purity, and turbidity.
9.	Control System: Feedback Control theory, Modes of control, generation of control modes, Controllers, feedback & feed forward control, final control elements and valve positioners.
10.	Safety principles: Trip logic, annunciators, simple logic circuits, and smoke/fire detectors.
11.	Current Trends In Instrumentation: Smart transmitters, Instrumentation for a process loop, Paperless recorders, DAS, PLC, DRS, etc.

Books Suggested:

1. Instrument Technology Vol. I to V E.B. Jones.
2. Mechanical & Industrial Measurements, R.K. Jain
3. Automotive Process Control, Donald P. Eckman
4. Measurement Systems Application & Design, Ernest Doebelin.
5. Process Instrument & Control Handbook, Douglas Considine.
6. Instrument Engineers Handbook, Vol. I&II, Dela G. Liptak
7. Instrumentation for Process Measurement & Control, N.A. Anderson

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
ELECTRONICS AND INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
EL2	Reactor Control Engineering	20	2
EL3	Nuclear Instrumentation	20	2
EL4	Reliability Engineering	20	2
EL5	Software Engineering	20	2
EL8	Human Machine Interface for Reactor Control Instrumentation	45	6
EL10	Modern Control of Dynamic Systems	30	4
Total		**155**	**18**

SPECIALISED COURSES

Course Code	Course Name	Hours	Credits
EL6	Artificial Intelligence and Digital Signal Processing	40	4
EL7	Process Instrumentation	35	4
EL9	Embedded and Computer based systems Design	45	6
EL11	Analytical Instrumentation	25	2
Total		**145**	**16**

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-002-P	Project	Duration : 9 Weeks	
2.	02ENGG04-002-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

8. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
9. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
10. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
11. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
12. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).

13. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
14. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

Sl.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

13. Introduction to Materials Science for Engineers - James Shackelford
14. Physical Metallurgy Principles & Practice - V.Raghavan
15. Introduction to Solids - L.V.Azaroff
16. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
17. Materials in Nuclear Application - C.K.Gupta
18. Nuclear Chemical Engineering - Benedict and Pigford
19. Physical Metallurgy, Reed - Hill
20. Heat treatment of steel - Avener
21. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
22. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
23. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
24. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Fast Reactor Physics and Shielding (RP) (35 hours)

S.No.	Course content
A	NUCLEAR THEORY BASICS :
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units
2	**Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

8. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
9. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
10. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
11. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
12. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
13. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
14. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics and Radiological Safety (HP) (25 hours)

S.No. **Course content**

1.

Introduction: Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.

Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**

Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**

Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.

Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.

Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.

Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.

4. **Radiation protection and measurement (External and Internal):**

Control of external exposures (with problems in each case).

Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.
Routes of intake of radioactive material

Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

13. Introduction to Health Physics – Herman Cember
14. Introduction to Radiation Protection – Alan Martin
15. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
16. Nuclear Radiation Detection - W.J. Price
17. Radiation Detection and Measurement - G.F. Knoll
18. Biological Effects of Radiation – J.E. Coggle
19. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
20. Atoms, Radiation and Radiation Protection by James E. Turner 1986
21. Problems and solutions in Radiation Protection by James E. Turner, 1988
22. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
23. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
24. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) – (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :**
	Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology (NRST)**

1 **Properties of Sodium:** Physical and chemical properties, (hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

11. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
12. Steam Power Station, G.A. Gassort.
13. Power Plant Engineering & Economics, Strosal & Vapet.
14. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
15. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
16. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
17. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
18. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
19. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
20. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Reactor Control Engineering (EL2) (20 hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (EL3) (20 hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (EL4) (20 hours)

S.No. **Course content**

12. **Introduction: Reliability Engg. Applied to C&I Systems**

Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.

Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.

Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

13. **Reliability Maths/Statistics:**

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye’s theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

14. **Fault Tolerance and Systems Reliability:**

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model

Example from C&I system in the NPPs

15. **QA/QC Concepts in Brief:**

- QA/QC Concepts in the components, systems procurement, manufacture and
- Site installation for C&I systems in the NPPs.

16. **Environmental Qualification and Reliability Testing:**

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

17. **PSA/PRA Concepts in NPPs:**

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

18. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Software Engineering (EL5) (20 hours)

S.No.	Course content
1.	Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work- products of different phases
2.	Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics, CASE tools.
3.	Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalization, composition, polymorphism. Modeling structure and behavior, Use case diagrams, class diagrams, state diagrams, sequence diagrams, architectural and detailed design., Modeling real-time software. Introduction to Object Oriented Languages. CASE tools.
4.	Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities.
5.	Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods. Testing principles, unit testing, Integration testing, acceptance testing., Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing.
6.	Software Configuration Management: Configuration items (with examples), baselines, libraries, version control
7.	Software Engineering Standards

Books suggested:

1. Software Engineering by Roger S. Pressman, McGraw Hill International Students Edition
2. Software Engineering by Ian Sommerville, 5th Edition, Addison Wesley
3. An Integrated Approach to Software Engg. by P. Jalote, Springer/Narosa Publishers
4. Unified Modeling Language User Guide by G. Booch, J. Rumbaugh, I. Jacobson, Addison Wesley
5. Real-time UML, second edition, Bruce P. Douglass, Addison Wesley

5. Human Machine Interface for Reactor Control Instrumentation (EL8) (45hours)

S.No.	Course content
A .	**Reactor Instrumentation:**
1.	Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification
2.	RPS & RRS for FBRs : Core Temperature Monitoring System, Diversified Safety Logics, Control Logics for CSRDM & DSRDM
3.	Supervision Systems : Startup systems, Discordance supervision systems for SCRAM signals & CSRs, Alarm Generation system, ESR & PDA
4.	Component Handling Systems: I & C for Rotatable plugs, Transfer Arm, IFTM, CTM, Under Water Trolley and Storage Bays, HMI in HCR for Component handling and fuel movement monitoring.
5.	Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, low selector, high selector, median selector, voting logics, Interfaces with electrical Control gear.
6.	C & I Cables : Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
7.	Incident monitoring & mitigation systems : RCB Isolation, I&C for SGDHR, Seismic Instrumentation, Post Accident monitoring system, Video monitoring system
8.	Special systems: Fire Alarm System, Physical protection systems, Biometric Sensors, etc.
9.	Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station, DDCS for PFBR. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards, PLCs for package systems.
10.	PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

11. Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

B. Human Machine Interface (HMI)

1. Overview of plant automation.
2. Design of HMI, Soft Console versus Conventional control panels.
3. Guidelines for design of HMI displays.
4. Case study of a commercially available Professional HMI package.
5. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package
6. Practical.

Books suggested:

1. Intellution Ifix documentation
2. NPC Guidelines for development of soft consoles.

6. Modern Control of Dynamic Systems (EL10) (30 hours)

S.No.	Course content
1.	**1.** State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	**.** Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	**.** Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart
and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

SPECIALISED COURSES

1. Artificial Intelligence & DSP (EL6) (40 hours)

S.No.	Course content
	A. Introduction to Artificial Intelligence
1.	Introduction – Nature of AI problems
2.	Search – State space search
3.	Robotics – Kinematics and dynamics
4.	Knowledge Representation – Predicate logic
5.	Neural Networks – Feed forward vs Feedback
6.	Fuzzy Logic – membership functions
7.	Reinforcement Learning – Intelligent agents
8.	Genetic Algorithm – Solution representation
9.	Engineering applications including in Robotics
	B. Digital Signal Processing
1.	Introduction: Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, convolution, correlation, sampling theory, aliasing, anti-aliasing filter, quantization noise, signal reconstruction.
2.	Discrete Fourier Transform: Interpretation of DFT, properties of DFT, DFT of real signals, periodic & linear convolution and correlation using DFT.
3.	Fast Fourier Transform: Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, computation of Inverse DFT using FFT algorithm, efficient computation of the DFT of two real sequences and a 2N-point real sequence,

spectrum analysis using the FFT, windows in spectrum analysis, use of FFT algorithm in linear filtering and correlation.

4. Digital filters: FIR and IIR filters, design techniques for FIR and IIR filters, realization of FIR and IIR systems, overview of DSP processors.

5. DSP Applications: Applications of digital signal processing in nuclear and other fields.

Books suggested:

1.Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
2.John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice- Hall of India,1995.
3.Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.

2. Embedded & Computer based systems Design (EL9) (45 hours)

S.No.	Course content
A.	**Microprocessor Based Hardware Design:**
1.	Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Micro-controllers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
2.	Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3.	Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
4.	Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
5.	IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, testability.
6.	Embedded computer system design example.
B.	**Computer Communication and Networks**
	Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.)

C. **Fault Tolerant and Distributed Architectures**

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. **Real-Time System Design**

1. Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.
2. Overview of LINUX and Embedded NT.

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.

3. Process Instrumentation (EL7) (35 hours)

S.No.	Course content
7.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors,

flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.

8. Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.

   Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

9. Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

10. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

11. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

12. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type-Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

    Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

13. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
    Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.

14. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.
    Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.

15. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrment Engineer’s Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Fieldbus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

4. Analytical Instrumentation (EL11) (25 hours)

S.No.	Course content
	Measurement related issues
1.	Sensitivity, detection limit, signal-to-noise ratio enhancement
2.	Absorption and Emission Spectroscopy
3.	UV-VIS-IR Spectrophotometry
4.	Atomic Absorption Spectrophotometry
	IR absorption methods for detection of Carbon, Sulphur, Oxygen, Nitrogen
5.	**Fluorescence Spectrometry**
6.	Generation of X-Rays
7.	X-Ray Fluorescence Spectrometry
8.	X-Ray Diffraction Spectrometry
9.	Laser florescence
10.	**Mass Spectrometry**
	Applications and importance of mass spectrometry
	Various types of ion sources
	Various types of mass analysers
	Various methods of detection
	Computer based automation and measurements
11.	**Thermo analytical methods**
	Thermal analysers-DTA and TG
	Differential Scanning Calorimeters
12.	**Electro analytical instruments**
	Voltametry, amperometry and Coulometry
	Conductivity and pH

Books Suggested:

1. Instrumental methods of analysis, - Willard & Others, Pub: CBS, New Delhi, 7th Ed.
2. Principles of instrumental analysis, - Douglas A.Skoog and James J. Leary, Saunders College Publishing, Harcourt Brace College Publishers. (IGCAR Acc. No. 063944)

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
CHEMICAL ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING (CHEMICAL)
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE1	Nuclear Chemical Engineering	35	4
CE2	Chemical Engineering Thermodynamics	40	4
CE3	Transport Phenomena	40	4
CE4	Multi Phase Flow Systems	40	4
CE5	Code Design for Pressure Vessels and Piping	25	2
CE6	Computational Fluid Dynamics and Heat Transfer	40	4
CE7	Advanced Chemical Reaction Engineering	25	2
Total		**245**	**24**

SPECIALISED COURSE
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE8	Process Analysis and Control	25	2
CE9	Advanced Mass Transfer	25	2
Total		**50**	**4**

ELECTIVE COURSES
(One course amongst the three to be chosen)

Course Code	Course Name	Hours	credits
CEEL	Preparedness &Response to Nuclear Emergencies	30	4
	Artificial Intelligence Methods &Applications	30	4
	Membrane/ Separation Process and Technology	30	4

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-003-P	Project	Duration : 9 Weeks	
2.	02ENGG04-003-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers. B-splines,Bezier curves, Response surface method, different levels of factorial design.

Book suggested

15. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
16. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
17. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
18. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
19. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
20. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
21. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
9.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
10.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
11.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
12.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
13.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
14.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
15.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
16.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

25. Introduction to Materials Science for Engineers - James Shackelford
26. Physical Metallurgy Principles & Practice - V.Raghavan
27. Introduction to Solids - L.V.Azaroff
28. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
29. Materials in Nuclear Application - C.K.Gupta
30. Nuclear Chemical Engineering - Benedict and Pigford
31. Physical Metallurgy, Reed - Hill
32. Heat treatment of steel - Avener
33. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
34. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
35. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
36. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

15. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
16. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
17. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
18. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
19. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
20. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
21. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.

Course content

1. **Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.

   Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**

   Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**

   Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.

   Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.

   Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.

   Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.

4. **Radiation protection and measurement (External and Internal):**

   Control of external exposures (with problems in each case).

   Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.

   Routes of intake of radioactive material,

   Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

25. Introduction to Health Physics – Herman Cember
26. Introduction to Radiation Protection – Alan Martin
27. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
28. Nuclear Radiation Detection - W.J. Price
29. Radiation Detection and Measurement - G.F. Knoll
30. Biological Effects of Radiation – J.E. Coggle
31. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
32. Atoms, Radiation and Radiation Protection by James E. Turner 1986
33. Problems and solutions in Radiation Protection by James E. Turner, 1988
34. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
35. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
36. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. **Thermal Power Reactors :**

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. **Fast Power Reactors :**

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology**

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

21. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
22. Steam Power Station, G.A. Gassort.
23. Power Plant Engineering & Economics, Strosal & Vapet.
24. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
25. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
26. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
27. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
28. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
29. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
30. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.

9. Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.

10. Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.

11. Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.

12. Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements

2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.

3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types

4. Design criteria, Loadings to be considered, Analysis method and validation methodology

5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features

7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Nuclear Chemical Engineering (CE1) (30 Hours)

S.No.	Course content
1.	**An Introduction to Nuclear Chemical Engineering** General Introduction and course schematics
2.	**Production of Nuclear Materials** Production of nuclear fuels (i.e.)uranium, thorium and zirconium form ores. Alternate sources for uranium Isotope separation technologies for uranium and water Fuel fabrication technologies for various types of reactors Less common nuclear materials like Zr, Hf, Th, Be,V, Nb and Ta
3.	**Solvent Extraction of Nuclear Materials** Introduction to archival extractants and flowsheets Science and technology of primary extractant (TBP) Alternate extractants for fuel reprocessing applications Extractants for nuclear waste management applications Classical and novel nuclear solvent extraction equipment Criticality and its prevention. Other safety aspects
4.	**Nuclear Fuel Reprocessing** PUREX, Advanced PUREX, SuperPUREX processes Reprocessing of thermal reactor (PHWR and AHWR) Fuels Reprocessing of fast reactor (FBTR & PFBR) Fuels UREX process and its variants Supercritical Fluid Extraction based Superdirex Process Pyrochemical and other non-aqueous processes for reprocessing
5.	**Nuclear Waste Management** Characterization of nuclear wastes Conditioning and remediation. Post-PUREX and Post-UREX processes for isolation of important radionuclides (TRUEX, UNEX, ARTIST, SETFICS, SESAME etc.) Decontamination and decommissioning
6.	**Modeling and Simulation in Nuclear Chemical Engineering** Generation of SX data by conventional & **AKUFVE** techniques Modeling of solvent extraction data Computer codes for simulation of nuclear SX Simulation of solvent extraction process flowsheets Experimental design based variation analysis of flowsheets

Books Suggested:

1. Benedict M., Pigford T.H. and Lewi H. Nuclear Chemical Engineering, McGraw Hill. 2nd ed. (1981)
2. Long, J.T. , Engineering for Nuclear Fuel Reprocessing, American Nuclear Society, IL (1978)

3. Schulz. W.W, Navratil, J.D. and Talbot A.E., Science and Technology of Tributyl Phosphate, Vol.1, CRC Press Inc., Boca Raton, FL (1984)
4. Schulz. W.W, Burger, L.L.,Navratil, J.D. and Bender K.P., Science and Technology of Tributyl Phosphate, Vol.3, CRC Press Inc., Boca Raton, FL (1984)
5. Knief, R.A. Nuclear Energy Technology, Hemisphere Publishing corporation, NY, (1981)
6. Vilani, J., Isotope Separation, (IGCAR library)
7. Selected IGCAR Reports Concurrent literature on AFCI, UREX and allied processes

2. Chemical Engineering Thermodynamics (CE2) (30 Hours)

S.No.	Course content
1.	Classical thermodynamics - the scope of classical thermodynamics, basic concepts and definitions. Laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures.
3.	Multicomponent systems: the chemical potential, fugacity, activities, and activity coefficients.
4.	Solubilities of gases in liquids, solids in gases and in liquids.
5.	Vapour liquid equilibria at low and high pressure. (Van Laar, Peng-Robinson equations). Thermodynamics of super critical fluid
6.	Liquid-Liquid equilibria.
7.	Models for Non ideal, Non-electrolyte solutions and ionic liquids.
8.	Solution thermodynamics
9.	Phase Equilibrium: Phase rule, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations, Equilibrium in systems with supercritical components, phase stability applications.
10.	Chemical Reaction Equilibria: Equilibrium constants for Homogeneous and heterogeneous reactions.
11.	Statistical Thermodynamics

Books Suggested:

1.Denbigh, K. G., The Principles of Chemical Equilibrium, Cambridge, 1971.

2.Tester, J. W. and Modell, M., Thermodynamics and its Applications, 3rd ed., Prentice-Hall, 1997.

3.Bejan, A., Advanced Engineering Thermodynamics, Wiley, 1988.

3. Transport Phenomena (CE3) (40 Hours)

S.No.	Course content
1.	Phenomenological description of continuum approach. Reynolds transport theorem. Basic laws of conservation of mass, momentum and Energy and Multicomponent systems.

2. Transport properties. Modeling of Engg systems and the specification of boundary conditions. Shell balances, Navier-Stokes equations; Momentum, Heat and Mass transfer in steady and unsteady viscous flows; turbulent flows; shell and differential thermal energy balances; steady and unsteady conduction; laminar, forced and natural convection; shell and energy balances of mass of species; diffusion under various driving forces, diffusion with chemical reaction; convective diffusion in dilute solutions; integral balances. Transport coefficient and the macroscopic treatment of momentum, Energy and mass transport in complex system.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Multi-phase flow systems (CE4) (30 Hours)

S.No.	Course content
1.	Multiphase flows and Classification of Multiphase, Flow Patterns (gas-liquid, liquid-liquid and gas-solid and gas-liquid-solid) - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum and energy transfer for different models: Multi-dimensional and flow regime specific models.
2.	Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. (Gas-liquid mixture transport in horizontal and vertical pipe.), vapour-liquid flow, flow boiling, sub-cooled boiling, critical heat flux.
3.	Applications of two-phase flow in the design of steam generators, thermo-syphon evaporators, condensers with non condensibles and air lift pumps. Hydrodynamic of liquid-liquid flow design variables such as holdup, characteristic velocity and pressure drop.
4.	Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. (Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile and pressure drop for turbulent slurry flow.)
5.	The phenomena of fluidization and its industrial application. Characteristics of particles. Principle of fluidization and mapping of various regimes. Two phase theory of fluidization. Bubbles in fluidized bed. Entrainment and Elutriation. Fast fluidized bed. Mixing, segregation and gas dispersion. Heat and mass transfer in fluidized bed. Solid-liquid fluidized bed and three phase fluidized bed. Design of fluidized bed reactors

Books suggested:

1. Wallis, G.B. - " One Dimensional Two phase flow", McGraw Hill Book Co., New York, 1969.
2. Govier, G.W. and K.Aziz., - " The flow of Complex Mixtures in Pipes ", Van Nostrand Reinhold Co., New York, 1972.
3. Brodkey, R.S. - " The Phenomena of Fluid Motions ", Addison - Wesley Publishing Co., New York, 1967.
4. Gad Hestsroni, (Ed.in Chief) - " Handbook of Multi Phase Systems ", Hemisphere Publishing Corporation, Washington and McGraw-Hill Book Company London, 1982.
5. Two-phase flow in pipe lines and heat exchangers – D.Chisholm, Longman Inc, NewYork.
6. Fluidization Engineering- Author: Daizo Kunni and Octave Levenspiel, Butterworth-Heinemann
7. Fluidized bed technology in Materials Processing**, -**Author: C. K. Gupta and D. Sathiyamoorthy, CRC Press.
8. Chemical Reaction Engineering, - Octave Levenspiel,Wiley Eastern Limited.
9. Handbook of separation techniques for Chemical Engineers, - Philip A. Schweitzer,: McGraw- Hill

5. Code Design for Pressure Vessels & Piping (CE5) (25 Hours)

S.No.	**Course content**
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.

6. Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.

7. Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.

8. Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.

9. Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.

10. Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , ‘Pressure vessel design’ CBS publication
2. Brownell. L. E & Young. E. D , ‘Process equipment design’, Wiley Eastern Ltd., India
3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

6. Computational Fluid Dynamics & Heat Transfer (CE6 & CE610) (40 Hours)

Syllabus for CE6 : Computational Fluid Dynamics (30 hrs.)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme

B. Numerical Solution of Complete Fluid Flow and Energy Equation:

1. Formulations of governing equations used in numerical simulation:
2. Streamfunction-temperature formulation
3. Stream function-vorticity-temperature formulation
4. Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5. Primitive-Variable (P-V-T) formulation
6. Pressure velocity coupling for incompressible flow.
7. Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8. Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9. Simple grid generation techniques for structured grid:
10. Elliptic. parabolic and hyperbolic equation method
11. Grid adaptation
12. Domain decompositions in CFD and heat transfer
13. SIP and preconditioned conjugate gradient methods for solution
14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

<u>Syllabus for CE610 : Heat Transfer (10 hrs.)</u>

C. Laminar Boundary Layer and Forced Convective Heat:

1. Formulation of differential equation for hydrodynamic and thermal boundary layer
2. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
3. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
4. Convective heat transfer for internal and external flows
5. Low and high Prandtl number limits and different thermal boundary conditions
Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

D. Turbulent Flow and Heat Transfer:

Reynolds decomposition for turbulence
Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder
Calculation of friction factor and drag coefficient
Analytical and semi-analytical correlations for calculating heat transfer coefficients
Analogy between heat and momentum transfer
Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models
Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

E. Natural Convection:

Basic Equations of natural convection
Boussinesq approximation
Derivation of Dimensionless groups from basic equations
Analytical approximations
Numerical solution of approximate equations

F. Reactor Heat Transfer:

Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.

Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.

Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.

low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.

Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.

Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies

G. Heat Transfer With Phase Change :

Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.

Basic equations of two phase flow; Homogenous & separated flow models for two hase flow; void fraction & phase velocity ratio (Zivi's model)

Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)

Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.

Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept.
Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
Critical Flow: Models for single – phase and two-phase critical flow.

Books suggested:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.

4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

7. Advanced Chemical Reaction Engineering (CE7) (30 Hours)

S.No.	Course content
1.	Stoichiometry rates and thermodynamics of chemical reactions. Influence of concentration and temperature. Reaction mechanism. Generalized balance equation for reactive systems.

2. Collection and analysis of rate data: differential method, Integral method, Graphical method, polynomial fit method, Methods of initial rates, Methods of excess, Methods of half life. Kinetics of homogeneous and heterogeneous reactions.

3. Conservation equations for chemically reacting mixtures; heterogeneous catalytic reactions.

4. Chemical reactions and processes of transport: external diffusion effects on heterogeneous reactions, diffusion and reaction in porous catalysts.

5. Design and analysis of chemical reactors: Isothermal and non-isothermal reacting systems, catalytic and non-catalytic reactions systems.

6. Uniqueness and multiplicity of steady states, stability analysis.
Non-ideal reactors: distributions of residence time for chemical reactors, models for non-ideal reactors.

7. Modeling of multiphase reactors: fixed, fluidized, trickle bed, slurry etc.

Books Suggested:

1. Aris R., Elementary Chemical Reactor Analysis, Prentice-Hall 1969.
2. Foggler, H. S., Elements of Chemical Reaction Engineering, Prentice Hall of India, 1994.
3. Fromment G.F. and Bischoff K.B., Chemical Reactor Analysis and Design, John Wiley, 1994.
4. Smith J.M. - " Chemical Engineering Kinetics ", McGraw-Hill, 1981.

SPECIALISED COURSES

1. Process Analysis and Control (CE8) (25 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.
2.	Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3.	Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.

4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

2. Advanced Mass Transfer (CE9) (25 Hours)

S.No.	Course content
1.	Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Film, Penetration & Surface Renewal models, Solvent extraction theory
2.	Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors. Adsorption and ion exchange equipment.
3.	Membrane separation and other advanced mass transfer processes. Process intensification approaches. (few hours for seminar by TSO's).

Books suggested:

1. Transport phenomena in liquid extraction – G.S. Laddha and T.E. Degaleesan. McGraw Hill, 1978.
2. Separation process principles – J.d. Seader, Ernest J.Henley. John Wiley & Sons. 2nd Ed. 2005.
3. Mass transfer – Thomas K.Sher wood, Robert L.Pigford, Charles R. Wilkey. McGraw hill.
4. Mass transfer operations - Robert E. Treybal. Mcgraw-hill (1980)
5. Handbook of solvent extraction – The. C. Lo. Malcolm, H.I. Baird, Carl Hanson (editor), Krieger Pub. Co. Reprint edition (Feb 1991).

ELECTIVE COURSES

1. Preparedness & Response to Nuclear Emergencies (CE-EL) (30 Hours)

S.No.	Course content
1.	Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
2.	Radiation Shielding & Study of Criticality parameters and control
3.	Nuclear Waste Management
4.	Nuclear Accidents/emergencies
5.	Transport of Radioactive material
6.	Radiological accidents/emergencies
7.	Effects of Hiroshima & Nagasaki bombing
8.	Detection of Nuclear detonation

9. Nuclear weapons: effect (Blast, heat, Radiation and EMP)

10. Medical decontamination with demonstration

11. Nuclear weapon tests (atmospheric)

12. Nuclear & Radiological terrorism (Method to contain and control)

13. Chemical warfare & Biological warfare (Method to contain and control it)

14. Emergency Response methodology/ Philosophy

15. Systems and methodology for Radiological impact assessment

16. Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities

17. Emergency Monitoring & Shelters

18. Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment

19. Civil defence WEB plan for Nuclear attack on major cities

20. Monitoring of High radiation field area

21. Lab Visits

Books suggested:

Material will be provided during the course.

2. Artificial Intelligence Methods & Applications (30 hours)

S.No.	Course content
1.	**Robotics** Forward and Inverse kinematics, Jacobians, Manipulator Dynamics, Trajectory generation, Sensors, Manipulator Control, Force control, Path planning, Mapping & Localisation of Mobile robots, Behavior based control, Robot learning.
2.	**Genetic Algorithm** Introduction to GA and its terminology, GA operators and working principle of GAs. Different selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling and elitism. Constraint handling. Multimodal function optimization. Application of GAs, real-coded GAs. Multiobjective optimization, difference with single objective optimization, concept of Dominance and Pareto-optimality. Multiobjective GAs.
3.	**Fuzzy Logic** Introduction;Need, Historical Development and Perspective of applications. Crisp and Fuzzy Sets, Operations on fuzzy Sets. Fuzzy Arithmetic, Fuzzy relations, Fuzzy logic. Possibility Theory and Uncertainty Based information. Construction of Fuzzy Sets (with examples), Approximate Reasoning.

Applications; Pattern Recognition and Process Control (with examples).

Books Suggested:
Material will be provided during the course.

3. Membrane/Separation Processes and Technology (30 hours)

S.No.	Course content
1.	Type of membranes and membrane processes
2.	Membrane transport theory – solution, diffusion model
3.	Membrane and modules
4.	Concentration polarization – boundary layer film model – concentration polarization in liquid separation processes
5.	Reverse osmosis – membranes and materials, RO membrane categories, membrane modules, fouling control and cleaning
6.	Ultra-filtration – characterization of UF, membrane fouling and cleaning – modules and system design
7.	Other membrane processes – microfiltration, nanofiltration, pervaporation and electrodialysis
8.	Application of membranes in water and wastewater treatment
9.	Application of membranes in radioactive waste management

Book suggested:

1. Membrane Technology and Applications (2nd edition) by Richards W. Baker
2. Membrane Filtration Handbook – Practical Tips and Hints (2nd edition) by Jorgen Wagner
3. Application of Membrane Technologies for Liquid Radioactive Waste Processing – IAEA Technical Report Series No. 431.

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
Materials Science

Course Code	Course Name	Hours	Credits
MS1	Engineering Mathematics	35	4
MS2	Computational Methods	30	4
MS3	Materials and Metallurgy	25	3
MS4	Reactor Physics and Fuel Design	30	4
MS5	Health Physics	25	2
MS6	Metallurgical Thermodynamics	30	4
MS7	Experimental Methods for Materials Research	45	6
MS8	Structural Materials for Nuclear Reactors	45	6
MS9	NDE Science and Technology	30	4
MS10	Physical Metallurgy	45	6
MS11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
MS12	Introduction to Materials Science and Engineering	45	6
MS13	Corrosion Science and Engineering	30	4
MS14	Mechanical Behavior of Engineering Materials	30	4
MS15	Manufacturing Technology	30	4
Total		**505**	**65**

1. Computational Methods (MS2 -45 hours)

S.No	Course content
1.	**Programming:** Introduction to programming with C# as the reference language (C# software will be provided for practice), Getting familiarized with Matlab
2.	**Numerical Techniques:** Overview of standard numerical techniques with wpecial emphasis on statistics and solving ordinary and partial differential equations
3.	**Optimization:** Overview of techniques with special emphasis on non-linear optimi9zation using gradient descent, conjugate gradient and genetic algorithm
4.	**Neural network for predictive applications:** Overview of various neural network architectures, Multilayer perceptron model for prediction, need for neuro-fuzzy models
5.	**Atomistic modeling:** Introduction to Monte-Carlo Simulation, Basics of molecular dynamics, prediction of thermo-physical properties by molecular dynamics, computational challenges
6.	**Introduction to application of FEM:**Introduction to FEM and its application, demonstration of few simple application using Abaqus (FEM software)
7.	**Current status in modeling and simulation:** With respect to mechanical metallurgy

Books Suggested:

1. Sams Teach Yourself C# in 21 Days, B.L. Jones, SAMS publications
2. Numarical Recipes in C++: The art of scientific computing, *W.H. Press et al*, Cambridge University Press
3. Numerical Mathematical Analysis *J.B. Scarborough, MacMillan Publishers*
4. Genetic algorithms in search, optimization and machine learning, *D.E. Goldberg, Addison Wesley*
5. Guide to neural computing applications, *L. Tarassenko, Arnold publishers*
6. Monte Carlo Basics, *K.P.N. Murthy, ISRP publishers*
7. Molecular Dynamics Simulation by *J.M. Haile, John Wiley and sons*

2. Fast Reactor Physics and Fuel Design (MS4/CH8- 30 hours)

S.No.	Course content
1.	**Basic Nuclear Physics Concepts:** Properties of nuclei. Nuclear forces, Nuclear models. Nuclear decay, Liquid drop model and nuclear stability, Nuclear reactions including fission, Compound nucleus formation, Microscopic cross-section, Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	**Chain Reaction:** four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.

5. **Reactor Kinetics:**Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.

Books Suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C. Edlund. Van Nostrand, 1952.
2. Introducation to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Physics of Nuclear Reactors, Jakeman D., English Universities Press, 1966.
4. A.E. Walter and A.B. Reynolds, “Fast Breeder Reactors”, Pergamon Press, 1981.

3. Metallurgical Thermodynamics(MS6- 30 hours)

S.No.	Course Content
1.	**Classical thermodynamics -** the scope of classical thermodynamics, basic concepts and definitions. First and second laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures. The chemical potential, fugacity, activities, and activity coefficients, Phase rule
3.	Solubilities of gases in liquids, and solids
4.	**Solution thermodynamics**: Integral and Partial Molar Thermodynamic Properties, Solution Models, Ideal Solution, Regular Solution, Real Solutions
5.	**Phase Equilibrium and Stability**: Phase equilibria in multicomponent systems, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations,
6.	**Chemical Reaction Equilibria**: Equilibrium constants for Homogeneous and heterogeneous reactions.
7.	Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Pourbaix Ellingham Diagrams, Phase Diagrams,
8.	**Experimental Methods**: Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.

Books Suggested:

1.D. Gaskell, Materials Thermodynamics, Talyor and Reid, 1981.
2. O. Kubaschewski, C.B. Alcock and P.J. Spencer, Materials Thermochemistry, Pergamon, 1985

4. Experimental Methods for Materials Research (MS7-45 hours)

S.No	Course Content
1	Vacuum Techniques (3): Fundamentals, Creation & Pressure Measurements, units, Pumps – fore Vacuum, high Vacuum and UHV
2	Thin Film synthesis methods- Physical, Chemical and MBE

3. X-RAY TECHNIQUES - techniques based on measuring the energy or angular distribution of scattered x-rays,

1.1 Wide angle elastic scattering (XRD): Atomistic – form factors; unit cell structure factors, Bragg equation, reciprocal lattice, Laue equations; Expwrimental methods- transmission, reflection, thin film, in-situ; Otjer information-particle size distributions.

1.2 Inelastic scattering- x-ray absorption spectroscopy: Basics- edges and extended fine structure; XANES and EXAFS quantitation; Surface sensitivity; Experimental methods
1.3 Small angle scattering-SAXS: Basics- what SAXS sees; Mathematical modeling;
1.4 X-ray fluorescence spectroscopy: Basics- core hole formation, fluorescence yield, transport ("ZAF"); Experimental realization – Bulk analysis; lab and synchrotron x-ray sources; Surface analysis – TXRF; Microscopy – x-ray beam manipulation.

4. **ELECTRON MICROSCOPIES:**

2.1 Transmission electron microscopy (TEM/STEM):
Electron interactions in solids-elastic and inelastic scatterin, phase change; Contrast generation-bright field, dark field, "high-resolution"; Images-information and resolution; Diffraction; Beam damage; Experimental methods hardware, specimen preparation; Inelastic scattering- electron energy loss; Emitted x-rays – elemental analysis, sensitivity, spatial resolution; STEM
2.2. Scanning electron microscopy:
Beam transport in bulk solids; Signals and images- backscattered and secondary electrons; Diffraction- channeling patterns – EBSD; X-ray generation and transport, detection and analysis; Other useful signals; Experimental methods;
EPMA Electron probe micro-analyzer
2.3. LEELS

5. ION BEAM TECHNIQUES

techniques using ions or neutrals made from them as the bombarding species
3.1. Ion beams – production-ion guns; manipulation- ion, filters
3.2. Rutherford (Nuclear) Backscattering Spectroscopy- (RBS):
High energy ions in solids- electronic and nuclear (Rutherford) stopping; Quantitative description; Experimental methods – energy spectroscopy
3.3. Nuclear reaction analysis – elemental specificity – depth profiling
3.4. PIXE (Proton Induced X-ray Emission) Signal to noise ratio – trace element analysis
3.5. Surface Mass Spectriscopy-SIMS:
Ejection of matter by bombardment: sputterin; Fate of ejected materials subsequent reaction, charge state; Mass dedtection – quad, magnetic sector, ToF; experimental issues

6. ELECTRON SPECTROSCOPIES -

techniques based on measuring the energy distribution of emitted electrons
4.1 Photoelectron spectroscopy:
Basics- energy balance, element identification; Not-so Basics- relaxation, chemical states, satellites; Surface sensitivity; Quantitation; UPS- the unfamiliar cousin
4.2 Auger Electron Sepctroscopy:
Electron excitation- why bother ? The Auger spectrum- energy balance; Chemical effects; Quantitation; Imaging- meaning of maps.
4.3 Experimental methods;
Surface of real-world things; Below the surface- profiling, variable energy; Hardware and software; samples and handling.

7. PROXIMAL PROBE MICROSCOPIES

Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM): Basics; Experimental methods; Spectroscopy in Scanning Probe Microscopy

8. NUCLEAR SPECTROSCOPY

Positron annihilation, Mossbauer – Application to defects, radiation damage defects in metals and alloys

9. VIBRATIONAL SPECTROSCOPIES

7.1 Vibrations in molecules and solids – normal coordinates, group frequencies

7.2 Infrared spectroscopy;

IR absorption – dipole scattering, selection rules; Optical arrangements-transmission, specular reflectance, diffuse reflectance, attenuated total reflectance, microscopy, in-situ; Signal collection and Fourier transform processing, data analysis

7.3 Raman: Energy transfer, selection rules; Normal, resonance, surface-enhances, Fourier transform, UV

10. 8.RESONANCE ABSORPTION SPECTROSCOPIES

8.1 Nuclear Magnetic Resonance (NMR):

Fundamentals; Experimental Techniques; Magnetic Resonance Imaging

8.2 Electron Paramagnetic Resonance (EPR): Fundamentals; Experimental Techniques

BOOKS FOR STUDY AND REFERENCE:

1. Cullity Addision, B.D., "Elements of X-ray Diffraction", Wesley Publishing Co., 1967.
2. Williams (D B), Carter (C B), Transmission Electron Microscopy: A Textbook For Materials Science, New York, Plenum, 1996
3. J.R. Tesmer et al 'Handbook of modern ion beam materials analysis' (MRS, Pittsburgh,1995)
4. L.C. Feldman, J.W. Mayer 'Fundamentals of surface and thin film analysis' (North-Holland, N.Y, 1986)
5. Prutton, M., "Surface Science and Technology, Volume27, "Analytical techniques for thin films", Academic Press, Inc.Newyork, 1991.
6. Bacon, G.E., "X-ray and Neutron Diffraction", Pergamon Press, 1966.
7. Concise Encyclopedia Of Materials Characterization Ed. Cahn (R W) and lifshin (E) Ed Oxfod, Pergamon, 1993
8. Advances in Materials Characterization Ed. G. Amarendra, Baldev Raj, M.H. Manghnani, University Press (India), 2007

<u>8. Structural Materials for Nuclear Reactors (MS8)(Coordinator: –45hrs)</u>

S.No.	**<u>Course Content</u>**
1.	Three stage Nuclear Power Program (Importance of Material Selection)
2.	**Thermal Reactors:** Concept, Selection of Materials – Core and out of core, Processing of Materials, Properties/Performance of Materials
3.	**Fast Breeder Reactors:** Concept, Selection of Materials for different systems, Brief description of different systems, Core materials, Design criteria for clad and wrapper, Radiation damage, Evolution of materials for clad and wrapper, Material performance, Material processing and fabrication, Structural materials, Design criteria, Materials processing and fabrication, Steam generator materials, Design criteria, Selection of materials, Materials processing and fabrication, Properties of materials and performance
4.	**Materials in Reprocessing Applications,** Closing of nuclear fuel cycle, Design concept of reprocessing plant component, Selection of materials, Processing and fabrication, Evaluation of properties and performance
5.	**Materials in Waste Storage Applications**

Books Suggested:

1. Materials research: Current scenario and future projections, Chidambaram R, Banerjee S Ed, Allied Publishers, New Delhi, 2003
2. High temperature reactor materials (workshop La Jolla,CA March18-21,2002), Allen T, Oak Ridge, U.S.Department of Energy, 2002.
3. Nuclear materials: Issues and concerns Vol 2., Bhaskara Rao D Discovery Publishing House, New Delhi, 2001.
4. Materials R & D for PFBR: Compilation of articles: (Eds) S.L. Mannan and M.D. Mathew, IGCAR, Kalpakkam, 2003.
5. An overview of R&D on fast reactor fuel cycle, Baldev Raj, Int. J. Nuclear Energy Science and Technology, Col.1, Nos.2/3, 2005, pp.164-177.
6. Selection of materials for PFBR, S.L. Mannan, S.C. Chetal, Baldev Raj, S.B. Bhoje, Trans IIM, Vol..56, No.2, April 2003, pp.155-178.
7. Development of fuels and structural materials for fast breeder reactors, Baldev Raj, S.L. Mannan, P.R. Vasudeva Rao and M.D. Mathew, Sadhana, Vol.27, Part 5, October 2002, pp. 527-558
8. Input of the atomic energy programme on special materials development in India, C. V. Sundaram, Trans IIM, vol. 41, No.5, Oct 1988, p.407.
9. Recent trends in fast breeder reactor materials, C.V. Sundaram, P. Rodriguez and S. L. Mannan, IE (I) Journal –MM, Vol.67, Sept. 1986, pp.1-11.
10. Radiation effects in nuclear reactor materials – correlation with structure, P. Rodriguez, R. Krishnan and C.V. Sundaram Bull. Mater. Sci. Vol. 6, No.5, May 1984, PP.339-367.

Nuclear Reactor Materials, C.O.Smith, Addison Wesley, 1967

9. NDE Science and Technology (MS9 - 30 hours)

S.No.	Course Content
1.	**Introduction to NDE:** Importance and need for NDE, classification of techniques, origin of defects; material processing related-casting, forging, rolling, welding etc., and service related-fatigue, creep, corrosion, irradiation etc. Detection, characterisation, sensitivity, reliability, accuracy,
2.	**Surface NDE:** Principle, instruments & sensors, capabilities, applications and limitations of visual, liquid penetrant, magnetic particle, eddy current and flux leakage techniques
3.	**Volumetric NDE:** Principle, instruments & sensors, capabilities, applications and limitations of radiography and ultrasonic techniques. Gamma, Micro-focal, LINAC and real-time radiography and tomography. IRIS, TOFD, SAFT, MEMS, Non-linear ultrasonics related to ultrasonics.
4.	**Dynamic NDE:** Acoustic emission, infrared radiography, intelligent processing of materials and continuous monitoring.
5.	**Digital NDE:** Forward and inverse problems, signal processing, numerical modeling, imaging, automation, probability of detection (POD), multiple NDE, data fusion and robotics.
6.	**Industrial NDE:** NDE for quality assurance, structural integrity, material characterization, condition monitoring and in-service inspection, reference standards for calibration, codes & standards, selection of NDE techniques
7.	**Practicals:** 1. Ultrasonic testing – detection of defects in weld/HAZ and measurement of thickness

2. X-radiography of welds and interpretation of radiographs
3. Eddy current testing of plates and heat exchanger tubes for defects
4. ***Seminar***: Preparation and submission of report on a topic in advanced NDE. Presentation and viva-voce

Books Suggested:

1. A practical NDT – Baldev Raj, T. Jayakumar and M. Thavasimuthu, Narosa, New Delhi, 1996.

2. ASNT Volumes on Visual, penetrant, magnetic particle, eddy current, ultrasonic, radiography, acoustic emission, thermography and other techniques, ANST, Ohio, Coloumbus.

3. Grandt, A. F. Jr., Fundamentals of Structural Integrity: Damage Tolerant Design and Non-destructive Evaluation, John Wiley & Sons, Inc. Hoboken, NJ, 2004.

4. Bray, D.E. and R.K. Stanley, 1997, Nondestructive Evaluation: A Tool for Design, Manufacturing and Service; CRC Press, 1996.

5. Peter J. Shull, Nondestructive Evaluation: Theory, Techniques, and Applications, Marcel Dekker Inc., 2002.

10. Physical Metallurgy (MS10- 45 Hrs)

S.No.	Course Content
1.	Structure and Properties of Materials
2.	**Crystalline solids:** Introduction: Engineering materials, materials cycle, application and selection criteria of materials. Significance of microstructure; crystalline defects:- dimensions, origin and their effect on properties; amorphous structure.
3.	**Phase diagrams**: Origin, construction, interpretation and application of binary phase diagrams with reference to a few important metallic and ceramic systems. introduction and classification of phase transformations, calculation of phase equilibria based on thermodynamic principles
4.	Correlation between Free energy, selection of a Phase and order parameter, different thermodynamic classification of phase transformations, order of a transformation
5.	**Diffusional transformations:** Diffusion in solids: phenomenological approach and atomistic approach. Nucleation and growth theories of vapour to liquid, liquid to solid, and solid to solid transformations; homogeneous and heterogeneous strain energy effect during nucleation; interface-controlled growth and diffusion controlled growth; overall transformation kinetics. Principles of solidification, evolution of microstructures in pure metals and alloys. Precipitation from solid solution: types of precipitation reactions, crystallographic description of precipitates, precipitation sequence and age hardening, spinoidal decomposition.
6.	**Iron-carbon alloy system:** iron-carbon diagram, nucleation and growth of pearlite, cooling of hypo-eutectoid, eutectoid, and hyper-eutectoid steels, development of microstructures in cast irons. Heat treatment of steels: TTT and CCT diagrams
7.	**Diffusionless transformations:** martensitic transformation, hardenability, role of alloying elements in steels. Bainitic transformation, Widmanstatten transformation, Massive transformation. Order-disorder transformation.

8. Diffusion, rate theory, mechanisms of, measurement techniques
9. Phase transformations in some nuclear non-ferrous metals and alloys
10. Characterization of microstructure – microscopy techniques, X-ray spectroscopy and diffraction.
11. **Metallographic techniques**: Optical metallography, image analysis, quantitative phase estimation.
12. Properties of X-rays: continuous and characteristics x-rays, absorption, filter, production and detection of X-ray Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.
13. **Electron optical methods**: (a) Scanning electron microscopy and X-ray microanalysis including electron probe microanalysis, electron optics, electron beam specimen interaction, image formation in the SEM; (b) Transmission electron microscopy and analytical transmission electron microscopy: Electron diffraction, reciprocal lattice, analysis of SAD patterns; different electron diffraction techniques, atomic resolution microscopy, analytical devices with TEM, field ion microscopy, scanning tunneling microscopy, advanced techniques.
14. **Introduction to novel materials and processes**: composites, intermetallics, cermets, metallic foams, intelligent materials, Dependence of their properties on structure, Nanocrystalline Materials: Synthesis, Structure and Properties.: Amorphous Materials; Metallic glasses, Glass forming ability, Bulk Metallic Glasses, Properties; Quasi crystalline Materials; Structure, Synthesis, Properties;
15. **Advanced Processes**: Rapid solidification processing, Laser surface Modification, Mechanical Alloying, Rapid prototyping, Self propagating High temperature synthesis, inert gas condensation etc.
16. **LABORATORY** Microstructures of alloys of Fe, Al, Cu and Ti for each type of transformation at different levels of resolution; Crystal structure by diffraction techniques; Defects of different dimensions; Advanced processes – Laser Ablation, Magnetron Sputtering and Plasma and Chemical deposition methods.

11. Fuel Cycle Physics& Introduction to Fuel Cycle (MS11/PY11 - 30 Hrs)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.

8. Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9. U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10. Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11. Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12. Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13. Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14. Isotopic separation operation of bred uranium in thorium cycles to remove U-232.
MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Introduction to Materials Science & Engineering (MS12/CH4-40 hours)

S.No.	Course content
1.	**Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.
2.	**Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.
3.	**Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.
5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.
6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.
7. **Phase Diagrams &Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley &Sons, N.Y., 2003.
7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

13. Corrosion Science and Engineering (MS13/CH13 - 30 hours)

S.No.	Course content
1.	Thermodynamics of Aqueous Corrosion: Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.
2.	Kinetics of Aqueous Corrosion: Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.
3.	Forms of Corrosion: General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion. Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.
4.	Corrosion in Reactor and Reprocessing Plants: Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.
5.	Prevention and Control of Corrosion: Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.
6.	**Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.
7.	**Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, “Corrosion and corrosion control – An introduction to corrosion science and engineering”, Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, “Corrosion Engineering”, Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.

4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

14. Mechanical Behaviour of Engineering Materials (MS14- 30 hours)

S.No.	Course Content
1.	**Engineering Materials:** Alloys, intermetallics, ceramics, composites, polymers.
2.	**Basic Crystal Structure of Materials**: Unit cell, packing fractions, planes and directions, slip systems
3.	**Defects in Materials:** Point defect, line defect (dislocation), surface defects (grain boundary, twins, stacking faults), volume defects
4.	**Dislocation:** Types, Burger's vector, stress field and energy, stacking faults, dislocation glide and slip systems in crystal, interaction between dislocations, interaction between dislocations and point defects, dislocation pile up, dislocation climb, dislocation sources, multiplication of dislocations.
5.	**Elastic Behaviour of Materials:** Stress and strain at a point and their relationship
6.	**Plastic Behaviour of Materials:**
7.	**Tensile Deformation:** single crystal, yield point, CRSS, polycrystalline materials (Schmidt's factor), grain size effect-Hall-Petch relation, thermally activated deformation, constitutive equation for plastic deformation, strain hardening and dynamic strain ageing (DSA).
8.	**Strengthening Mechanism:**Strain hardening, strengthening from grain boundary, solid-solution strengthening, order-disorder strengthening, precipitation strengthening, dispersion strengthening, strengthening by point defects, martenisitic strengthening, and composite materials.
9.	**Creep:** Creep curve, mechanisms of creep deformation, activation energy for creep deformation, structural changes during creep, deformation mechanism map, super plasticity, presentation of creep data, prediction of long-term creep properties, irradiation creep, grain boundary sliding, nucleation, growth and coalescence on inter granular cavities, effect of impurity segregation on cavitation, creep fracture of weld joint, design of creep deformation and fracture resistance materials.
10.	**Fatigue:** Types of loading, high cycle fatigue, low cycle fatigue, thermo-mechanical fatigue, creep-fatigue interaction, fretting fatigue and corrosion-fatigue of various engineering materials, effect of surface treatment and coating, fatigue behaviour of welds, characterization of fatigue deformation and damage, fatigue under combined stresses, notch sensitivity, design criterion, life prediction techniques, alloy design against fatigue.
11.	**Fracture Mechanics:** Ductile to brittle transition, Griffith's law, strain energy release rate, introduction to linear and non-linear fracture mechanics, fracture toughness, fatigue and creep crack growth, material design against fracture.

Books Suggested

1. Physical Metallurgy Principle – R. E. Reed-Hill
2. Modern Physical Metallurgy – R. E. Smallman
3. Mechanical Metallurgy – G. E. Dieter
4. Plastic Deformation of Metals – R. K. W. Honeycomb
5. Introduction to Creep – W. W. Evans
6. Fatigue of Materials - S. Suresh, CambridgeUniversity Press.
7. Deformation and Fracture Mechanics of Engineering Materials – R. W. Hertzberg

15. Manufacturing Technology (MS15 - 30 hours)

S.No.	Course content
1.	**Nuclear materials and their melting practices**: Selection criteria for in-core, structural and steam generator materials, Radiation damage, Properties of nuclear materials. Principles of Vacuum melting & casting processes, including general descriptions of vacuum induction melting, vacuum arc re-melting and electro-slag refining.
2.	**Hot and cold working processes and tube making processes**: Fundamentals of mechanical processing, defects during manufacturing, Various techniques for producing seamless pipes, design of tooling for hot extrusion and principles of pilgering and Various presses and their characteristics.
3.	**Special metal forming processes**: High velocity forming processes like explosive forming, pertroforge forming, electro magnetic and hydraulic forming, comparison of HVF methods, Super-plastic forming.
4.	**Powder metallurgy** : Introduction, characterization of metal powders. Manufacturing of metal and composite powders. Compaction and sintering of metal powders. Secondary operations. Applications of typical P/M components.
5.	**Computer aided design:** Role of computers in design and manufacture, Solid modeling – techniques and algorithms for modelling – data structures for solid models; Surface modeling – curves and surface representation – composite surfaces – application to computer aided manufacture; Current developments in CAD – feature based modeling – Design by feature – function, feature linkages – Application of feature based models. Parametric modeling.
6.	**Metal joining principles and processes**: Fusion and non- fusion welding processes, modern welding processes, design of welded joints, Introduction to residual stresses and distortion in welds.
7.	**Weldability of materials**: Welding of austenitic stainless steels, ferritic steels, weldability tests, dissimilar welding and selection of weld consumables and welding defects, principles of post weld heat treatment and stress relieving.
8.	**Welded Fabrication**: Codes and Standards, Procedure and performance Qualification, Evaluation of the welded joints, NDT of welds.
9.	**Hard facing Technology**: Introduction, Need for hard facing, Hard facing processes, Hard facing in nuclear power plants.
10.	**Heat Treatment**: Annealing, normalizing, quenching and tempering, Precipitation hardening, Recrystallisation annealing, Importance of heating and cooling rate and hold time in heat treatment, Heat Treatment furnaces.

Books Suggested:

1.Metal Forming Handbook, Schuler, Springer Verlag, Berlin, 1998.
2.Welding Technology for Engineers, Baldev Raj, Shankar (V) And Bhaduri (A K), Narosa Publishing House, New Delhi, 2006.
3.Fundamentals of Metal Forming, Wagoner (R H), John Wiley & Sons, New York, 1997.
4.CAD/CAM from Principles To Practice, Chris Mcmahon And Jimmie Browne, Addison – Wesley, 1993.
5.Manufacturing Technology: Foundry, Forming And Welding, Rao (P N), Tata Mcgraw-Hill, New Delhi, 1987

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING I

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (MECHANICAL/CHEMICAL)

S. No	*Code*	*SUBJECT TITLE*	***HOURS***	***CREDITS***
1.	FRE1	Code Design for pressure vessel and piping	30	4
2.	FRE2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	30	4
3.	FRE3	Transport Phenomena	30	4
4.	FRE4	Reliability Engineering	20	2
5.	FRE5	Process Design and Control	30	4
6.	FRE6	Vibration Engineering and Condition Monitoring	20	2
7.	FRE7	Seismic Design of Nuclear Reactors and Facilities	30	4
8.	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**210**	**26**

MODULE III- OPERATIONS

S. No	*Code*	*SUBJECT TITLE*	***HOURS***	***CREDITS***
1.	FRE9	Plant Dynamics and Control	25	3
2.	FRE10	Turbine Generator Fundamentals	25	3
3.	FRE11	Mechanical and Electrical Equipments	25	3
4.	FRE12	Maintenance Engineering	25	3
5.	FRE13	Regulatory Framework for NPPs	25	3
6.	FRE14	Practical’s	**6 Weeks**	**12**
		Total	**125**	**27**
		Total	**510**	**74**
1.	Viva Voce	**Grand Total**		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

31. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
32. Steam Power Station, G.A. Gassort.
33. Power Plant Engineering & Economics, Strosal & Vapet.
34. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
35. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
36. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
37. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
38. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
39. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
40. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**
1	**Diffusion of Neutrons:** Fick’s law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.

2. **Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3. **Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4. **Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5. **Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6. **Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7. **Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8. **Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities
8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II - CORE ENGINEERING (MECHANICAL/CHEMICAL)

1. Code Design for Pressure Vessel and Piping (FRE1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical, spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures. Thermal stresses in plates and shells.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc (WRC-297)
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Design of tube sheets as per TEMA and ASME Sec VIII Div. 1.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Difference between Sec. VIII Div.1 & Sec III-NB.

12. Introduction to design codes (structure of RCC-MRx) both insignificant and significant creep. Service levels and design class. Introduction to shell and piping design. Thin Shell Design Against Buckling as per RCC-MR Appendix A-7, Elastoplastic instability under monotonic loading – linear elastic analysis, Elastoplastic instability under cyclic loading - elastic linear analysis -negligible creep, Elastoplastic instability in significant creep - simplified method.

Books suggested:

11. Harvey J F , 'Pressure vessel design' CBS publication
12. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
13. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
14. American standard code for pressure piping , B 31.1
15. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Heat Transfer and Computational Fluid Dynamics (FRE2) (30 Hours)

S.No **Course content**

1. **Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity, momentum and energy equations) with special reference to Navier-Stokes & Bernoulli equations.
2. **Laminar Boundary Layer and Forced Convection:** Formulation of differential equations for hydrodynamic and thermal boundary layers. Different analytical methods for reduction of boundary layer equations and theoretical formulation for boundary layer thickness. Study of jets and flow separation in the light of Boundary Layer Theory. Convective heat transfer in internal and external flows. Low and high Prandtl number limits and different thermal boundary conditions.
3. **Turbulent Flow and Heat Transfer**: Reynolds decomposition for turbulence. Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical correlations for heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy.
4. **Natural Convection**: Basic Equations of natural convection. Boussinesq approximation. Derivation of dimensionless groups from basic equations. Analytical approximations.
5. **Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Law, porosity & permeability, homogenization method, continuity equation & energy equation.
6. **Heat Transfer with Phase Change**: Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling & (b) flow boiling: Heat transfer correlations for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post-dryout heat transfer. Various

models available for calculation of heat transfer coefficient. Critical Flow. Models for single - phase and two-phase critical flows.

7. **Radiation heat transfer**: Radiation heat transfer. Reflection, absorption, transmission and emission; concept of black and grey bodies; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Shape factor & law of reciprocity; Radiation heat transfer between two grey bodies

8. **Numerical Methods in Heat Transfer**: Discretization of conduction equation with Dirichlet & Neumann boundary conditions; Temporal integration: Explicit & Implicit schemes. Discretization of convection-diffusion equations (Upwind & Exponential schemes). Estimation of flow field: stream function-vorticity formulation and primitive variable formulation. SIMPLE family of algorithms. Turbulence Modeling: Eddy diffusivity models: k-ε and k-ω models. Reynolds stress models: algebraic & differential versions. Large eddy simulation and Director numerical simulation.

Books suggested:

AHMT

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974.
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.
3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

CFD

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

3. Advanced Mass Transfer (FRE3) (30 Hours)

S.No. **Course content**

1. **Momentum Transport:**

1.1 Viscosity and Mechanisms of Momentum Transport: Generalized Newton's Law of Viscosity, Pressure and Temperature Dependence of Viscosity, Molecular Theory of the Viscosity of Gases and Liquids, Viscosity of Suspensions and Emulsions, Convective Momentum Transport.

1.2 Velocity distributions with two independent variables: Time-Dependent Flow of Newtonian Fluids, Flow near Solid Surfaces by Boundary-Layer Theory.

1.3 Macroscopic Balances for Isothermal Flows: Macroscopic mass, momentum, mechanical energy balances; Estimation of viscous loss, Performance of Liquid-Liquid Ejector, Thrust on pipe bends.

2. **Energy Transport:**

Fourier's Law of Heat Conduction; Thermal Conductivity, its measurement & its dependence on temperature / pressure. Theory of thermal conductivity of gases, gas mixtures and liquids, Effective thermal conductivity of composite solids, Convective transport of energy.

3. **Mass Transport:**

3.1 Diffusivity and the Mechanisms of Mass Transport: Fick's Law of Binary Diffusion, Diffusivity, its measurement & its dependence on temperature / pressure, Theory of diffusion in gases, binary liquids, colloids etc. Molar transport by convection.

3.2 Concentration Distributions in Solids and Laminar Flows: Diffusion through Gas Films, homogenous / heterogeneous chemical reactions, Diffusion into a Falling Liquid Films.

3.3 Equations of Change for Multi-component Systems: Equations of Continuity for a Multi-component Mixture, Multi-component Equations of Change, Multi-component Fluxes and their applications.

3.4 Concentration Distributions with More than One Independent Variable: Time-Dependent Diffusion, Steady-State Transport in Binary Boundary Layers, Boundary Layer Mass Transfer with complex interfacial motion. Concentration Distributions in Turbulent Flows.

3.5 Interphase Transport in Nonisothermal Mixtures: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions, Combined Heat and Mass Transfer by Free Convection, Effects of Interfacial Forces on Heat and Mass Transfer, Transfer Coefficients at High Net Mass Transfer Rates.

3.6 Other Mechanisms for Mass Transport: Equation of Change for Entropy, The Flux Expressions for Heat and Mass, Concentration Diffusion and Driving Forces, Applications of the Generalized Maxwell-Stefan Equations, Mass Transport across Selectively Permeable Membranes, Mass Transport in Porous Media.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Reliability Engineering (FRE4) (20 hours)

S.No	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.
3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY

5. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.

2. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.
4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

6. Vibration Engineering and Condition Monitoring (FRE6) (20 Hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; A seismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

7. Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

7. Seismic Design of Nuclear Reactors and Facilities (FRE7) (30 Hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

7. **Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.
15. **High Temperature and Creep Fatigue Interaction:** Damage mechanisms and failure modes, Time-dependent and frequency-dependent damage, Cumulative damage rules, Different approaches for life prediction under creep-fatigue conditions: Frequency-modified approach, strain range partitioning (SRP), Ductility exhaustion method, Creep-fatigue interaction Diagram, Thermomechanical fatigue, Codes and Standards

Books Suggested:

1. Chopra, A.K., “Dynamics of Structures, Theory and applications to Earthquake Engineering”, Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures”, New York, McGraw-Hill Book Company.
3. Mariopaz, “Structural Dynamic (Theory and Computation)”, CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., “Numerical Methods in Finite Element Analysis”, Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, “Seismic Analysis of Safety Related Nuclear Structures and Commentary”, ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, “Engineering Seismology”, IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, “Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, “Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites”. AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design”, BIS, New Delhi.

8. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.

- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.
- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.
- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings, Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.

- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.
- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evolution of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extension of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Independence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.

- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974

11. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

1. **Class room Training**
    a. Reactor System

        Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

    b. Sodium system

        Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

    c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*
    d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

2. **Field training**
    a. Reactor Operation
    b. Maintenance Activities
    c. Technical Service Activities
    d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING II

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (ELECTRICAL/ELECTRONICS)

S. No.	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE15	Reactor Control Engineering	30	4
2	FRE16	Nuclear Instrumentation	25	2
3	FRE4	Reliability Engineering	20	2
4	FRE5	Process Design and Control	30	4
5	FRE17	Embedded System Design & Human Machine Interface	45	6
6	FRE18	Process Instrumentation	45	6
7	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**215**	**26**

MODULE III- OPERATIONS

S. No	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE9	Plant Control	25	3
2	FRE10	Turbine Generator Fundamentals	25	3
3	FRE11	Mechanical and Electrical Equipments	25	3
4	FRE12	Maintenance Engineering	25	3
5	FRE13	Regulatory Framework for NPPs	25	3
6	FRE14	Practical’s	6 Weeks	12
		Total	125	27
		Total	515	74
1	**Viva-Voce**			**2**
		Grand Total		**76**

Fast Reactor Engineering - 2018

MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP) (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No. **Course content**

1. **Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.
Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**
Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**
Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.
Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors
Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection

4. **Radiation protection and measurement (External and Internal):**
Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.
Routes of intake of radioactive material,
Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**
Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**
Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**
Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II A- CORE ENGINEERING (ELECTRICAL AND ELECTRONICS)

1. Reactor Control Engineering (FRE15) (30 Hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (FRE16) (25 Hours)

S.No. **Course content**

1. Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2. Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3. Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4. Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5. Introduction to various reactor instrumentation and radiation monitors:
6. Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (FRE4) (20 Hours)

S.No **Course content**

1. **Introduction: Reliability Engineering Applied to C&I Systems**
   Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
   Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
   Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
2. **Reliability Maths/Statistics:**
   - Mathematical and statistical expressions required for reliability study
   - Types of failures in electrical, electronic and computer components
   - Failure probability concept, statistical distribution models
   - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
   - Chi-square distribution and its use in confidence and risk factors
   - Baye's theorem
   - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
   - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions
   - Derivation of exponential reliability expression

- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

3. **Fault Tolerance and Systems Reliability:**
   - Fault tolerance concept for electronic and Computer based C&I systems.
   - Circuit hardware redundancy concept to enhance system reliability, types of redundancy
   - Series, parallel, active, passive, and voting redundancy
   - Redundancy and other fault tolerance methods for software
   - FMEA, FMECA concepts for C&I and Examples to solve
   - Concepts for the analysis of System Reliability, availability, and maintainability.
   - System reliability and availability analysis methods
   - Boolean logic
   - Digraph, cutest-tie set method
   - Fault tree model, and consideration of CCF, CMF, software errors
   - Markov Model

   Example from C&I system in the NPPs
4. **QA/QC Concepts in Brief:**
   - QA/QC Concepts in the components, systems procurement, manufacture and Site installation for C&I systems in the NPPs.
5. **Environmental Qualification and Reliability Testing:**
   - Environmental qualification, testing of the C&I systems
   - Effects of various environments on the electrical/ electronic components
   - Climatic Qualification tests: Temperature, Humidity
   - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
   - Reliability Testing of the electronic components, equipment and C&I systems
   - Reliability screening tests for electronic components
   - Accelerated environmental tests
   - Failure terminated and time terminated tests
   - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
   - Few examples to solve
6. **PSA/PRA Concepts in NPPs:**
   - Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs
   - Explain Event Tree
   - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency
   - Level-1, Level-2, Level-3 PSA studies (Brief introduction only)

7. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier
Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ.
(1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill
Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants
(2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment
(1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier
Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher
(2001),
('Formal Methods' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

5. Embedded System Design and Human Machine Interface(FRE17) (45 Hours)

S.No. **Course content**

Embedded System Design

A. Microprocessor Based Hardware Design:

1. Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16-bit Micro-controllers (e.g. 80196), Overview of 8-bit Atmel Micro-controller (AT89C51), Real Time Clock, DSPs (e.g. TMS320, SHARC family) and ARM processor.
2. Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3. Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play
4. Design Case Study: Single board computer architectures, Remote Terminal Unit, Circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.

B. Computer Communication and Networks

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.);Concept of Fieldbus, fieldbus standards, Industrial networks and Protocols.

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Programmable Logic Controller Design

Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, Relevant communication protocol and standards, PLCs for package systems.

Human Machine Interface

E. Human Machine Interface (HMI)

1. Overview of plant automation, Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
2. Design of HMI, Soft Console versus Conventional control panels, Virtual Control Panel.
3. PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.
4. Guidelines for design of HMI displays.
5. Case study of a commercially available Professional HMI package.
6. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons

7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek& R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.
17. IntellutionIfix documentation
18. NPC Guidelines for development of soft consoles

6. Process Instrumentation (FRE18) (45 Hours)

S.No.	Course content
1.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.
2.	Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions-grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors - performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques. Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry-Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
3.	Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and

differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

4. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

5. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

6. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

   Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

7. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

   Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.

8. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

   Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.

9. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

   Note:Course Work -35 Hours and Practicals -10 Hours

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication

3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrument Engineer's Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Field bus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

7. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.
- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.

- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal

pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.

- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings,

Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.
- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.

- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evoluation of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extention of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Indepence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.
- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
-

6. Practicals (FRE 14) (6 Weeks)

12. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

3. Class room Training

a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

4. Field training

a. Reactor Operation

b. Maintenance Activities

c. Technical Service Activities

d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

M.Sc
ENGINEERING SCIENCES

(PROGRAM CODE: ENGG03)

INSTITUTE for PLASMA RESEARCH
BHAT, Gandhinagar

Submitted to
HOMI BHABHA NATIONAL INSTITUTE
Anushaktinagar, Mumbai

Contributors

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MTech in Fusion Science and Technology (for BTech, BE, AMIE, MSc Physics)

Course CI – IPR, Gandhinagar: Degree to be awarded by HBNI, Mumbai

Starting time – 01 August 2015

Course pattern
1st year – 2 trimester courses, 1 trimester Mini Project
2nd year – Project thesis/Dissertation

IMPORTANT:
After 1st year, people who qualify will be given a job in IPR as per Scientist / Engineer SC – details to be mentioned in the Technical Training Programme (TTP) 2015 advt. IPR employees who have BTech/BE/AMIE/MSc degree can also take this course as per HBNI guidelines for employees.

Only BTech/ BE / AMIE in following disciplines are considered: Mechanical, Electrical/Electronics/Instrumentation. MSc – Physics is also considered.

Trimester 1:
All courses are common to all: 1 class (lecture) – 60 minutes, 3 classes a day; 2 classes a week / faculty per subject; total number of classes/subject ~ 30 (including assignment, presentation, etc.)

Subject	Credits	Marks
Basic Plasma Physics (FC1)	3	100
Experimental Plasma Physics (FC2)	3	100
Tokamaks (FC3)	3	100
Fusion Plasma Diagnostics (FC4)	3	100
Measurement Techniques (FC5)	3	100
Numerical Methods (FC6)	3	100
Mathematical Methods (FC7)	3	100
Vacuum, Cryogenics and Magnets (FC8)	3	100
TOTAL	**24**	**800**

Trimester 2:
All courses in part (A) are common to all: 1 class – 60 minutes, 3 classes a day; 2 classes a week / faculty per subject; total number of classes/subject ~ 30 (including assignment, presentation, etc.). Courses in part (B) are subject/discipline specific.

Part (A): Advanced Subjects

Subject	Credit	Marks
Fusion Neutronics (AS1)	3	100
Plasma Facing Components: First Wall, Divertors, Blankets (AS2)	3	100
Fusion Materials (AS3)	3	100
RF, Current Drive and Neutral Beam Heating (AS4)	3	100
TOTAL	**12**	**400**

Part (B): All courses in part (B) consist of 4 classes a week; 1 class – 60 minutes, 2 classes a week / faculty per subject; total number of classes/subject ~ 60 (including assignment, presentation, etc.)
Subject Credit: 30 hours – 3 Credits
60 hours – 6 Credits

Subject	Hours	Total Credits	Marks	Remarks
Magneto Hydro Dynamics (PH1)	60	21	700	For Physics
Kinetic Theory and Statistical Mechanics (PH2)	60			
Advanced Heat Transfer and Cryogenics (PH3/ME5)	60			
Tokamak Related Code (PH4)	30			
Code Design for Internal and External Pressure Vessel (ME1)	30	21	700	Mechanical Engineering
Finite Element and Volume Methods (ME2)	60			
Mechanics of Solid/Vibration/Remote Handling (ME3)	30			
Advanced Manufacturing Technologies (ME4)	30			
Advanced Heat Transfer and Cryogenics (ME5)	60			
Advanced Data Acquisition System (EE1)	30	21	700	Electrical/Electronics/ Instrumentation Engineering
Advanced Tokamak controls (EE2)	30			
High Voltage, DC& AC/ Power Supplies (EE3)	60			
Signal Conditioning and EMI/EMC Aspects (EE4)	30			
Computer Based System Design (EE5)	30			
Digital Signal Processing and Image Processing (EE6)	30			

Trimester 3: Subject/Discipline specific project work

	Credit	Marks
Mini Project	**9**	**300**

TOTAL CREDITS IN 1ST YEAR: 24 + 12 + 21 + 9 = 66
TOTAL MARKS IN 1ST YEAR - 2200

2nd YEAR: M.Tech Thesis work

	Credit	Marks
1-year project/dissertation	**30**	**1000**

TOTAL CREDITS FOR 2 YEARS: 66 + 30 = 96
TOTAL MARKS for 2 YEARS – 3200

TRIMESTER 1

FC1 - Basic Plasma Physics (30 Lectures)

- **Introduction**

Definition of plasma, description of collective behaviour in contrast to single particle behaviour, derivation of plasma frequency (slab model), Debye length (description of Boltzmann distribution), conditions for collective behaviour (Physical basis for these conditions), binary collisions (derivation of Rutherford scattering), derivation of collision frequency ν_{ei} (large angle collisions, cumulative effect of many small angle collisions, Coulomb logarithm), discussion of collective behaviour revisited with relationship between various conditions (discussion of $k\lambda_D << 1$, plasma parameter).

- **Single Particle Motion**

Lorentz force equation, Nonrelativistic motion of a charged particle in constant electric and magnetic field: motion in constant **E** field, constant **B** field (derivation of cyclotron frequency, Larmor radius), motion in crossed **E** and **B** field, general solution for arbitrary angle between **E** and **B** field (Gantmakher formula), drift in a combined magnetic field and a general force field (non-magnetic), Motion in non-uniform **B** field (guiding centre approximation): Grad B drift ($\nabla \mathbf{B} \perp \mathbf{B}$), curvature drift, $\nabla \mathbf{B} \| \mathbf{B}$ (magnetic mirrors, invariance of μ, concept of adiabatic invariance), Uniform **B** and spatially varying **E** field (Finite Larmor radius effects), Time and space varying **E** field (Ponderomotive force), Time varying magnetic field (adiabatic compression), Time varying **E** field (polarization drift)

- **Fluid Description of Plasma**

Fluid equations, Equation of state, Complete set of two fluid equations, Fluid drifts parallel and perpendicular to **B** (diamagnetic drift), Plasma Equilibrium, Transport and Stability

- **Waves in Plasma**

Notion of phase and group speeds, High frequency electrostatic waves in an unmagnetized plasma (Langmuir waves, Bohm-Gross waves), High frequency electrostatic waves in a magnetized plasma (upper hybrid oscillation), High frequency electromagnetic modes in an unmagnetized and magnetized plasma, Low frequency electrostatic waves in unmagnetized and magnetized plasma: ion-acoustic wave, ion cyclotron wave, lower hybrid oscillation, low frequency electromagnetic modes: Alfven wave, magnetosonic wave.

- **MHD Description**

Derivation of single fluid equations from two fluid equations, complete set of equations of Magneto Hydro Dynamics (MHD), MHD waves, MHD energy.

FC2 - Experimental Plasma Physics (30 Lectures)

- **Fundamental Gas Processes**

Maxwell-Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization, Thermal Ionization, De-ionization, Diffusion, Different Mechanisms of Electron-Ion Recombination, Electron Attachment and Detachment Processes, Ion-Ion Recombination Processes, Formation of Negative Ions, Electronic Properties of Solids, Surface Emission Processes, Thermionic Emission, Field Emission, Photoemission, Particle Interaction with Solids, Interaction of Electrons with Surfaces, Interaction of Ions with Surfaces, Interaction of Neutrals with Surfaces, Sputtering Phenomena.

- **Charged Particles in a Gas in Electric Field of Low and High E/p**

Diffusion and Drift in an Electric Field, Redistribution of Particles through Diffusion and Drift, Ion Mobility, Ambipolar Diffusion, Electron Drift Velocity, Concept of High E/p, Primary Ionization Processes, Electron Avalanche, First Ionization Coefficient.

- **Self-sustaining Discharge**

Over-exponential Carrier Multiplication, Ionization by Positive Ion Collision, Cathode Processes, Processes in the Gas, Secondary Ionization Processes, Second Townsend ionization Coefficient, Paschen's Law, Breakdown Criterion, Limitations of Townsend Mechanism.

- **Glow Discharge**

Structure of Glow Discharge, Current-Voltage Characteristics of Glow Discharges, Physical Interpretation and Theoretical Analysis of Cathode Zone, Negative and Faraday Dark Space, Positive Column and Anode Layer, Striations, Specific Glow Discharge Plasma Sources.

- **Breakdown under Special Conditions**

Breakdown under Alternating Fields, Microwave Controlled Breakdown, Mobility Controlled Breakdown, Inductively Coupled Discharge, Capacitive Coupled Discharge.

- **Arc Discharge**

Glow to Arc Transition, Current-Voltage Characteristics of Arc Discharges, Classification of Arc Discharges, Cathode and Anode Layers, Different Models of Positive Column, Different Configurations of Arc Discharges, Bennet Pinch and Electrode Jet Formation.

- **Plasma Sheath and Diagnostics**

Basic Concepts, Bohm Sheath Criterion, High Voltage Sheath, Generalized Criteria for Sheath Formation, Electrostatic Probe Diagnostics, Single Langmuir Probe, Double Probe and Emissive Probe.

- **Experimental Plasma Devices**

Large Volume Plasma Device, BETA machine, SMARTEX, Helicon Plasma Expt., Q-machine, SYMPLE, Linear Magnetized Plasma Beam Expt., Plasma Wakefield Expt., Plasma Torch.

FC3 - Tokamaks (30 Lectures)

- **Introduction to tokamaks**

Thermonuclear Fusion reactions, Power Balance and Lawson Criteria, Tokamak as Fusion reactor, Tokamak Research, Major constituents of Tokamaks, Indian Tokamaks, Tokamak Confinement, Confinement times, Ohmic Confinement, L-mode and H-mode Confinement, Confinement scaling, Radiation loses.

- **Equilibrium and Transport**

Tokamak Equilibrium, Grad-Shafranov Equation, Safety Factor, q and Plasma Beta, Shafranov Shift and Plasma position control, Classical Transport, Neoclassical Transport.

- **Heating**

Ohmic Heating, Neutral Beam Heating, Wave Heating, Lower Hybrid Heating and Current Drive
Ion Cyclotron Resonance Heating, Electron Cyclotron Resonance Heating.

- **MHD Stability**

Ideal Kink modes, Ideal internal modes, Resistive tearing modes, Mirnov Oscillations, Saw-tooth oscillations, ELMs, Disruption scenarios.

- **Tokamak Devices and Other Fusion Devices**

Operating Regimes, Tokamak Magnetic Systems, Power systems, Plasma Production, Measurements of major operational parameters, Plasma wall interaction, Runaway electrons, Impurities, Operational experience in Aditya and SST-1, Other Fusion Devices.

FC4 - Fusion Plasma Diagnostics (30Lectures)

- **Introduction to Tokomak diagnostics**
  Introduction to all the tokomak diagnostics and related measurements.

- **Electrical diagnostics**

Langmuir probe: Single probe characterisation, explanation and other issues, Probe configurations, Double and Triple probes, Emissive probes.

- **Magnetic diagnostics**

Rogowski, flux and diamagnetic loops, Configuration and other details, plasma position and shape measurements, Introduction to MHD instabilities and Mirnov oscillations.

- **Measurements of plasma density and electron temperature**

Thomson scattering diagnostics: General concepts of Thomson scattering. Principles of Thomson scattering diagnostics. Types of Thomson scattering diagnostics used in tokamaks, Description of a typical diagnostics set up, technical features of the diagnostics set-up. Advantages and limitations of the technique.

Reflectometery: General concepts of Reflectometery. Physics principles of diagnostics. Different types of Reflectometry techniques, description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis. Advantages and limitations of the techniques.

Interferometry: General concepts of Interferometry. Physics principles of diagnostics. Description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis. Advantages and limitations of the techniques.

ECE diagnostics: Concepts of Electron Cyclotron Emission. Physics principles of the diagnostics. Description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis, Advantages and limitations of the techniques.

- **Measurement of impurities**

Introduction to spectroscopy, basics of passive and active spectroscopy and introduction to Visible, VUV and X-ray spectroscopy. Measurements of impurities by Visible spectroscopy and VUV/X-ray spectroscopy Data analysis by using actual spectra.

- **Measurement of ion temperatures**

Charge exchange recombination spectroscopy (CXRS) : Physics principles of CXRS , typical diagnostic set up, technical features of set up and brief on analysis techniques. Estimation of ion temperature using actual data.

X –ray crystal spectroscopy : Physics principles of X-ray crystal spectroscopy diagnostics , typical diagnostic set up, technical features of set up and brief on analysis techniques.

Neutral particle analyser: Concept of charge exchange (CX) neutral flux escaping from the tokamak plasmas, introduction to the different techniques for measurement of CX flux and energy distribution, description of the diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of the techniques, presentation of data analysis and estimation of core-ion temperature, analysis of actual plasma discharge data and estimation of ion-temperature.

- **Measurements of Radiated power**

Bolometers: Concept of Bolometry, requirement of bolometric measurements for tokamak plasmas, introduction to the different Bolometry techniques available for measurement of total radiated power loss from toakamak plasma, description of the different bolometers namely: Metal foil, AXUV and Imaging Video Bolometers, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each Bolomters, presentation of data analysis and estimation of total radiated power loss, analysis of actual plasma discharge data and estimation of total radiated power loss from the plasma.

- **Measurements of operational parameters**

Soft X-ray diagnostics: Introduction to the Soft X-ray diagnostics, physics principles and measurement technique, description of the diagnostics set up, description of the technical features of the diagnostics set up, advantages and limitation of the SXR diagnostic for electron temperature measurements.

Imaging Diagnostics: Requirement of imaging diagnostics for tokamak plasma, concept of different imaging diagnostics namely: Infrared Imaging Diagnostics, Visible Imaging Diagnostics etc., physics principles involved, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each imaging diagnostics, presentation of data analysis and analysis of actual plasma discharge data available for the imaging diagnostics.

Hard X-ray monitors: Concept of runaway electrons production in tokamaks, different measurement techniques available for the runaway detections, requirements of HXR measurements on tokamaks, principles of Hard X-Ray (HXR) generation due to runaways, introduction to HXR monitors for confined and de-confined runaways, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of HXR monitors.

Motional Stark Effect diagnostics and Beam emission spectroscopy: Introduction to beam based diagnostics, description of various beam based techniques for different types of operational parameters (q profile, ne(edge),Te(edge) and neutral beam density). Description of the diagnostics setup and technical features of the diagnostics setup and data analysis techniques.

Dust and Erosion monitors and Tritium monitors : Introduction to the concept of the Dust, erosion in tokomaks. Importance of the measurement of Dust, Erosion and Tritium. Challenges involved in the measurements. Example schemes of the measurement techniques.

- **Measurement of fusion products**

Introduction to fusion product measurements and importance of the measurement and control of fusion product generation. Various techniques available for measuring fusion products.

Confined and Lost alphas: Requirements of lost alpha particle diagnostics on future fusion devices, different diagnostics techniques available for the lost alpha diagnostics, principle of detection techniques, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each techniques and future applicability to fusion devices.

Gamma ray spectroscopy: Requirements of gamma ray spectroscopy on future fusion devices, principle of detection technique, diagnostics set up, description of the technical features of the diagnostics set-up.

Neutron flux and neutron profiles: Introduction to neutron flux and neutron profile measurements, measurement principles, measurement schemes and typical diagnostics set ups and discussion on challenges involved.

- **Overview and summary of ITER Diagnostics**

Discussion on the challenges involved in diagnosing fusion grade plasmas, over view of ITER diagnostics.

FC5 - Measurement Techniques (30Lectures)

- **Measurement System**

Introduction, Measurement system architecture, Computer based measurement systems, Errors in measurements, Measurement Units, Standard used in measurements, Types of Measurement Systems: Differential Measurement System, Referenced and Non-Referenced Single-Ended Measurement Systems.

- **Specifications parameters of Measurement Systems**

Sensitivity, Resolution, Nonlinearity, Saturation, Dynamic Range, Offset, Drift, Electromagnetic Compatibility, Reliability.

- **Electrical Measurements and Disturbances in Measuring System**

Measurement of Electrical Parameters: Voltage, Current, Resistance, Capacitance, Impedance, Frequency, Phase shift, Power.
Disturbances in Measuring System, Leakage Current, Parasitic Capacitive Coupling, Parasitic Inductive Coupling, Disturbances caused by: Electromagnetic Field, Feeding Cables, Improper Grounding.

- **Sensors/Transducers and Their Applications to Physical Measurements**

Sensors and Transducers – Performance Parameters, Selection of Sensors/Transducers, Temperature measurements, Pressure measurements, Flow measurements, Measurement of Linear/Angular acceleration, Velocity and Displacement, Measurement of Force and Torque, Measurement of radiant energy/light with Photosensitive Devices, Physical parameters sensing with Plasma diagnostics.

- **Analog Electronics**

  Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Pre-amplifiers, Pulse Amplifier, Signal isolation, Filters, Attenuators.

- **Introduction to Data Acquisition**

  Data Acquisition (DAQ) overview, Major components in development of Data Acquisition System (DAS), PC based data acquisition system, Data plotting and analysis. DAQ Software: Overview of Graphical/command based programming for the acquisition, Data processing and presentation of data: MATLAB, LabVIEW Application development environment, Concept and importance of Data Storage System, Microprocessors/Microcontrollers based measurement system.

- **Noise in Measurement System**

  Introduction to EMI/EMC, Methods of Noise Coupling, Methods of eliminating interference, Grounding, Cabling, Shielding, Intrinsic Noise source, Digital Circuit Noise, Sensor – DAS interface, Grounded Signal Sources, Floating Signal Sources, Grounding Issues: Various Grounding schemes for measurement.

FC6 - Numerical Methods (30 Lectures)

•Modeling, computation and error analysis:
Mathematical modeling, numerical methods and problem solving, Introduction to MATLAB programming, Error analysis methods, Case study.

•Solutions of Linear Algebraic equations:
Matrix algebra, Eigen value problems, Gauss elimination and LU factorization, Matrix inverse and conditions, Singular value decomposition, Iterative methods, Case study.

• Numerical Differentiation and Integration
Numerical differentiation, Numerical Integration, Case study.

• Roots, optimization and nonlinear sets of Equations
Bracketing methods, Open methods Optimization - Case study.

• Application of Ordinary Differential equations
Initial Value problems, Adaptive methods and stiff systems, Boundary value problems, Case study.

•**Application of Partial Differential equations**
Methods to solve PDEs, Case study.

•**Application of Curve fitting methods**
Linear Regression analysis, Fast Fourier Transform, Power spectral analysis, Bispectral analysis, Polynomial interpolation and extrapolation, Cubic spline interpolation, Nonlinear Least **Square** methods Case study.

FC7 - Mathematical Methods (30 Lectures)

- Vector analysis: vector identities, Use of Levi Civita and Kronecker delta functions for the derivation of vector identities, Notion of gradient, divergence and curl. Gauss, Green's And Stokes Theorems. Laplacian Operator in Different Coordinate Systems.
- Matrix Algebra: Classification of matrices; Elementary operations; Determinant, rank and inverse of a matrix; Solution of linear equations; Eigenvalues and eigenvectors; Similarity transformation and diagonalisation of a matrix.
- Complex analysis: Complex variables, function of a complex variable, continuity and differentiability, Cauchy-Riemann conditions, Analytic functions, Taylor and Laurent Series, singularities(poles and essential singularity) , Residues, Cauchy Residue theorem, Contour integration, Conformal Mapping and its application to the solution of Laplace equation.
- Differential equations: First and second order differential equations with constant and variable coefficients; Linear differential equations: Approximate method for solving ODE's (Series method of solution; Legendre and Bessel's differential equations and their solutions); Orthogonal polynomials and Special functions - Bessel functions, Gamma functions and Beta functions.
- Partial differential equations: First order partial differential equations, complete integral and general solution, methods of solution of a first order partial differential equation, second order partial differential equations, Laplace's equation, wave equation, diffusion equations. Method of charateristics, Separation of variables.
- Integral Transforms: Fourier, Laplace Transforms and the inverse transforms, connection to physical problems. Applications for obtaining solution of ordinary/partial differential equations.

FC8 - Vacuum, Cryogenics and Magnets (30 Lectures)

- **Fundamental of vacuum**
- The vacuum and its applications, Gas laws, Pressure and mean free path, Flow regimes, Conductance, Throughput and pumping speed, Ultimate pressure and pumpdown time, Outgassing and permeation. Exposure to pumps and gauges.

- **Design of a vacuum system**

Selection of materials, Pumps, Gauges, Valves, Rules for operating vacuum system. Permanent seals, Demountable seals, Vacuum components, Cleaning techniques.

- **Fundamental of cryogenics**

Cryogens properties, Heat loads in Cryogenic systems, Basic Thermodynamics and Cryogenic Processes, Material properties at low temperatures.

- **Design of cryogenics system**

Design aspects of Cryostat, Dewars and Cryolines. Fundamentals of Thermo-hydraulics and distribution network, Economics of Cryogens, Recovery of Helium and Thermal insulation.
Basics of Cryogenic valves, sizing, leaks and heat load estimation, Instrumentation at cryogenic temperatures. Safety aspects in handling cryogens.

- **Applications of Cryogenics Engineering in Fusion machines**

SST-1 Magnets, Cryo pumps, pellet injectors.

- **Fundamentals of Magnet system**

Resistive and Superconducting Magnet Systems,LTS and HTS based conductors, Flux Jumps, Filament twisting, AC losses, Cryo-stability, Monolithic & Cable-in-conduit-conductor (CICC) concepts.

- **Design and fabrication of magnet system**

Magnetic field calculations (analytical & computational tools), Magnetic force calculations, Structural design for magnets, Conductor design & Magnet winding pack design. Magnet winding pack fabrication & engineering issues, Insulation systems in magnets manufacturing, Magnets winding pack consolidation, QA/QC in magnets manufacturing.

- **Magnet operation**

Sensors and Instrumentations in Superconducting Magnets, Superconducting Magnet Quench and Protection aspects, Superconducting Magnet Tests & auxiliary test facilities, SST-1 Magnet System.

TRIMESTER 2 – PART A

(Part A is common to all)

AS1 - Fusion Neutronics (30 Lectures)

- **Neutronics Basics**

Fusion Neutronics Principles, neutron production & detection techniques, nuclear interaction processes, nuclear reactions, cross section, and thermalisation, scattering & absorption processes.

- **Particle transport phenomena in matter**

Neutron & photon transport, mathematical transport problem-Boltzmann transport equation, -probabilistic particle transport simulation - MCNP Monte Carlo code, tools: MCNP, Attila, Validation of computational tools and data.

- **Basics of fusion neutronics & blanket neutronics**

Neutronics design optimization, nuclear design of reactor components (blankets, divertor, first wall, heating systems, diagnostics etc.), Nuclear design analysis – optimization, source modelling, nuclearresponsecalculations,neutronandgammafluxes,nuclearheating,tritiumproductionrates,gasproductionanddpa.Amountoftritiumrequiredforafusionreactor,TritiumBreedingRatio, activation products & decay heat assessments, radiation damage & transmutation

- **Principles of Neutron & Fusion product diagnostics**

Processes in the plasma leading to non-maxwellian fuel ion distribution, experimental neutron, gamma-ray & alpha particle detection techniques, computational techniques to extract relevant information about the velocity functions of fusing ions out of measured neutron signals. Concepts of integrated modelling to assess and analyze the neutron emission features.

- **Radiation and licensing**

Radiation units, Radiation protection standards, Biological & genetic effects of radiations, Radiation shielding principles, composite shielding materials. Concepts of licensing & decommissioning of nuclear installations.

- **Radiation damage & transmutation**

Activation & after-heat, tools for calculations EASY-2010, concept of direct one step (D1S) method and Rigorous 2 step (RS2) process (MCNP-FISPACT) in estimating the dose rate on components of a fusion reactor after reactor shut down. Generation & management of radioactivewastefromatypicalfusionreactor.Quantification&Categorizationofradioactivewaste

- **Nuclear Safety aspects**

Basic concepts in safety, reliability and RAMI analysis, loss of coolant accidents, conceptual design of safety systems, risk and reliability analysis of systems, operational safety procedures, regulatory process, introduction to safety related instrumentation, remote handling of irradiated components

- **Fusion Neutronic Activities Worldwide**

Overview &Latest neutron facilities being built all over the world and recent trends. 4th generation nuclear reactors (high temp & compact reactors), Accelerator Driven Systems (ADS), IFMIF & CTF, Spallation Neutron Source (SNS), Fus-Fis hybrid systems (breeders), Transmutation of radiation wastes

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AS2 - Plasma Facing Components: First Wall, Divertors, Blankets (30 Lectures)

- **First Wall**
  - **Firstwall Concepts :** Basic Design of Firstwall.
  - **Loads on Firswtall: I**nertial loads, Kinetic Pressure Loads, Electromagnetic loads, Thermal & Particle loads, Neutronic Loads.
  - **Challenges for Firstwall:** Material Challenges, Fabrication Challenges, Operational Challenges.

- **Divertors**
  - **Divertor Concepts:** Basic Design of Diveror, Toroidal & Poloidal Divertor, Single-Null Divertor, Double-Null Divertor.
  - **Loads on Divertor:** Inertial loads, Kinetic Pressure Loads, Electromagnetic loads, Thermal & Particle loads, Neutronic Loads.
  - **Challenges for Divertor:** Material Challenges, Fabrication Challenges, Operational Challenges.
  - **Divertor Testing:** Destructive Testing, Non-Destructive Testing, Metrology.
  - **Novel Divertor Concepts:** Helium Cooled Divertor, Liquid Divertor.

- **Blankets**
  - **Blanket Concept**: Requirement and essential features of Shield Blanket (SB) and Breeding Blanket (BB) in a fusion reactor.
  - **Shield Blanket:** Types of SB and SB material, SB Design Concept, Thermal-hydraulic and thermo-mechanical analysis of SB.
  - **Breeding Blanket:** Types of BB and blanket materials (solid and liquid), concept of Indian BB, Indian Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) for ITER, concept of LLCB-TBM design, thermal-hydraulic and thermo-mechanical analysis of SB, LOCA and LOFA analysis of BB, Diagnostics of BB.
  - **Solid Ceramic Breeder (CB) Technology:** Development of Li CB, characterization of Li CB material, characterization of Li CB pebble bed, thermal and thermo-mechanical analysis of pebble bed.
  - **Liquid Metal (PbLi) Technology: C**omposition and developmental process of PbLi eutectic alloy, Study of basic (PbLi) loop and loop components, PbLi diagnostics. Liquid

metal MHD studies – basic analytical formulation (Velocity profile and Pressure drop studies), liquid metal MHD code development (Electric potential Method and Magnetic induction method), code benchmarking, Liquid Metal MHD experiments (Experimental set up, experimental results), liquid metal (Pb-Li) Corrosion studies (Corrosion experiments, experimental results, numerical formulation).

- **Fusion Fuel Cycle:** Requirement and essential features of fusion cycle of a fusion reactor, inner & outer fuel cycle of a fusion reactor, tritium handling technologies, tritium storage & delivery system, tritium extraction system, Tokamak exhaust processing system, tritium diagnostics.
- **Blanket Safety:** Gaseous and liquid releases during normal operation and maintenance, accidental conditions – Design Basis Accidents (DBA), Beyond Design Based Accidents (BDBA), Loss of Coolant Accidents (LOCA), Loss of Flow Accidents (LOFA), complete loss of active cooling.

AS3 - <u>Fusion Materials</u> (30 Lectures)

- **Fundamentals of Material Science**

  - Crystalline nature of matter - Structure and bonding of atoms, atomic arrangements in materials, Structural phase formation and transition, Types of materials (Metals, Alloys, ceramics, composites, glasses, polymers, Superconductors).
  - Defects in solids – Imperfections, Frenkel pairs, Dislocation theory, Grain-boundary, Stress Fields and Strain Energy
  - Metallurgical Aspects of materials – Solid solutions, solubility, Precipitation, Diffusion in solids (Diffusion Laws), ordering in alloys, Phase diagrams, strengthening and hardening Mechanisms, Annealing and heat treatment.
  - Physical Properties of materials – Electrical, Thermal, Magnetic, Dielectric, optical and other properties of materials
  - Mechanical Behaviour of materials – Elastic and Plastic deformation, metallic Creep and fatigue, Strengthening and toughening of steels and non-ferrous alloys, fracture and DBTT , toughness
  - Introduction & Survey of Computational Tools, Multi-scale Models

- **Fusion Materials Requirements & Issues**

  - High heat flux handling – HHF source types, parameters and effects.
  - Erosion & Corrosion – Sputtering, erosion due to heat and particle bombardment, erosion and corrosion due to liquid metals, Hydrogen embrittlement, Oxidation, Pitting and crevice corrosion

- **Material Development and Joining Technologies**

- Manufacturing Methods & Processes – Steels and alloys melting, Powder metallurgy route, Ceramics preparation methods, Composites developments, Superconducting materials manufacturing.
- Structural Materials – Austenite and Ferritic Martensitic (FM) steels, ODS alloys, Vanadium and Titanium alloys, Carbon and SiCf/SiC composites
- Functional Materials – Plasma facing Materials (Tungsten, graded and other materials), Tritium Breeding & Blanket materials, special ceramics, Superconducting materials, Heat sink Materials, shielding Materials, Diagnostics and window materials, coatings
- Joining Technologies – Methods and Issues (Welding, Brazing, Diffusion Bonding, Hiping)

- **Material Characterization & Qualification**

  - Structural Characterization – Crystal and Microstructural Analysis, defect structure, Phase Transition (XRD, SEM, TEM, Neutron Diffraction, PAS)
  - Compositional Characterization & Surface Techniques (EPMA, EDX, ICP-MS, XPS and AES, SIMS), Impurity limits
  - Particle beam Techniques (ERDA, RBS, NRA, Synchrotron Source)
  - Mechanical Property Testing- Hardness, Fatigue, Fracture, Tensile, Creep
  - Thermal Property Testing – High Heat Flux test, Thermal conductivity, Thermal Expansion coefficient, Electrical Property Testing & NDT, codes and standards – Resistivity (AC &DC), Radiography, Ultrasonic techniques

AS4 - RF, Current Drive and Neutral Beam Heating (30Lectures)

- **Heating and current drive physics by neutral beam**

Basic process during beam-plasma interaction, Beam injection geometry and its implication, Energy transfer mechanism from energetic neutral beam particle to plasma, Energetic particles orbits in asymmetric field structure, Physics of current drive by NBI, Role of fast ions in Neutral Beam Current Drive efficiency.

- **Neutral beam injector system design and engineering**

Basic NBI configuration, Optimization procedure of beamline configuration, Pressure profile optimization, Beam transmission optimization.I on source design and engineering, Different Plasma production mechanism, Positive ion and negative ion production, Ion extractor and accelerator system, Beamline component design and engineering, Neutralizer, Residual Ion Dump (RID), Calorimeter or V – target, Vacuum system design and engineering, Vacuum vessel, NBI – tokamak interface duct, Cryopumps and cryogenic system, Auxiliary pumping system, Diagnostic system design and engineering, Ion source plasma diagnostics, Electrical Probe based, Spectroscopy based, Negative ion diagnostic, Laser photo-detachment, Cavity ring down method, Hairpin resonator based, Ion-acoustic wave based, Beam profile diagnostic, Doppler shift spectroscopy, Thermal imaging diagnostic, Calorimetric diagnostic, Power supply system design and engineering, RF Power supply, HV power supply for ion extraction and acceleration.

- **Introduction to RF heating**

Introduction to Fusion Reactor: Why RF and Microwave Power is required for Fusion? Interaction of electromagnetic waves with plasma.

- **Waves**

Theory of waves in unmagnetized plasma, EM waves, Longitudinal waves, Transverse wave, Ion acoustic waves. Theory of waves in magnetized plasma, EM waves, X-mode, O-mode, Hybrid waves. Classification of RF regimes. RF Requirements of Fusion Reactor, Different heating, pre-ionization and current drive mechanisms. Dispersion relations. Wave propagation in toroidal plasma geometry. Power absorption, Landau damping, Current drive mechanisms in different regime.

- **RF devices and Design tools**

Introduction to general type Waveguide, RF amplifier and Oscillators, Antennas, Engineering issues, RF design software.

- **ICRH**

Introduction to RF applications in ICRH, its design and issues. Introduction to RF transmitter, Power transmission, Antenna design, Auxiliary systems for ICRH. Diagnostic system, Impedance matching unit, Control system. Important results on different tokamaks about ICRH system. Introduction to Aditya and SST-1 ICRH Systems

- **ECRH**

Introduction to RF application in ECRH its design and issues. Introduction to Gyrotron source. Power transmission, Antenna design, Auxiliary systems for ECRH. Diagnostic system. Control system. Important results on different tokamaks about ECRH system. Introduction to Aditya and SST-1 ECRH Systems.

- **LHCD**

Introduction to LHCD system its design and issues. Introduction to Klystron source, Power transmission, Antenna design, Auxiliary systems for LHCD. Impedance matching unit, Diagnostic system, Control system. Important results on different tokamaks about LHCD system. Introduction to Aditya and SST-1 LHCD System.

- **Other types of wave heating**

Alfven wave heating, Bernstein wave heating, Design and its issues, Introduction to its sources, Power transmission, Antenna design, Impedance matching unit, Diagnostic system, Control system. Important results on different machines.

TRIMESTER II – PART B

Part –B contains the details of the core subjects.

PHYSICS

PH1 - Magnetohydrodynamics (60 Lectures)

- Physical description of electrically conducting fluids
- Derivation of basic MHD equations: Continuity, Equation of motion, Energy flow, Ohm's law, Validity of MHD equations
- The low frequency dynamics of the electromagnetic field
- Some properties of MHD: Ideal MHD equations, The Frozen Flux theorem, The effect of resistivity, Similarity scaling, The Wöltjer invariants and helicity
- Equilibrium: General considerations, The Virial Theorem, Examples of simple equilibria: -pinch, Z-pinch, screw pinch, Poloidal , paramagnetic and diamagnetic states, Force-free fields, Toroidal equilibrium: the Grad-Shafranov equation, nonlinearity, Definition of q, beta, plasm ashape, etc.
- Comparison of fusion confinement systems: Spheromak, FRC, RFP, Spherical Tokamak
- Tokamak Equilibrium: In large aspect ratio limit with arbitrary choice of profile, Solovev equilibrium with finite aspect ratio and linear profile in poloidal flux, Solution with arbitrary aspect ratio and arbitrary choice of profiles (numerical)

PH2 - Kinetic theory and Statistical mechanics (60 Lectures)

- Gas dynamic way of describing an uncharged fluid – heuristic
- Recollect derivation of basic MHD equations – one fluid only (Continuity, Eqn of motion, Energy equation [thermodynamic closure], Electron equation of motion [Ohm's Law])
- Introduce ideas of Phase Space (x,v) and distribution functions f(x,v,t)
- Using heuristic arguments in single particle phase space (x,v) to obtain "fluid equations" in phase space – namely – the Vlasov-Poisson Equations
- Introduce conservation of Energy and other physical quantities as constraints.
- Using constrained variation technique demonstrate how entropy extremization leads to Maxwell-Boltzmann distribution f_mb(x,v) and importance of Maxwell-Boltzmann distribution
- Langmuir Oscillations and Waves – Vlasov-Poisson dispersion
- Linear Landau Damping – why is this not seen in fluid equations?
- Two stream instability and Phase Space structure formation
- Many stream interpretation of an equilibrium distribution f_mb(x,v)

- Stability – Newcomb-Gardner Theorems and Penrose Stability Criteria
- Nonlinear Landau damping and Theory of BGK modes – revisit Two stream instability.
- Stability of BGK modes.
- Particle correlations and need for two-body and higher order distributions
- Equations governing two body distrution f_2(x,v,t) and its relationship to f(x,v,t) the one-body or Vlasov distribution studied earlier – Introduction of pair correlations
- Construction of a N-body distribution function f_N and BBGKY Hierarchy issues.
- Klimontovich-Dupree (KD) procedure – Obtaining a "statistical N-body" distrituion from KD equation.
- Green-Kubo formalism – Transport and Correlations
- Examples of GK formalism and obtained transport
- Very cursory introduction to Onsager relationships

PH3 - Advanced Heat Transfer and Cryogencis (60 Lectures)

(PLEASE SEE ME5 – these are common courses for Physics and Mechanical disciplines)

PH4 - Tokamak related Code (30 Lectures)

- **Plasma core modelling:**

— Plasma equilibrium IPREQ

— Plasma transport TSC

— Plasma stability ERATO, PEST2

— ICRH heating TORIC

— NBI heating NUBEAMS

— Plasma start up model

— Reactor system code

— Eddy current analysis

— TF modelling EFFI

— Vertical instability analysis

- **Edge-SOL studies**

— 2D blob transport

— Divertor study SOLPS (B2+ERINE)

— 3D plasma study ERINE-3D

- **First principle simulations**
  - Low frequency (w/wc <<1) transport – what is Gyrokinetic method?
  - What are the transport processes neglected by gyrokinetic formalism?
  - What are global and local simulations – examples (flux tube modes and global models)?
  - Under what conditions do results from these two simulations are expected to match?
  - Gyrokinetic equations derived from Vlasov-Poisson equations using Bessel function procedure
  - How does Gyrokinetic formation capture the physics of Finite Larmor Radius to all orders at low frequencies?
  - Numerical Advantages of Gyrokinetic formalism – examples
  - Simulating very large scale systems (100s of larmor radii) using very large parallel computers – Issues and Advantages
  - Modelling energetic particle transport using Gyrokinetic formalism

MECHANICAL

ME1- Code Design for internal and external pressure vessel (30 Lectures)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and tori spherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div – II equations for cylindrical / Spherical shell and conical, ellipsoidal and tori spherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3.
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive

Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1and Div.2.

- Difference between metallic pressure vessel and FRP pressure vessels.
- Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Failure modes of pressure vessels, Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and piping's.

ME2 - Finite element and volume methods (60 Lectures)

Finite Elements methods (30 Lectures):

- Introduction to FEM: Weighted residual method, Galerkin's methods, Weak form formulation, piecewise approximations. Basis of Finite Element Method, Variation principles, energy principles in structural mechanics, Element libraries
- Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements
- Bar element: Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss.
- Beam element: Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- 2D plane elements – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- 2D isoparametric formulation – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress.
- Introduction and Application to 3D elements: Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Shell element: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions.
- Introduction to Nonlinear problems: Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method.

- Finite element applications for design: Finite element modelling and discretization criterion,h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

Finite Volume Methods (30 Lectures):

Basics of Fluid Flow, Heat Transfer and Numerical Analysis

- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity',momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme

Laminar Boundary Layer and Forced Convective Heat

- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Convective heat transfer for internal and external flows.
- Low and high Prandtl number limits and different thermal boundary conditions.

Turbulent Flow and Heat Transfer

- Reynolds decomposition for turbulence.
- Prandtl's mixing length theory, Mixing length models.
- Structure of turbulent boundary layer over flat plate and through circular cylinder.
- Calculation of friction factor and drag coefficient.
- Analytical and semi-analytical correlations for calculating heat transfer coefficients.
- Reynolds analogy & Low Reynolds number models.
- Turbulence Modelling.
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model.
- Reynolds stress models: algebraic and differential models.

Natural Convection

- Basic Equations of natural convection.
- Derivation of Dimensionless groups from basic equations.
- Analytical approximations.
- Numerical solution of approximate equations.

Numerical Solution of Complete Fluid Flow and Energy Equation

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation.
- Primitive-Variable (P-V-T) formulation.
- Pressure velocity coupling for incompressible flow
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE, SIP and SIMPLEN family of Methods.
- Simple grid generation techniques for structured grid.
- Elliptic, parabolic and hyperbolic equation method.
- Domain decompositions in CFD and heat transfer.

ME3 - Mechanics of solid/vibration/ remote handling (30 Lectures)

Mechanics of solids

- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of stress

- Description / Notations of Forces & Stress.
- Component of stress.
- Reciprocity of shear stress in 3D.
- Stresses Transformation using direction cosines.
- Stress Traction Vectors or Traction Vectors.
- Stress component on an arbitrary plane.
- Principal stresses & Mohr's Diagram for 3D state of stress.
- Stress Invariants.
- Hydrostatic and Deviator components of stress.
- Principle planes and their orthogonally.
- Octahedral plane, Octahedral stresses.
- State of pure shear.

Analysis of strain

- Description / Notation of Strain in 3D.
- Components of strain.
- Strain Transformation using direction cosines.
- Principle Strains, Strain Invariants.
- Strain Deviator Tensor.

Principles and fundamental Equations of Elasticity

- Strain and displacement relations (Cauchy's equations).
- Compatibility equations (Saint-Venant's Equations).
- Generalized Hook's Law.
- Anisotropy and Isotropy of elastic behaviour.
- Stress and strain relationship.
- Equations of equilibrium (Navier's Equations, Lame's equations).
- Strain Energy.
- Uniqueness theorem.
- Bounds on elastic constants.
- Superposition Principles.
- Saint-Venant's Principle.
- General Solution Procedures for an elasticity problem.

Vibrations

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations underdamped, overdamped and critically damped systems; Response to harmonic loading -complementary solution and particular solution; Response to periodic loadings using Fourier Series
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems;Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration).

Remote handling

- Automation and introduction to remote handling.
- Industrial manipulators.
- Kinematics of manipulators specifying position and orientation of rigid bodies, Euler angles, homogeneous coordinate transformations, D-H representations of kinematic linkage, velocity analysis of manipulators.

ME4 - Advanced Manufacturing Technology (30 Lectures)

ADVANCE MANUFACTURING PROCESSES

- INTRODUCTION: Unconventional Machining Process, Need – clarification – Brief overview of all techniques.
- MECHANICAL ENERGY BASED PROCESSES: Abrasive Water Jet Machining, Water Jet Machining, Ultrasonic Machining (AJM / WJM/ USM). Working principles – equipments used – process parameters – MRR – Variation in techniques used – Applications.
- ELECTRICAL ENERGY BASED PROCESSES: Electro Discharge Machining, Working principles – Equipments – Process parameters – MRR – electrodes/ tools / power circuits – tool wear – Dielectric- flushing- Wire cut EDM – Applications.
- CHEMICAL AND ELECTRO-CHEMICAL ENERGY BASED PROCESSES: Chemical Machining, Electro- Chemical Machining – Etchants- maskant-Techniques of applying maskants – Process parameters – MRR –Applications. Principles of ECM-MRR-Electrical circuit – process parameters – ECG and ECH applications.
- THERMAL ENERGY BASED PROCESSES: Laser Beam Machining, Plasma Arc Machining and Electron Beam Machining. Principles – equipments – types – beam control techniques applications.

ADVANCED MATERIALS JOINING AND TESTING

- INTRODUCTION: Classification – heat sources – metallurgical effect of weld – residual stresses: formation and relieving – capillary and welding action – temperature range – filler material and fluxes – types of joints and welding positions – weldability: design, process and metallurgical consideration – testing and improvement.
- JOINING TECHNIQUES: Bolting – riveting – soldering – blazing – adhesive bonding – diffusion bonding – mechanical joining. Fusion welding: Oxyacetylene welding – SMAW – GTAW – GMAW – FCAW – SAW – ESW – High energy beam welding: EBW, LBW, PAW – friction stir welding. Output parameter variation – advantages and disadvantages – applications.
- RESPONSES OF MATERIALS TO WELDING: Microstructural changes – distortion – defects: undercuts –overlaps – grain growth – blowholes – inclusions – segregation – lamellar tearing – porosity. Remedies: Edge preparation – alignment – control of heat input – preheating – peening – heat treatment – jigs and fixtures – number of passes.
- DESTRUCTIVE AND NON-DESTRUCTIVE TESTS FOR WELDS: Introduction – need – principles – applications –destructive tests: tensile, bend, impact, hardness, fatigue, cracking,

etching. Non-destructive tests: Visual, dye penetrants, magnetic particle, acoustics, pressure, radiographic, ultrasonic, eddy current.

ME5 - Advanced Heat Transfer and Cryogenics (60 Lectures)

Computational Fluid Dynamics

- Basics of fluid flow and heat transfer, Mathematical description of fluid flow, conservation equations for mass and momentum, Classification of partial differential equations, discretization techniques using finite difference and Finite volume methods, Taylor's series and control volume formulations, stability, consistency and Convergence of numerical schemes, application of numerical methods to model equations.
- Natural convention and Forced convection heat transfer and calculation heat transfer coefficient for different geometrical configurations and analytical approximations relations
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and adiabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio.

Heat Transfer

Conduction:

- Derivation of energy equation for conduction in three dimensions – Initial and boundary conditions. Solution of simple problems in steady state conduction with analytical solutions – Concept of electrical analogy – fin heat transfer and concept of fin efficiency and fin effectiveness.
- Concept of Biot number – Lumped capacitance formulation – simple problems – unsteady conduction from a semi-infinite solid- solution by similarity transformation method. Solutionof the general 1D unsteady problem by separation of variables and charts- example problems.
- Laplace equation – solution by variable separable method – concept of superposition and homogeneous boundary conditions. Phase change problems – The Stefan and Neumannproblems – analytical solutions.

Convection:

- Natural Convection heat transfer: Governing equations for natural convection, Bossiness approximation, Dimensional Analysis, Similarity solutions for Laminar flow past a vertical plate with constant wall temperature and heat flux conditions, Integral method for natural convection flow past vertical plate, effects of inclination, Natural convection in enclosures, mixed convection heat transfer past vertical plate and in enclosures.
- Laminar External flow and heat transfer:
  Similarity solutions for flat plate (Blasius solution), flows with pressure gradient(Falkner-Skan and Eckert solutions), and flow with transpiration,

Integral method solutions for flow over an isothermal flat plate, flat plate with constant heat flux and with varying surface temperature (Duhamel's method), flows with pressure gradient (von Karman-Pohlhausen method).

- Laminar internal flow and heat transfer:
  Exact solutions to N-S equations for flow through channels and circular pipe, Fully developed forced convection in pipes with different wall boundary conditions, Forced convection in the thermal entrance region of ducts and channels (Graetz solution), heat transfer in the combined entrance region,
  Integral method for internal flows with different wall boundary conditions.

Radiation:

- Fundamental of thermal radiation and electromagnetic wave theory
- View factors.
- Radiative exchange between grey and diffuse surfaces.
- Radiation between non-ideal surfaces.
- Surface radiative exchange in the presence of conduction and convection.
- The equations of radiative transfer in participating media.
- Radiative properties of molecular gases.
- Introduction to monte Carlo method for thermal radiation.
- Governing Equations: Continuity, Momentum and Energy Equations and their derivations indifferent coordinate systems, Boundary layer Approximations to momentum and energy.

Cryogenics

- **Basic Principles of Cryogenics:**

Thermodynamics, Heat Transfer, Heat Leak, Pressure drop, Cool down, Applications of cryogenics, Properties of cryogenic fluids, Properties of materials (Structural & thermal) at cryogenic temperature, Material selection criteria

Gas-Liquefaction and Refrigeration Systems:
Refrigeration and Liquefaction, Recuperative cycles, Liquefaction of gases, Inversion temperature, Expansion processes, Refrigerator efficiency, Refrigeration and Liquefaction Methods, Regenerative cycles, Ultra low temperature refrigerators, Cryo-coolers.

Cryogenic Insulations:
Types of insulations, Vacuum Insulation, Evacuated Porous Insulation, Gas-filled Powders and fibrous materials, Solid foams, Multilayer Insulations, Liquid and vapor shields, Composite insulations, Placement of insulation systems, Comparison of insulations

Instrumentation in Cryogenics:
Measurement: Strain, Displacement and position, Pressure, Temperature, Flow, Liquid level, Density

Cryogenic Equipment and Cryogenic System Analysis:
Introduction, Compressors, Pumps, Expansion Engines, Valves, Heat Exchangers, Storage, Transfer of liquefied gas

Safety with Cryogenic Systems:
Physiological Hazards, Suitability of materials and construction techniques, Explosions and Flammability, Excessive pressure gas, Special considerations for Hydrogen and Oxygen, General Safety Principles, Safety Checklist

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Electrical/Electronics/Instrumentation

EE1 - Advanced Data Acquisition System (30 Lectures)

- **Theory of Quantization**
  Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, antialiasing filters.

- **Advanced Data Acquisition Systems**

  Modular Data Acquisition Systems in Nuclear Instrumentation: CAMAC, VME, PXI, PXIe. DAQ system architecture and major components. Data Archival and Retrieval. DAQ Data server architecture and interface, Data plotting and analysis tools

- **Data Acquisition Interface**

  Sensor – DAQ interface: Grounded Signal Sources, Floating Signal Sources, Grounding Issues: Various Grounding schemes for accurate measurements, Types of Measurement Systems: Differential Measurement System, Referenced and Non-Referenced Single-Ended Measurement Systems, Graphical/command based programming for the acquisition, processing, and presentation of data: MATLAB, LabVIEW Application development environment.

- **Analog Input/output**
  Analog Input Circuitry, Anti-aliasing Filters, sampling and DAQ device architecture, Analog Output Architecture, Analog Output Circuitry, Update rate and output interface.

- **DAQ Clock and Trigger**
  Theory and concepts of analog and digital triggering, Continuous and event-based acquisition, Clock and trigger input and output to DAQ device for timing and synchronization, Counter I/O: Edge Counting, Pulse Generation, Pulse Measurement, Frequency Measurements.

- **Synchronization**
  Single Device Synchronization: Simultaneous sampling, Multiple Device Synchronization: Clock and trigger synchronization, Introduction to Timing system.

- **SST-1 Data Acquisition System**

  Architecture of SST-1 Data Acquisition System: overview and major components, System requirements, Various DAQ interfaces: CAMAC, PXI, PXIe, digitization requirements, Signal-conditioning system: Channel requirements, various stages in signal conditioning system, CAN bus interface, DAQ Software: LabVIEW based GUI for remote operation, Networking requirements and TCP/IP based communication with subsystems, distributed system, DAQ NAS server, Central Data storage server, server management, data plotting utilities.

EE2 - Advanced Tokamak Controls (30 Lectures)

- **Fundamentals of Control System**

  Systems and their representation: Terminology and basic structure of control system, Open loop and Closed loop systems, servomechanism, regulatory system, analogous systems, electrical analogy of physical systems, Physical Systems and their models, transfer function, Block diagram representation of physical systems, Block diagram algebra, Signal Flow graph. Systems in state space: Concept of states and state model, State equation from transfer function, modelling of dynamical systems, State space representation of multivariable systems, Building blocks of state space models. Advanced control system: Cascade control, ratio control, feed forward control. Over-ride, split range and selective control. Multivariable process control, interaction of control loops Process Control System: Terms and objectives, piping and Instrumentation diagram, instrument terms and symbols. Regulator and servo control, classification of variables. Process characteristics: Process equation, degrees of freedom, modelling of simple systems – thermal, gas, liquid systems. Process lag, load disturbance and their effect on processes. Self-regulating processes, interacting and non-interacting processes.

- **Different types of Control Systems**

  Feedback control system, Real-time control system, Nonlinear and Adaptive Control, Robust control system, Embedded Systems: Hardware and software architecture, Neural Networks, Fuzzy Logic Systems

- **Introduction to Plasma Control**

  Plasma Position Control, Shape Control, Density Control, modelling aspect, simulations, Plasma Control case studies: D-III-D, JT-60, JET, SST-1, EAST, ITER.

- **ITER Instrumentation & Control**

  CODAC (Control, Data Access and Communication) System, Central Interlock System (CIS), Central Safety Systems (CSS), Plant Control System, Plant Interlock System, Plant Safety System, CODAC Core Systems, EPICS, SNL, CSS, MDS Plus, LabVIEW, Matlab Simulink, Python, Grid Computing, Parallel Processing, Diagnostic Data Analysis Tools and Codes, Real-Time OS.

- **SST-1 Operation &Control**

Architecture of SST-1 Operation &Control System, System requirements, system overview and major components. Signal-conditioning system: Channel requirements, various stages in signal conditioning system, CAN bus interface, GUI based remote operation, TCP/IP based communication with subsystems, distributed system. Data Acquisition System: System overview, various interfaces, CAMAC, PXI, PXIe based technology; LabVIEW based GUI, digitization requirements, system architecture, technical requirements, network storage server, server management, data plotting utilities. Operation and Control System: Timing system, Central Data storage server, Interlock system, Tokamak operation and subsystem control, VME based control system

- **Monitoring and Control of Auxiliary Systems**

Monitoring& Control for ICRH, ECRH, NBI. Vacuum System, RHVPS and Switching scheme, Cryogenic Cooling Plant, CWS, BMS, Access Control, Super conducting Magnet Quench detection and protection.

EE3 - High Voltage DC & AC/ Power Supplies (60 Lectures)

- **Overview of Electrical systems in Fusion machines**

Basic introduction to electrical systems in Tokamak, Stellarator and Z-machine; Tokamak as a transformer, Electrical systems for plasma formation – Ohmic discharge, Arc discharge, RF discharge, MW discharge; Electrical systems for plasma confinement – Magnet power supplies, Electrical systems for plasma acceleration – Accelerator power supplies for charged particles. Use of other HV equipment in Fusion Technology: Capacitor bank, Van-de-graf generator, Pulse forming lines, Marx generator, Power supply systems applications in fusion machines.

- **High Voltage DC & AC**

High Voltage Generation, High AC, DC and Impulse Voltages, High Voltage Components, Basic design features of High Voltage Power Transformer: Basic design of HV Transformer, Transformer insulation requirements, dielectric strength and voltage conditions, winding arrangements, surge behavior, behavior of liquid dielectric, electrode surface phenomena, gas evolution, processing techniques, construction of EHV transformer, short circuit behavior. High Voltage Circuit Breakers: Air break, SF6 and vacuum circuit breakers. Gas Insulated Substation (GIS): Advantages of GIS, comparison of GIS and air insulated substations, design and layout of GIS, description of various components of GIS. High Voltage Measurement: CVT, Peak voltmeters, sphere gaps, impulse recording, Over-voltage and protection, Insulation coordination, High voltage testing methods using Partial discharge (PD), Causes and effects of PD, PD diagnostic techniques. HV and UHV systems: Fusion Technology Applications. Basic Overview of Pulse Power Technology.

- **Power Supplies**

- DC Power Supplies: Linear and switching power supplies, DC to DC converters and their operating characteristics, Selection of Power Semiconductor Devices, Magnetic component behavior and

selection. Control pulse generation and control techniques, Feedback isolation techniques, Auxiliary power supply generation, Parallel operation.

- AC Power Supplies: Linear mode AC power supplies. Switching mode Inverters, Sine wave inverters, Parallel operation, AC voltage regulators, UPS systems.
- Special Power Supplies: Power supplies for pulsed gas discharge tubes, High current power supplies. Power supplies for heating and current drive: Power Supply for Neutral beams, Power Supply for Ion cyclotron & Electron Cyclotron heating.
- Power supplies required for RF amplifiers or Oscillators. HV supplies, their interconnections for RF applications. Specific requirements of power supply protections etc., General topologies with emphasis on conventional and modular topologies, Performance requirements, Critical protections, Remote control and Monitoring requirements.
- Requirement for arc fault protection, Protection by crowbar, Deices used for crowbar applications, Importance of fault energy and techniques to limit the fault energy, wire-burn test.
- Auxiliary supplies: Screen grid, Control Grid, Filament and ion pump power supplies, General topologies for each of the supply. Performance requirements, important performance requirements, Critical protections, monitoring and remote control requirements.
- Safety and System Grounding: Power supplies inter connection at load end. Issues related to system grounding, choices available for system grounding. Safety of system and personnel for RF system.
- Integrated operation, Protection and Monitoring: HV isolation for input power of auxiliary supplies. Monitoring power supplies' status and performance. Remote and local control of power supplies. Fast and slow interlocks.

- **Power Electronics and design through modelling & simulation**

Junction Transistors (BJT, HBT), Field Effect Transistors (JEFT, MESFET, MOSFET, HEMT), Power semiconductor devices, IGBT, GTO and MCT: AC-DC Converters; Forced commutation; synchronous link converters, DC-AC converters, buck, boost, buck-boost, cuk, flyback configuration, resonant converters, PWM inverters; active filters. Machine modelling, DC machines, induction motor and synchronous machines; simulation of transients; Simulation tools: SABER, PSPICE, and MATLAB-SIMULINK; Simulations of converters, inverters and cyclo-converters etc.

EE4 - Analog Signal Conditioning and EMI/EMC Aspects (30 Lectures)

- **Analog Signal Conditioning**

Principles of Analog Signal Conditioning, Signal Conditioning Configuration, Signal Conditioning Functions, Amplification, Transducer Excitation, Filtering, Isolation, Signal Conditioning for Plasma Diagnostics, Operational Amplifiers, Op-amps/ integrated circuits in instrumentation, Phase-sensitive rectifiers, Industrial Electronics.

- **Signal Processing and Applications**

Review of signals and systems: Introduction, advantages and limitations of Analog and Digital Signal Processing, Advantages and Disadvantages of Digital Filters over Analog Filters, Introduction to Infinite Impulse Response Filters and Finite Impulse Response Filters, Applications of digital signal processing in measurement and control systems.

- **EMI/EMC**

Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Fusion Devices, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards, Testing Standards for Emissivity & Susceptance.

- **EMI Modelling**

Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling &Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EE5 - Computer Based System Design (30 Lectures)

- **Computer Fundamentals**

Personal computer architecture, memory organization, industrial PC, Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications, Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL).

- **Communication**

Asynchronous and synchronous communication, Standards like RS232, RS422, RS485, USB, Encoding schemes.

- **Networking**

Local Area Networks, OSI 7 layer model and TCP/IP reference model, Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth, Networking hardware – cables, hub, switch, router etc. Role of fibre optics in communication, Fieldbus standards, Deterministic communication techniques, Case study: various techniques used in Tokamak/Fusion devices for communication and networking.

- **Real-time systems**

Real-time Systems, their characteristics and applications, Real-time Operating Systems, Concepts of Process and threads, Concurrency, Latency, context switching, Scheduling policies, Inter process communication, Semaphores, Priority inversion, Shared memory, Common systems calls, Communication features in RTOS, Comparative study of various RTOS, Integrated software development environment

EE6 - Digital Signal Processing & Image Processing (30 Lectures)

Digital Signal Processing

- **Introduction**
  Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**
  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT

- **Fast Fourier Transform**
  Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- **Digital filters**
  FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- **DSP Applications**
  Applications of digital signal processing in fusion and other fields.

Image Processing

- **Introduction**
  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format.

- **Image Enhancement**
  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing.

- **Image Segmentation and Analysis**
  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation, Boundary extraction and representation.

- **Morphological operations**
  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy based Methods, Image Compression Models, Error free compression, Lossy compression, Standards.

Courses of Study

For PhD Program

SCHOOL OF HUMANITIES & SOCIAL SCIENCES

SYLLABUS FOR

Ph.D. in APPLIED SYSTEMS ANALYSIS

(Program Code: APSA04)

National Institute of Science Education and Research Bhubaneswar

(An Off-Campus Center of HomiBhabha National Institute– a deemed to be University, Anushakti Nagar, Mumbai)

With effect from the Academic Year 2018

PhD Programme in the School of Humanities and Social Sciences

(Economics, English, Psychology and Sociology)
National Institute of Science Education and Research Bhubaneswar

Duration of Course work : 1 year

Structure of the Course work:

	No of courses	Credits
Core	**2**	**12**
***Discipline Elective**	**4**	**24**
Open Elective	**2**	**12**
Self-study/online/predoctoral work	**2**	**12**
Total	**10**	**60**

** Discipline means Economics, English, Psychology and Sociology*

Core Courses

List of Core Courses

Course No	Credits	Course Name	Semester
H 601	6	Research Methods - I	I
H 602	6	Research Methods - II	II

Elective Courses

A student has to choose at least four elective courses on his/her area of interest for research from a list of courses offered by different disciplines during a particular semester. It may be noted that the courses offered will depend on the availability of faculty with expertise in a particular area as well as critical number of students opting for the course. In some cases students will be asked to obtain a few credits from other schools. Additionally, students are required to take two self-study and/or credit seminars and/or online courses from the NPTEL/SWAYAM portal or do 6/12 credits of pre-doctoral research work. The school retains the authority to make the final decisions in this regard depending upon the individual need of the student.

List of Elective Courses

Course No	Credits	Course Name	Discipline
H 611	6	Advanced Economic Theory	Economics
H 612	6	Econometric Theory and Applications	Economics
H613	6	Issues in Public Finance	Economics
H614	6	Development Economics	Economics
H615	6	Environmental and Ecological Economics	Economics

H616	6	Poverty, inequality and Development	Economics
H617	6	Project Evaluation	Economics
H618	6	Indian Industrial Development	Economics
H619	6	New Institutional Economics	Economics
H620	6	International Trade and Finance	Economics
H621	6	Topics in experimental and behavioural approaches to economic development	Economics
H 622	6	Environmental Economics and EIA	Economics
H631	6	Humanities and the Institutional Space	English
H632	6	The Modern European Novel	English
H633	6	The idea of the nation in Indian English Fiction	English
H634	6	Black Intellectual traditions and the Narratives of Race in America	English
H 635	6	Writings of the South Asian Diaspora	English
H 636	6	Translation and Culture: Issues and Perspectives	English
H 651	6	Organizational Behaviour	Psychology
H 652	6	Leadership	Psychology
H 653	6	Organizational Change and Development	Psychology
H 654	6	Positive Psychology	Psychology
H 655	6	Cross Cultural Psychology	Psychology
H 656	6	Business Ethics	Psychology
H 671	6	Classical Sociological Theory	Sociology
H 672	6	Information and Society (Theory)	Sociology
H 673	6	Sociology of Development	Sociology
H 674	6	Contemporary Social Theory	Sociology
H 675	6	Qualitative Research Methods	Sociology
H 676	6	Quantitative Research Method I	Sociology
H 677	6	Social Network Analysis I	Sociology

Details of the Course

COMMON CORE SYLLABUS (Compulsory for all incoming PG students)

Research Methods – I (H 601)

Core, Semester 1

(Teaching Faculty drawn from across the disciplines of the school)

1. Defining a research project (8 classes + 2 tutorials)

Asking questions, Big five: What,How,Why, What will it be and What should it be, Deciding a right methodology, Understanding the difference between qualitative and quantitative research, Sampling methods.

2. Methods of Studying Psychology (8 classes + 2 tutorials)

Experimental method, Observational study, Survey method, Interviews, Self report, Case Studies. Geneological, Managing perceptual biases in research.

3. Socio Economic data mining and computer applications (8 classes + 2 tutorials)

Mining of different data sets such as Census, NSS, RBI, Public Finance. Introduction to SPSS and STATA for data analysis.

4. Critical Theory and textual analysis (8 classes + 2 tutorials)

The notion of critique. Spatialization and context. Rigor and the idea of meaning. Text as narrative.

5. Historical Analysis (8 classes + 2 tutorials)

Why study history, Historical process, Discovery and analysis, Methodological framework, Historical evidence, Rules of evidence, Primary and secondary sources.

References

Beins, B.C. (2004). *Research methods: A tool for life*. Boston: Allyn & Bacon.

Bell, C. and Newby, H. (eds) (1977). *Doing sociological research*. London: Allen and Unwin.

Breakwell, G., Hammond, S. and Fife-Shaw, C. (eds) (1995). *Research methods in psychology*. London: Sage.

Breakwell, G., Hammond, S. and Fife-Shaw, C. (eds) (1995). *Research methods in psychology*. London: Sage.

Briggs, Asa A. (1984). *Social history and human Experience*. Cedar City, UT: Grace A. Tanner Center for Human Values.

Cozby, P. C. (1993). *Methods in behavioral research* (5th ed.). Mountain View, CA: Mayfield Publishing Co.

Davidson, James West, and Mark Hamilton Lytle. (2000). *After the fact: the art of historical detection*. Boston MA: McGraw Hill.

Field, Andy (2013). *Discovering statistics using IBM, SPSS*. London: Sage Publications.

Guerin, Wilfred L., et. al. (2010). *A Handbook of Critical Approaches to Literature* (6^{th} edition). London: OUP.

Hammersley, M. (ed.) (1993). *Social research: philosophy, politics, and practice*. London: Sage.

Kalton, G. (1983). *Introduction to survey sampling.* London: Sage.

Marwick, Arthur. (1989). *The nature of History*. 3rd ed. London: MacMillan Education.

Parker, Robert Dale (2012). *Critical Theory: A Reader for Literary and Cultural Studies* (1st Edition). London: OUP.

Peter H., Stearns. (XXXX). *Why study history?* American Historical Association: http:// www.historians.org/pubs/free/WhyStudyHistory.htm.

Shaughnessy,J.J., Zechmeister, E. B. Zechmeister, J.J. (2008). *Research methods in Psychology* (5^{th} ed). London: McGraw–Hill.

Startt, James D., and William David Sloan. (2003). *Historical methods in mass Communication*. Rev. ed. Northport, AL: Vision Press.

STATA Corp (2014). *STATA Users's Guide.* Stata Press Publication, Stata Corp. LP College Station, Texas.

Wolfreys, Julian (2000). *Readings: Acts of Close Reading in Literary Theory*. Edinburgh:EUP.

Research Methods – II (H 602)

Core, Semester II

(Teaching Faculty drawn from across the disciplines of the school)

1. **Ethical aspects of Research (8 classes + 2tutorials)**

Historical background, Fundamental ethical principles, Informed consent, Institutional review, Data safety monitoring, Adverse and serious adverse events

2. **Contextual aspects of research (8 classes + 2 tutorials)**

Environmental challenges, structure of organizations and its impact on behavior, understanding the culture from where information is gathered.

3. **Methods of Policy Analysis (8 classes + 2 tutorials)**

Introduce methods of policy analysis. Examine prescriptive methods; i.e. methods for weighing the "costs and benefits" of alternative courses of policy action. Which policy "option" represents the best--most effective, most efficient, most equitable choice for government action. Second, methods for evaluating policy and program performance *post*-implementation. How do we know when a policy or program is working? We consider both process evaluations (is the implementing agency actually carrying out its assigned tasks?) and outcome/impact evaluations (is the policy/program actually having the expected effect?). Third, consider methods for assessing policy outcomes–i.e. broad social impact. Our toolkit of methods will include both quantitative and qualitative models and techniques.

4. **Rhetoric and Research writing (8 classes + 2 tutorials)**

The argument. Dialectics. Visual narratives. Mechanics of writing.

5. **Logical system and causation (8 classes + 2 tutorials)**

Foundations of social science, Two logical systems, Cause and effect relationship, Different Causal claims, Statistical causality in social sciences

References

Abbott, A. (1998). “The causal devolution.” *Sociological Methods and Research*, 27(2), 148–181.

Aguayo, Angela J. and Timothy R. Steffensmeier (2008). *Readings on Argumentation*. State College, Pennsylvania: Strata Press.

Alfano, Christine and Alyssa O'Brien (2004). *Manuscript*. London: Longman.

Bunge, M. A. (2004). “How does it work? The search for explanatory mechanisms.” *Philosophy of the Social Sciences*, 34(2), 182–210.

Cassileth, B. R., Zupkis, R. V., Sutton-Smith, K., & March, V. (1980). “Informed consent: Why are its goals imperfectly realized?” *New England Journal of Medicine*, 302, 869–900.

Cook, Claire Kehrwald (1985). *Line by Line* (1st edition). New York: Houghton Mifflin.

Cozby, P. C. (1993). *Methods in behavioral research* (5th ed.). Mountain View, CA: Mayfield Publishing Co.

Gibaldi, Joseph and Phyllis Franklin (2003). *The MLA Handbook for the Writers of Research Papers.* 6th ed. New York: MLA.

Graziano, A. M., & Raulin, M. L. (2004). *Research methods: A process of inquiry* (5th ed.). Boston: Allyn & Bacon.

Heckman, J. (2005). "The scientific model of causality." *Sociological Methodology*, 35(1), 1–97.

Kaplan, A. (1964). *The conduct of inquiry: Methodology for behavioral science*. San Francisco: Chandler.

Little, D. (1990). *Varieties of social explanations: An introduction to the philosophy of social science*. Boulder: Westview Press.

Munger, Michael (2000). *Analyzing Policy.* New York: W.W. Norton & Co.

Popper, K. (1963). *Conjectures and refutations*. London: Routledge & Kegan Paul.

Radin, Beryl (2000). *Beyond Machiavelli: Policy Analysis Comes of Age.* Washington D.C: Georgetown University Press.

Roselberg, S.G.(ed) (2002). *Blackwell Handboook of Research Methods in Industrial and Organizational Psychology*. London: Blackwell.

Schwab, D.P. (2004). *Research Methods for Organizational Studies* (2nd Ed). New York: Psychology Press.

Sieber, J. E., & Stanley, B. (1988). "Ethical and professional dimensions of socially sensitive research." *American Psychologist*, 43,49–55.

Weiss, Carol (1998). *Evaluation.* New Jersey: Prentice-Hall.

Williams, Joseph (2002). *Style: Ten Lessons in Clarity and Grace* (7th edition). London: Longman.

Elective Courses

<u>ECONOMICS</u>

H 611: Advanced Economic Theory

Proposed by/instructor: Amarendra Das

Prerequisite: None

Micro Economics

1. Choice under uncertainty **(3 classes, 1 tutorial)**

Theory and application in rural insurance market

2. Topics in interlinked markets **(6 classes, 2 tutorials)**

Imperfect competition and fragmented markets a. rural markets – land, labour and credit

3. Topics on asymmetric information **(4 classes , 2 tutorials)**

a. Principal agent problem b. Adverse selection

4. Externalities and public goods **(3 classes, 1 tutorials)**

5. Issues in rural urban interactions **(2 classes, 1 tutorial)**

Harris-Todaro model

6. Inequality, occupational choice and human capital **(4 classes, 2 tutorials)**

Access to credit market b. Choice of occupation

7. Poverty and intra-household resource allocation **(2 classes, 1 tutorial)**

Macro Economics

1. Inflation **(4 classes, 2 tutorials)**

Quantity Theory of Money, Natural rate hypothesis, Models of nominal rigidities, New Keynesian view on inflation, Structuralist view, Welfare costs of inflation

2. Unemployment **(2 classes, 1 tutorial)**

Demand failures and Keynesian unemployment, Search theoretic models of unemployment, Efficiency wage models

3. Debt and Deficits **(4 classes, 1 tutorial)**

Debt-deflation theory of depressions, Public debt sustainability, Ricardian Equivalence

4. Business Cycles **(4 classes, 1 tutorial)**

Keynesian models of endogenous cycles, Growth cycles, Real business cycles, Money and DSGE

5. Finance in Macroeconomics **(4 classes, 1 tutorial)**

Minskian instability hypotheses, Financial bubbles and crashes, the Efficient market hypothesis, Crises and policy responses

6. Crises **(4 classes, 1 tutorial)**

Financial, Fiscal and External: Models of crisis, Great recession, Lessons from the East Asian crisis and Global financial crisis

7. Stabilisation policy **(4 classes, 1 tutorial)**

Monetary and Fiscal Policies: Dynamic inconsistency and rules versus discretion, Policy ineffectiveness, Monetary policy transmission mechanisms, Optimal monetary policy rules, Inflation targeting, Fiscal policy, Coordination of fiscal and monetary policies

Suggested Readings for Micro Economics

Books:

1. Bardhan, P. and C. Udry (1999). Development Microeconomics. Oxford University Press, New Delhi.

2. Basu, K. (1997). Analytical Development Economics: The Developed Economy Revisited. The MIT Press, Cambridge: M A.

3. Jehle, G. A. and P. J. Reny (2006). Advanced Microeconomic Theory. 2nd Edn. Pearson Education, New Delhi.

4. Kreps, D. (1999). A Course in Microeconomic Theory. Prentice Hall, New Delhi.

5. Mas-Collel, A., M. D. Whinston and J. R. Green (2006). Oxford University Press, New Delhi.

6. Ray, D. (1999). Development Economics. Oxford University Press, New Delhi.

7. Sen, A. (1996). Industrial Organization. Oxford University Press: New Delhi.

Journal Papers:

1. Banerjee, A. V. & Newman, A. F. (1993), 'Occupational Choice and the Process of Development', Journal of Political Economy 101(2), 274-298.

2. Dasgupta, P. & Ray, D. (1987), 'Inequality as a Determinant of Malnutrition and Unemployment: Policy', The Economic Journal 97(385), 177--188.

3. Dasgupta, P. & Ray, D. (1986), 'Inequality as a Determinant of Malnutrition and Unemployment: Theory', The Economic Journal 96(384), 1011--1034.

4. Bardhan, P. (1980). Interlocking Factor Markets and Agrarian Development: A Review of Issues. Oxford Economic Papers, Vol. 32, No. 1, 82-98.

5. Bhaduri, A. (1973). Agricultural Backwardness under Semi-Feudalism. Economic Journal, Vol. 83, 120-37.

6. Harris, J. R. and M. P. Todaro (1970). Migration, Unemployment and Development: A Two-Sector Analysis. The American Economic Review, Vol. 60, No. 1, 126-142.

Selected Readings for Macro Economics

1. Alan S. Blinder (1982) issues in the coordination of monetary and fiscal policy, NBER working paper series, NBER working paper series, working paper No. 982.

2. Barro, R. J. & D. B. Gordon (1983) “Rules, Discretion and Reputation in a Model of Monetary Policy”, Journal of Monetary Economics 12(1): 101-121.

3. Bean, C., J. Larsen and K. Nikolov (2002) “The Monetary Transmission Mechanism: Theory, Evidence and Policy Implications”, European Central Bank Working Paper No 133: 1-67.

4. Bernanke, B.S. & F.S. Mishkin (1997) “Inflation Targeting: A New Framework for Monetary Policy,” Journal of Economic Perspectives 11(2): 97-116.

5. Blanchard, O.J., G. Akerlof, D. Romer, and J. Stiglitz (2014) “Macroeconomic Policy after the Crisis”, Cambridge, Mass: MIT Press.

6. Boivin, Michael T. Kiley & F.S. Mishkin (2010) “How Has the Monetary Transmission Mechanism Evolved Over Time?”, Handbook of Monetary Economics, Chap.8, 3: 369 422.

7. Bordo, M. & A. J. Shwartz (1999) “Monetary Policy Regimes and Economic Performance: The Historical Record”, Handbook of Macroeconomics 1: 149-234.

8. Chari, V. & Kehoe, P. (1999)“Optimal Fiscal and Monetary Policy”, in J. Taylor and M. Woodford (eds.), Handbook of Macroeconomics, Vol.1. Part C, North Holland:1671-1745.

9. Cross, Rod (ed.) “Unemployment, Hysteresis, and the Natural Rate Hypothesis”, Oxford: Blackwell,1988.

10. Dixit, A. & Lambertini, L. (2003) “Interactions of Commitment and Discretion in Monetary and Fiscal Policies”, American Economic Review 93:1522-1542.

11. Domar, E. (1944) “The Burden of the Debt and the National Income”, American Economic Review, 34: 798-827.

12. Friedman, M. (1967) “The Role of Monetary Policy”, American Economic Review, 58(1):117.

13. Gali Jordi (2008) “Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework”, Princeton University Press.

14. Guillermo A. Calvo & Carlos A Vegh (1999) “Inflation Stabilization and BOP Crises in Developing Countries”, Chap.24, Handbook of Macroeconomics, Vol. 1, Part C: 1531-1614.

15. Hartley, James, Kevin D. Hoover & Kevin D. Salyer(eds.)“Real Business Cycles: A Reader”,London: Routledge, 1998.

16. Kaldor N. & Trevithick J. (1981) “A Keynesian Perspective on Money, in N. Kaldor”, Collected Economic Essays, 9.

17. Keynes, J. M. (1936) “The General Theory of Employment, Interest and Money”, London: Macmillan.

18. Krugman Paul (1979) “A Model of Balance of Payment Crisis”, Journal of Money Credit and Banking 11(3): 311-325.

19. Krugman, P. (2008) “The Return of Depression Economics and the Crisis of 2008”, New York: W.W. Norton.

20. Kydland, Finn E & Edward C. Prescott (1977) “Rules rather than Discretion: The Inconsistency of Optimal Plans”, The Journal of Political Economy 85:473-492.

21. Lucas, R.E. & Sargent, T. J. (1979) “After Keynesian Macroeconomics”, Federal Reserve Bank of Minneapolis Quarterly Review 3:1-16.

22. Lucas, Robert E., Jr., & Thomas J. Sargent, (eds.) “Rational Expectations and Econometric Practice”, London: Allen and Unwin, 1981.

23. Maria Luisa Petit (1989) “Fiscal and Monetary Policy Co-Ordination: A Differential Game Approach”, Journal of Applied Econometrics 4 (2):161-179.

24. Minsky, J. (1986) “Stabilizing an Unstable Economy”, New York: McGraw-Hill.

25. Mishkin, F.S. & Miguel A. Savastano (2002) “Monetary Policy Strategies for Emerging Market Countries: Case Studies from Latin America”, Comparative Economic Studies 44: 45-82.

26. Mishkin, F.S. (1995) “Symposium on the Monetary Transmission Mechanism”. Journal of Economic Perspectives 9(4): 3-10.

27. Mishkin, F.S. (2001) “The Transmission Mechanism and the Role of Asset Prices in Monetary Policy”, NBER Working Paper 8617.

28. Obstfeld, M. (1986) “Rational and Self-fulfilling Balance-of-Payments Crises”, American Economic Review 76(1): 72-81.

29. Radelet, S. & J. Sachs (1998) “The East Asian Financial Crisis: Diagnosis, Remedies, Prospects”, Brookings Papers on Economic Activity 29: 1-90.

30. Romer, D. (2012) “Advanced Macroeconomics”, New York: McGraw-Hill Irwin.

31. Sargent Thomas J & Neil Wallace (1975) “Rational Expectations, the Optimal Monetary Instruments, the Optimal Money Supply Rule, Journal of Political Economy 83: 241-254.

32. Stock, J. & M. Watson (1999) “Business Cycle Fluctuations in US Macroeconomic Time Series”, Handbook of Macroeconomics 1:3-64.

33. Symposium (1997) “The Natural Rate of Unemployment,” Journal of Economic Perspectives, 11(1): 3–108.

34. Taylor, L. (2004) “Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream”, Cambridge, Mass.: Harvard University Press.

35. W. D. Nordhaus (1994) “Policy Games: Co-ordination and Independence in Monetary and Fiscal Policies”, Brookings Papers on Economic Activity 2:139-216.

36. Wickens, M. (2012) “Macroeconomic Theory: A Dynamic General Equilibrium Approach”, Princeton: Princeton University Press.

37. Woodford Michael (2003) “Interest and Prices: Foundations of a Theory of Monetary Policy”, Princeton University Press.

H 612: Econometrics Theory and Application

Proposed by/instructor: Amarendra Das

Prerequisite: Basic knowledge of statistics and econometrics

1. Sampling: (6 lectures, 4 tutorials)

i) Sample size and sampling error

ii) Probability sampling (Simple Random Sampling, Systematic Sampling, Stratified

Sampling, Probability Proportional to Size Sampling, and Cluster or Multistage Sampling) and

iii) Nonprobability sampling (Accidental Sampling, Quota Sampling and Purposive Sampling, Line-intercept sampling, Panel sampling, snowball (chain) sampling).

2. Multiple Regression with R (6 lectures, 4 tutorials)

(OLS estimation and interpretation; Violation of assumptions; Simultaneous equation model estimation; Binary and multi-nomial logit and probit models; Tobit model)

3. Multivariate Analysis with SPSS (8 lectures, 4 tutorials)

(ANOVA, ANCOVA and MANOVA; Principal components analysis/ Factor analysis

Multidimensional scaling; Clustering systems; Discriminant analysis)

4. Time Series Analysis with Gretl/Stata (8 lectures, 4 tutorials)

(ACF and PAF; Units roots tests; ARIMA model; ARCH/GARCH models; VAR models; Cointegration)

5. Panel data Analysis with Gretl/Stata (6 lectures, 4 tutorials)

(Fixed Effects and Random Effects method; Hypotheses testing; Dynamic Panel Data models)

Essential Readings

1. Asteriou, Dimitrios and Hall, Stephen G. (2011) Applied Econometrics 2nd ed. Macmillan.

2. Baltagi, B. H. (2001) Econometric Analysis of Panel Data, 2nd edition, John Wiley.

3. Bond, Trevor G., and Fox, Christine M. (2007) Applying the Rasch Model. 2nd ed. Lawrence Erlbaum Associates.

4. Cameron, A. Colin and Trivedi, Pravin K. (2005). Microeconometrics: Methods and Applications. Cambridge University press. 5. Chambers, R L, and Skinner, C J (editors) (2003), Analysis of Survey Data, Wiley

6. Cheng, Hsian (1986) Analysis of Panel Data, Cambridge University Press.

7. Cochran, William G. (1977) Sampling Techniques. 3rd ed. Wiley Eastern.

8. Denzin, Norman K. and Lincoln, Yvonna S. (ed.) (2005) The Sage Handbook of Qualitative Research. Sage.

9. Draper, Norman R. and Smith, Harry. (1998). Applied Regression Analysis. Third Edition. Wiley.

10. Enders, Walter (1995) Applied Econometric Time Series, John Wiley & Sons.

11. Everitt, Brian S and Dunn, Graham. (2001). Applied Multivariate Data Analysis. Second Edition. Arnold.

12. Fox, John. (2008). Applied Regression Analysis and Generalized Linear Models. Sage.

13. Gelman, Andrew and Cortina, Jeronima (ed.) (2009) A Quantitative tour of the Social Sciences. CUP.

14. Granger, C. W. J. (ed.) (2001) Essays in Econometrics: Collected Papers, Edited by Eric Ghyseis et al., Cambridge University Press.

15. Greene, William H. (2003). Econometric Analysis Fifth Edition. Pearson Education.

16. Groves, Robert, et al. (2010) Survey methodology Second edition. Wiley.

17. Hamilton, J. D. (1994) Time Series Analysis, Princeton University Press.

18. Hammersley, Martyn (2013) What is Qualitative Research? Bloombury.

19. Hendry, David F. (1995) Dynamic Econometrics, Oxford University Press.

20. Holland, Jermey with John Campbell (ed.) (2005) Methods in Development Research: Combining Qualitative and Quantitative Approaches. Practical Action Publishing.

21. Johnston, J (1984). Econometric Methods. Third Edition. Mcgraw-Hill.

22. Korn, E.L., and Graubard, B.I. (1999) Analysis of Health Surveys, Wiley

23. Kmenta, Jan (1971). Elements of Econometrics. Macmillan.

24. Lutkepohl, Helmut (2006) New Introduction to Multiple Time series Analysis. Springer.

25. Maddala G. S. and Kim, In-Moo (1998) Unit Roots, Cointegration and Structural Change, Cambridge University Press.

26. Maddala, G.S. (2002), Introduction to Econometrics, 3rd ed., Wiley.

27. Makridakis, S., Wheelwright, S. C. and McGee, V. E. (1983) Forecasting – Methods and Applications, Second edition, John Wiley & Sons.

28. Mills, Terrence C. (1990) Time Series Techniques for Economists, Cambridge University Press.

29. Mukherjee, C.M. et al. (1998). Econometrics and Data Analysis for Developing Countries, Routledge.

30. Taylor, Geroge R. (ed.) (2010) Integrating Quantitative and Qualitative Methods in Research. 3rd ed. University Press of America.

31. Tracy, Sarah J. (2013) Qualitative Research Methods. Wiley-Blackwell.

32. Verbeek, Marno. (2012). A Guide to Modern Econometrics. 4th Edition. Wiley

H 613: Issues in Public Finance

Proposed by/instructor: New Faculty

Prerequisite: None

1. Role of Government and Budgeting **(6 lectures, 4 tutorials)**

Measurement of deficits, Budgeting - Performance based budget; Outcome budget, Rule based budgeting.

2. Fiscal Policy & Monetary Policy **(4 lectures, 2 tutorials)**

Fiscal Accommodation/ accommodative monetary policy. Ricardian Equivalence Theorem (RET): A Critical perspective.

3. Fiscal Performances **(4 lectures, 2 tutorials)**

Of both Center and State governments in India - Expenditure, revenue and deficits trends.

4. Issues in Public Debt **(4 lectures, 2 tutorials)**

Assessment of sustainability of debt - (a) Accounting Approach and (b) Present Value Budget Constraint Approach.

5. Fiscal Transfer **(6 lectures, 4 tutorials)**

Evolution in the Federal Fiscal Mechanism of Transfers: some perspectives on various Finance Commissions' recommendation and policy design with a specific reference to 12^{th} , 13th and 14^{th} FCs.

6. Equity and Efficiency in Fiscal Transfer **(3 lectures, 1 tutorials)**

Assessment of equity aspect in transfer mechanism in Indian context. An International Comparison with other Federal Countries' Transfer mechanism.

7. Fiscal Decentralization Experience in India **(3 lectures, 1 tutorials)**

8. Taxation **(4 lectures, 2 tutorials)**

Optimality in Taxation, Elasticity and Buoyancy, Direct tax and Indirect taxes,

9. Major Tax reforms. **(6 lectures, 4 tutorials)**

Implementation of VAT and GST, Expenditure Reforms and Management, Government subsidy and its implication on the economy.

11. Fiscal Consolidation and its consequences (2 lectures, 1 tutorials)

Selected Readings

1. Aian Schenk & Oliver Oldman (2007) "VAT: A Comparative Approach", Cambridge University Press.

2. Bagchi A. (2005) "Readings in Public Finance", Oxford University Press.

3. Bagchi, A. (2005) "Symposium on Report of Twelfth Finance Commission: Introduction and Overview", EPW, Pp.3388-3395.

4. Bagchi, A. & Stern, N. (1994) "Tax Policy and Planning in Developing Countries", Oxford University Press.

5. Barro, R. J. (1974) "Are Government Bonds Net Wealth?' Journal of Political Economy, 82 (6), Pp. 1095-1170.

6. Blejer, M, I. and Andrienne, C. (1991) “Measurement of Fiscal Deficits: Analytical and Methodological Issues”, Journal of Economic Literature., 29(4), Pp.1644-78.

7. Buiter, W. H.(1990) “Principles of Budgetary and Financial Policy”, Harvester Wheatsheafhm, New York.

8. Diamond, P. (1965) National Debt in a Neoclassical Growth Model”, The American Economic Review, 55(5), Pp.1126-50.

9. Easterly, W., Roddriguez, A. and Schmidt-Hebbel, K. (eds) (1994) “Public Sector Deficits and Macroeconomic performance”, Oxford University Press for the World Bank, New York.

10. Ehtisham Ahmed & Giorgio Brosio (2008) “Handbook of Fiscal Federalism”, Edward Elgar publishing ltd.

11. Gurumurthi, S. (1999) “Fiscal Federalism Towards an Appropriate VAT System for a Federal Economy,” Economic and Political Economy, 2875-2888.

12. Isaac, T. M. Thomas, P. Chakraborty (2008) “Intergovernmental Transfers: Disquieting Trends and the Thirteenth Finance Commission”, Economic and Political Economy, Pp. 86-92.

13. Kannan, R., S. M. Pillai, R. Kausaliya, J. Chander (2004) “Finance Commission Awards and Fiscal Stability in States”, Economic and Political Economy, Vol.XXXIX(5), Pp.477-491.

14. Oates, Wallace (1999) “An Essay on Fiscal Federalism”, Journal of Economic Literature, Vol. XXXVII.

15. Pethe Abhay (2009) “Aide-memoire to the13th Finance Commission on Devolution of Funds”, Economic and Political Economy, Vol. XLIV (24), Pp.16-22.

16. Rakshit, M. (2000) “On Correcting Fiscal Imbalances in the Indian Economy: Some Perspectives”. ICRA Bulletin. 61

17. Rao, M. G. (2003) “Reform in Central Sales Tax in the context of VAT,” Economic and Political Economy, EPW, Vol.XXXVII (6), Pp.627-636.

18. Rao, M. G. (2004) “Linking Central Transfers to Fiscal Performance of States”, Economic and Political Economy, Pp.1820-25.

19. Rao, R. Kavita (2004) “Impact of VAT on Central and State Finances”, Economic and Political Economy, Pp.2773-2777.

20. Twelfth FC (Nov. 2004) “Report of 12th FC - 2005-10” .

21. Thirteenth FC (Dec. 2009) “Report of 13th FC - 20010-15”.

22. Fourteenth FC (Jan, 2015) Report of 14^{th} FC -2015-20

H 614: Development Economics

Proposed by/instructor: New Faculty

Prerequisites: None

1. Economic development (4 lectures, 2 tutorials)

1.1 Concepts and Dimensions

1.2 Methodologies and Disciplinarity

1.3 Development and Underdevelopment

1.4 Developmentalism, Alternatives

2. Dual Economy models of development (4 lectures, 4 tutorials)

2.1 Underlying theories: Lewis-Ranis- Fei Model, Harris-Todaro Model

3. Economic Inequality and Development (4 lectures, 2 tutorials)

3.1 Concepts and Measurement (Basics of measurement issues only to enable literature reading)

3.2 Economic inequality and access to credit market

3.3 Economic inequality and choice of occupation.

3.4 Economic inequality and Human capital formation

3.5 Economic inequality and conflict.

4. Poverty (4 lectures, 2 tutorials)

4.1 Concepts and measurement

4.2 Impact of poverty on intra-household allocation, and access to labour market and credit market.

4.3 Poverty and Social structure

4.4 Poverty, health and nutrition

5. Issues on Health and Nutrition (4 lectures, 2 tutorials)

5.1 Importance of Health in Development

5.2 Intrahousehold Allocation of Nutrients among the children

5.3 Window of opportunity

6. Issues in Education **(6 lectures, 4 tutorials)**

6.1 Access to Education

6.2 Public Provision and infrastructure

6.3 Incentivising education

7. Social Security and Public Policy **(6 lectures, 4 tutorials)**

7.1 Issues in Targeting, Measurement

7.2 Social security policies: Public works programme, food security programme, conditional cash transfers.

Suggested Readings:

Books:

Basu, K. (1997), Analytical Development Economics: The Less Developed Economy Revisited, The MIT Press, Cambridge M A..

Bryman, A. and Burgess, R.G. (1999): Qualitative Research. London: Sage.

Chambers, R. (2008): Revolutions in Development Inquiry. Earthscan.

Chant ,S.. 2003. Engendering Poverty Analysis in Developing Regions, London: LSE research online

Desai, V. and Potter, R.B (eds.). (2006): Doing development research. London: Sage.

Dréze, J. & Sen, A. (2013), An Uncertain Glory: India and its Contradictions, Allen Lane.

Escobar, A. (1995) Encountering Development, Princeton, NJ, Princeton University

J. Timmons Roberts, Amy Bellone Hite (editors), The Globalization and Development Reader: Perspectives on Development and Global Change (Paperback). Blackwell 2007

Gupta, Akhil (1998) Postcolonial Developments: Agriculture in the Making of Modern India, Duke University Press.

Jan Nederveen Pieterse, Development Theory, Sage, 2nd edition, 2010.

Mary Romero and Eric Margolis (eds), The Blackwell Companion to Social Inequalities, Blackwell: Oxford, 2005.

Ray, D. (1999), Development Economics, Oxford University Press, New Delhi

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H 615: Environmental and Ecological Economics

Proposed by/instructor: New/Guest Faculty

Prerequisites: None

1. Measuring values (6 lectures, 4 tutorials)

Benefits and costs – overview; total value – use and non-use values of goods; Willingness-to-Pay versus Willingness-to-Accept; economic valuation of changes in human health – mortality and morbidity concepts; statistical value of life; economic valuation of biodiversity – existential value concept

2. Production Function Approaches to Economic Valuation (6 lectures, 4 tutorials)

Environmental valuation from market information including prices – dose response function, productivity change method, substitution cost method, illness costs, human capital; applications

3. Revealed Preference Approaches (6 lectures, 4 tutorials)

Revealed preference models of valuation – basic theory; Hedonic pricing method – property market and labour market; travel cost method – individual model and zonal model; defensive cost method – defensive costs of decreased drinking water quality; applications

4. Stated Preference Approaches and Benefit Transfer: (6 lectures, 4 tutorials)

Contingent valuation method – bias, experimental markets; choice modelling – choice experiment, contingent comparison, contingent scoring, pair comparison; applications; benefit transfer approaches – value transfer in theory and practice.

5. An introduction to ecological economics (6 lectures, 4 tutorials)

The economy in the environment – a conceptual framework, Economic accounting, Input–output accounting, National income accounting conventions, National income as the measure of economic performance, National income accounting and the environment, Environmental policy instruments, Choice of environmental policy instruments; Climate change; the nature and extent of the problem, Mitigation targets and instruments, what is being done about the problem?

6. Biodiversity loss (3 lectures, 1 tutorials)

The biodiversity-loss problem, why it is a difficult problem, Conservation policy

References:

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Ghosh, Nilanjan, Pranab Mukhopadhyay, Amita Shah and Manoj Panda [ed] (2016) Nature, Economy and Society: Understanding the Linkages, Springer, New Delhi.

Bateman, Ian J. et al. (2002) Economic Valuation with Stated Preference Techniques: A Manual, Edward Elgar.

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Kadekodi, G.K. (ed.) (2004), Environmental Economics in Practice – Case Studies from India, Oxford University Press, Delhi.

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Kolstad, C. (2000), Environmental Economics, Oxford University Press.

Sankar, U. (2001), Environmental Economics, Oxford University Press, Delhi

H 616: Poverty, Inequality and Human Development

Proposed by/instructor: New/Guest Faculty

Prerequisite: None

1. Poverty **(4 lectures , 2 tutorials)**

Concepts, Definitions, dimensions and analytical context

2. Measures of Poverty **(6 lectures, 4 tutorials)**

Headcount index, poverty gap and poverty severity indexes; FGT(Foster-Greer-Thorbecke) family of poverty measures; Sen and Sen-Shorrocks-Thon indexes of poverty and decomposition ; Watts index and exit measure.

3. Poverty in India **(6 lectures, 4 tutorials)**

Definition and measurement of Poverty in India: A Chronological Examination; The Great Indian Poverty Debate: A Snapshot; Identification of the Poor in India's Five year plans.

4. Poverty Profiles **(6 lectures, 4 tutorials)**

Rationale for poverty profile; Presentation of dimensions of poverty; Use of additive poverty measures and poverty comparisons; Poverty comparisons over time: sampling frame and method, adjustment for price differences; Poverty mapping and relative risk.

5. Inequality Measures **(4 lectures , 2 tutorials)**

Difference between inequality and poverty; Measures of Inequality : Lorenz Curve; Gini Coefficient; generalized entropy measures including Theil's T and Theil's L., Atkinson's inequality measure; Axioms of inequality and satisfying conditions of the measures of inequality; Decomposition of inequality measures.

6. Growth, inequality and Poverty **(4 lectures , 2 tutorials)**

Debates on Growth versus inequality and poverty growth linkages.

7. Multidimensional Poverty **(4 lectures , 2 tutorials)**

Properties of multidimensional poverty; Multidimensional poverty measures: issues of identification and aggregation; Multidimensional Poverty Measures.

8. Human Development **(4 lectures , 2 tutorials)**

Human Development Concepts and Approaches ; Introduction to HD Measurement Issues

9. Growth, inequality and Human Development **(4 lectures , 2 tutorials)**

10. Inequality Adjustment and inclusiveness of Human Development (4 lectures , 2 tutorials)

The need for inequality adjustment in HDI: HDI in India Patterns and Trends; Disaggregating human development: An assessment of inclusiveness; Inter-dimensional response across the three dimensions: the optimal evaluation

Readings

Readings for Topic 1

1. Ravallion, Martin. 1992. "Poverty Comparisons: A Guide to Concepts and Methods." Living Standards Measurement Surveys Working Paper No. 88, World Bank, Washington, DC.

2. ———. 1998. "Poverty Lines in Theory and Practice." Living Standards Measurement Surveys Working Paper No. 133, World Bank, Washington, DC.

3. Sen, Amartya. 1987. Commodities and Capabilities. Amsterdam: North-Holland.

4. World Bank. 2000. World Development Report 2000/2001: Attacking Poverty. Washington, DC: World Bank.

Readings for Topic 2

5. Atkinson, Anthony. 1987. "On the Measurement of Poverty." Econometrica 55: 749–64. Clark, Stephen, Richard Hemming, and David Ulph. 1981. "On Indices for the Measurementof Poverty." Economic Journal 91 (361): 515–26.

6. Dalton, Hugh. 1920. "The Measurement of the Inequality of Incomes." Economic Journal 30:384–61.

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8. Morduch, Jonathan. 1998. "Poverty, Economic Growth, and Average Exit Time." Economics Letters 59: 385–90.

9. Ravallion, Martin. 1996. "How Well Can Method Substitute for Data? Five Experiments in Poverty Analysis." The World Bank Research Observer 11 (2): 199–221.

10. Ravallion, Martin, and Shaohua Chen. 2001. "Measuring Pro-Poor Growth." Policy Research Working Paper No. 2666, World Bank, Washington, DC

11. Sen, Amartya K. 1976. "Poverty: An Ordinal Approach to Measurement." Econometrica 44 (2): 219–31.

12. Xu, Kuan, and Lars Osberg. 2002. "On Sen's Approach to Poverty Measures and Recent Developments." Working Paper, Department of Economics, Dalhousie University, Halifax, Nova Scotia.

13. Zheng, B. 1993. "An Axiomatic Characterization of the Watts Poverty Index." Economics Letters 42 (1): 81–6.

Readings for Topic 3

14. Ahluwalia, M. S., 'Rural Poverty and Agricultural Performance in India', Journal of Development Studies, April 1978.

15. Bandyopadhyay, K.R., Poverty Alleviation and Pro-poor Growth in India, New Delhi: Asian Institute of Transport Development, 2007.

16. Bardhan, P. K., and T N Srinivasan (eds.) Poverty and Income Distribution in India, Calcutta: Indian Statistical Publishing Society, 1974.

17. Council for Social Development (CSD), India Social Development Report, New Delhi: Oxford University Press, 2006.

18. Dandekar, V.M. and N. Rath, Poverty in India, 1971, (Pune: Indian School of Political Economy).

19. Datta, K.L. and Savita Sharma, Facets of Indian Poverty, New Delhi: Concept Publishing, 2002.

20. Deaton, Angus and Valerie Kozel, The Great Indian Poverty Debate, Delhi: MacMillan, 2005.

21. Deaton, Angus and Jean Dreze, 'India's Food Puzzle: Growth, Poverty and Malnutrition', paper presented at the International Conference on Microeconomics of Growth in India, organized by ICRIER at New Delhi on December, 2006.

22. Government of India, 'Task Force on Projections of Minimum Needs and Effective Consumption Demand', Perspective Planning Division, Planning Commission, 1979.

23. Government of India, 'Study Group on Estimation of Poverty Line', Perspective Planning Division, Planning Commission, 1984.

24. Government of India, 'Report of the Expert Group on Estimation of Proportion and Number of Poor', Perspective Planning Division, Planning Commission, 1993.

25. Government of India, 'Report of the Expert Group on the Methodology for the BPL Census 2009', Economic and Monitoring Wing, Ministry of Rural Development, Government of India, August, 2009.

26. Government of India, 'Report of the Expert Group to Review the Methodology for Estimation of Poverty', Planning Commission, November, 2009.

27. Lancaster, G. and R. Ray, 'On Setting the Poverty Line Based on Estimated Nutrient Prices: Condition of Socially Disadvantaged Groups During the Reform Period', Economic and Political Weekly, January 1, 2005.

28. Mehta, J. and S. Venkatraman, 'Poverty Statistics: Bermicide's Feast', Economic and PoliticalWeekly, July 1, 2000.

29. Palmer-Jones, R. and K. Sen, 'On India's Poverty Puzzles and the Statistics of Poverty', Economic and Political Weekly, January 20, 2001.

30. Sen, Pronab, ''Of Calories and Things: Reflections on Nutritional Norms, Poverty Lines and Consumption Behaviour in India', Economic and Political Weekly, October 22, 2005. 31. Saxena, N. C., 'Poverty Estimates for 1999-2000', Planning Commission, New Delhi, 2001.

32. Sen, Amartya, 'Development as Capability Expansion', Journal of Development Planning,Vol.19, pp.41-58, 1989.

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34. World Bank, World Development Report, Washington DC: World Bank, 2001.

Readings for Topic 4

35. Ravallion, Martin, and Monika Huppi. 1991. "Measuring Changes in Poverty: A Methodological Case Study of Indonesia during an Adjustment Period." World Bank Economic Review5 (1): 57–82.

36. Huppi, Monika, and Martin Ravallion. 1991. "The Sectoral Structure of Poverty during an Adjustment Period: Evidence for Indonesia in the Mid-1980s." World Development 19 (12): 1653–78.

37. Deaton, Angus. 2001. "Computing Prices and Poverty Rates in India, 1999–2000." Working Paper, Research Program in Development Studies, Princeton University.

Readings for Topic 5

38. Adams, Richard H., Jr. 1999. "Nonfarm Income, Inequality, and Land in Rural Egypt." PolicyResearch Working Paper No. 2178, World Bank, Washington, DC.

39. Atkinson, A. B. 1970. "On the Measurement of Inequality." Journal of Economic Theory 2 (3):244–63.

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41. Bourguignon, François, Francisco Ferreira, and Nora Lustig, eds. 2005. The Microeconomics of Income Distribution Dynamics in East Asia and Latin America. Washington, DC: World Bank and Oxford University Press.

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46. Gottschalk, P., and T. Smeeding. 2000. “Empirical Evidence on Income Inequality in IndustrialCountries.” In Handbook of Income Distribution. Volume 1. Handbooks in Economics, vol. 16, 119

Readings for Topic 6

47. Dollar, David and Aart Kraay (2000). “Growth is good for the poor”, World Bank, Washington DC

48. Fields, Gary (1989). “Changes in poverty and inequality in developing countries”, World Bank Research Observer, 4:167-186.

49. Datt, Gaurav (1999): “Has Poverty in India Declined since the Economic Reforms?,”Economic and Political Weekly 34 (December 11-17).

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53. Ravallion, M. and Chen, S. (1997) “What Can New Survey Data Tell us about Recent Changes in Distribution and Poverty ?”. The World Bank Economic Review. Vol. 11 (2): 357-82

Readings for Topic 7

54. Alkire, S. and J. Foster. (2008): “Counting and Multidimensional Poverty Measurement”, Working Paper No 7, Oxford Poverty and Human Development Initiative

55. Bourguignon , F. and S. Chakravarty. (2003): “The Measurement of Multidimensional Poverty”, Journal of Economic Inequality. 1: 25-19.

56. Deutsch, J. and J. Silber (2005), “Measuring Multidimensional Poverty: An Empirical Comparison of Various Approaches”, Review of Income and Wealth. 51 (1): 145-174.

Readings for Topic 8

57. Filmer,D. and Scott,K. (2008). Assessing Asset Indices. World bank Policy Research Working Paper No. 4605, World Bank.

58. Foster, J.E., Lopez-Calva, L. and Szekely,M. (2005). Measuring the distribution of human development: methodology and application to Mexico. Journal of Human Development, 6 ,529.

59. Foster, J. E. (2000). Path Independent Inequality Measures. Journal of Economic Theory,91 , 199-222.

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61. Grimm, M., Harttgen, K., Klasen, S., & Misselhorn, M., Munzi , T., Smeeding, T. (2009). Inequality in Human Development: An Empirical Assessment of 32 Countries. Social Indicators Research, Published on line.

Readings for Topic 9

62. Filmer,D. and Scott,K. (2008). Assessing Asset Indices. World bank Policy Research Working Paper No. 4605, World Bank.

63. Foster, J.E., Lopez-Calva, L. and Szekely,M. (2005). Measuring the distribution of human development: methodology and application to Mexico. Journal of Human Development, 6 , 5-29.

64. Foster, J. E. (2000). Path Independent Inequality Measures. Journal of Economic Theory,91

65. Grimm, M., Harttgen, K., Klasen, S., & Misselhorn, M.(2008). A Human Development Index by income groups. World Development 36, 2527-2546.

66. Grimm, M., Harttgen, K., Klasen, S., & Misselhorn, M., Munzi , T., Smeeding, T. (2009).Inequality in Human Development: An Empirical Assessment of 32 Countries. SocialIndicators Research, Published on line.

H 617: Project Evaluation

Introduction **(8 lectures , 3 tutorials)**

Meaning of a project and its basic characteristics, Role of Projects in a Development Planning Framework, Stages of Planning and Scope of Projects, Project Cycles:- Ex-Ante Analysis (i.e. conceptualization, identification, technical as well as economic feasibility analysis), Project Cycle:- Ex-Post Analysis (i.e., project selection, execution, action plan, monitoring, post-evaluation and reformulation)

Basic Tenets of Project Appraisal/ Evaluation: the Welfare foundations (6 lectures , 2 tutorials)

Classical welfare economic analysis, neo-classical economic analysis, new welfare economic analysis,

Approaches and Techniques **(8 lectures , 2 tutorials)**

Approaches and Steps in Appraisal/ Evaluation, General Criteria of Project Appraisal, Commercial Profitability Analysis / BCA of Projects, Capital Budgeting Decisions in terms of Methods of Investment Criteria, National Economic Profitability Analysis or SBCA of Projects,

Methods Project Appraisal / Evaluation **(8 lectures , 3 tutorials)**

Various Methods: the OECD Method, the UNIDO Guidelines Methods, the World Bank Method, the Effects Method, Significance of Externalities in Project Evaluation, Risk and Uncertainty Analysis,

Case Studies **(8 lectures , 2 tutorials)**

Water Resource Development Projects, Industrial Projects, Forestry Projects, and Non-conventional Energy Projects.

Project Assignments

References:

1) Bela Balassa, (1976), "*The Effects Method of Project Evaluation*", Oxford Bulletin of Eco. & Statistics, November Issue
2) IMD Little & James Mirrlees, (1974) "*Project Appraisal and Planning for Developing Countries*", Heinemann Educational Books, London
3) Lyn Squire & HG Van Tak, (1975) "*Economic Analysis of Projects*", John Hopkins
4) Prasanna Chandra, (1986) "*Projects Preparation, Appraisal, Budgeting and Implementation*", Tata Mc Graw Hill Publishing Company Ltd, New Delhi
5) OECD,(1972), *"Manual of Industrial Project Analysis in developing Countries-Methodology and Case Studies",* OECD, Paris
6) UNIDO, (1972), "*Guidelines for Project Evaluation"* (authored by Amartya sen, Parth Dasgupta & Stephen Marglin),United Nations, New York
7) UNIDO, (1978), "*Manual for the Preparation of Industrial Feasibility Studies,* United Nations, New York
8) UNIDO, (1978), "*Guide to Practical Project Appraisal"* United Nations, New York

Additional Readings

a) Lal Deeak, (1972), "*Wells and Welfare: An Exploratory Cost-Benefit Study of Small-Scale Irrigation in Maharashtra"*
b) Layard Richard (Ed), (1976), *"Cost Benefit Analysis",* Penguin Books Ltd, Middlesex, England
c) Mishra, S.N.& John Beyer,(1978*), "Cost-benefit analysis: a case study of the Ratnagiri Fisheries Project",* Hindustan Publishing Co
a) Rath, B. (1980),"*Social Benefit Cost Analysis of the Rengali Multi-purpose Project, Orissa".* Ph.D. thesis, IIT, Kanpur, (mimeo)
b) Rath, B. (1984),"*A Note on Approaches to Project Evaluation*". The India Journal of Economics, Vol.64, Part III, pp.353-360.
c) Rath, B. & Singhania, R. (1988), "*Economic Evaluation of Solar Water Heating System as a Device to Conserve Conventional Fuel in the Dairy Industry*". Proceedings Eighth National Symposium on Refrigeration and Air Conditioning, IIT Kanpur, February 26-27, pp. 207-219.

H 618: Indian Industrial Development

Proposed by/instructor: New/Guest Faculty

Prerequisites: None

1. Industrial Development in India Since 1951: **(4 classes, 2 tutorials)**

An Overview Industrialization strategy: Import Substitution and State control. BoP crisis, SAP and Economic Reforms; Critical issues for discussion in the context of globalization;

2. New Industrial Policy and Institutional Changes: (4 classes, 2 tutorials)

Delicensing and de-reservation; Removal of FERA, MRTP etc; FEMA and Competition Policy Act; Debates on Competition.

3. Overall Industrial Performance under Liberalization: (6 classes, 2 tutorials)

Structural change; Growth strategies of Business Groups; M&As and market concentration; Growth pattern of Industrial output, value added and employment; Productivity & Technological change.

4. Small-scale Industries and their new challenges: (4 classes, 2 tutorials)

Growth and structure of MSMEs; Size distribution of Unorganized and Informal Sector

5. Disinvestment Strategies and Debates on Privatisation: (4 classes, 2 tutorials)

Experience of disinvestment; Performance of public sector Enterprises

6. Industrial finance and Corporate Governance (4 classes, 2 tutorials)

Foreign investment; Foreign Portfolio investment; Financial Derivates; Capital Market and Role of stock exchange

7. Challenges ahead for Strengthening Industrialisation in India under WTO regime. (6 classes, 2 tutorials)

Demand factors; Supply factors such as Infrastructure Development, Energy issues, Environmental issues/Standards on Pollution control, etc. Data base on Industrial Statistics and Methodological Issues.

Readings:

1. Bhattacharjea Aditya (2004) Trade, Investment, and Competition Policy: An Indian Perspective in Aaditya Mattoo and Robert M Stern (ed) India and the WTO, The World Bank and Rawat Publications, Jaipur and New Delhi.

2. Ahluwalia I.J (1985) Industrial Growth In India: Stagnation since the Mid-Sixties, OUP, Delhi.

3. Amsden A.H (2001) The Rise of “The Rest” Challenges to the West from Late-Industrializing economies, OUP, New York.

4. Beena PL (2014) Mergers and Acquisitions: India Under Globalisation, Routledge, India and UK.

5. Bhagwati J N and P Desai (1970) India: Planning for Industrialisation:Trade and Industrialisation Policies 1950-66, Delhi, OUP.

6. Bagchi Amiya K (1999) Economy and Organisation: Indian Institutions under the Neoliberal Regime, New Delhi, Sage Publications.

7. Chandrasekhar CP (1988) Aspects of Growth and Structural Change in Indian Industry, EPW, Vol.23, No. 45/47, Pp 2359-2370.

8. Chandrasekhar CP (2007) India’s Industrial Performance: Revisiting a Debate in Vaidyanathan A and KL Krishna (ed) Institutions & Markets in India’s Development, OUP.

9. Chandrasekhar CP (2001) Factory Production: An Analysis of Data Availability and Coverage in CP Chandrasekhar and Jandhyala BG Tilak (ed) India’s Socio-Economic Database : Surveys of Selected Areas.

10. Desai V.V (1971) Pursuit of Industrial Self Efficiency: A Critique of the first Three Plans, EPW, May 1.

11. Govt. of India (1965) Report of the Monopolies Inquiry Commission.

12. Hazari R.K (1986) Essays on Industrial Policy, Concept Publishing House, Delhi.

13. Nagaraj R (1990) Industrial Growth: Further evidence and towards an explanation and issues, EPW, October 13.

14. Nagaraj R (2003): “Industrial Policy and Performance: Which Way Now?” EPW, Vol. 38, No. 35, August 30.

15. Nagaraj R (2006): Public Sector Performance since 1950: A Fresh Look, Economic and Political Weekly, Vol. 41, No. 25, June 24-29, 2006.

16. Nagaraj (2007) Industrial Growth in China and India: A Preliminary Comparison in Vaidyanathan A and KL Krishna (ed) Institutions & Markets in India’s Development, OUP.

17. Pushpangathan K and N Shanta (2009) The Dynamics of Competition: Understanding India’s Manufacturing Sector, OUP.

18. Raj K.N (1976) Growth and Stagnation in Indian Industrial Development, EPW, Annual Number, February.

19. Reed, Darryl and Sanjoy Mukherjee (2004) Corporate Governance, Economic Reforms and Development: The Indian Experience, New Delhi, OUP.

20. Lall, Sanjaya 2001: Competitiveness, Technology and Skills, Cheltenham, Edward Elgar, 2001.

21. Mookherjee Dilip 1997(ed): Indian Industry: Policies and Performance, OUP.

22. Nayyar Deepak 1994(ed): Industrial Growth and Stagnation, OUP.

23. Singh Ajit and Jayati Ghosh (1988) Import Liberalisation and New Industrial Strategy: An Analysis of their impact on Output and Employment, EPW, Vol.23, No. 45/47,Pp 2313-2342.

24. Sunanda Sen and Byasdeb Sengupta (2008) Unfreedom and Waged Work: Labour in India's Manufacturing Industry, Sage Publications.

25. Uchikava S (2002) (ed): Economic Reforms and Industrial Structure in India, New Delhi, Manohar.

H 619: The New Institutional Economics

Proposed by/instructor: New/Guest Faculty

Prerequisite: None

1. The NIE: **(4 classes, 2 tutorials)**

What is it?

2. Property Rights I **(6 classes, 2 tutorials)**

– Where it all began; Property Rights on Historical Frontiers; Property Rights on Current Frontiers:

3. Why Don't We Get It Right? **(6 classes, 2 tutorials)**

Why do firms exist? Insights from the NIE for Business Management and Strategy, Technology,

4. Transaction Costs **(6 classes, 2 tutorials)**

Transaction Costs and Contracts in Agriculture, Agricultural Contracts and the Growth of the Welfare State,

5. Norms and Contracts, **(6 classes, 2 tutorials)**

Understanding the Big Picture

References

- Alston, Lee J.: "The New Institutional Economics"
- Coase: "The Problem of Social Cost"
- Alston, Harris, and Mueller: "Development of Property Rights on Frontiers: Endowments, Norms and Politics"
- Baumol: "Entrepreneurship: Productive, Unproductive and Destructive"
- Alston, Libecap, and Schneider: "The Determinants and Impact of Property Rights: Census Data and Survey Results for Land Titles on the Brazilian Frontier"
- Alston and Mueller: "Property Rights and the State"
- Coase: "The Nature of the Firm"
- Alston and Gillepsie: "Resource Coordination and Transaction Costs: A Framework for Analyzing the Firm/Market Boundary"
- Alston and Higgs: "Contractual Mix in Southern Agriculture Since the Civil War: Facts, Hypotheses and Tests"
- Alston and Ferrie: "Paternalism in Agricultural Labor Contracts in the U.S. South: Implications for the Growth of the Welfare State"
- Alston, Mattiace, and Nonnenmacher: "Coercion, Culture and Debt-Contracts: The Henequen Industry: Yucatán, Mexico, 1870-1915"
- Eggertsson: "Analyzing Institutional Successes and Failures: A Millennium of Common Mountain Pastures in Iceland"
- North, Wallis, Webb, and Weingast: "In the Shadow of Violence"
- Wallis: "Institutions, Organizations, Impersonality, and Interests: The Dynamics of Institutions"
- Alston and Gallo: "Electoral Fraud, the Rise of Peron and Decline in Checks and Balances in Argentina"
- Alston, Melo, Mueller, and Pereira: "Beliefs, Leadership, and Critical Transitions: Brazil 1964-2014"
- Alston, Melo, Mueller, and Pereira: "Chapter 2: A Conceptual Framework: Beliefs, Leadership and Critical Transitions; Brazil 1964-2014"
- Alston, Melo, Mueller, and Pereira: "Part II: Introduction to the Case Study of Brazil, 1964-2014"
- Alston, Melo, Mueller, and Pereira: "Chapter 3: From Disorder to Growth and Back: The Military Regime (1964-1985)"
- Alston, Melo, Mueller, and Pereira: "Chapter 4: Transition to Democracy and the Belief in Social Inclusion (1985-1994)"
- Alston, Melo, Mueller, and Pereira: "Chapter 5: Cardoso seizes a Window of Opportunity"
- Alston, Melo, Mueller, and Pereira: "Chapter 6: Deepening Beliefs and Institutions"
- Hunt: "Parity, Paternalism and Peonage in the Informal Economy: and Empirical Study of Off-the-books Loans"
- Bretsen and Hill: "Irrigation Institutions in the American West"

H 620: International Trade and Finance

Proposed by/instructor: New/Guest Faculty

Prerequisites: None

1. Evolution of IT Theory **(4 Lectures, 2 tutorials)**

Evolution of international division of labour and economic transactions among countries

2. Review of theories of trade and trade flows: **(4 Lectures, 2 tutorials)**

Comparative advantage and its interpretations, economies of scale, imperfect competition, preference similarity

3. Arguments for and history of discriminatory commercial policy: **(4 Lectures, 2 tutorials)**

Theory of tariff, domestic distortions, strategic trade policies, discriminatory trading arrangements, new protectionism in the post war period, contemporary trade policy conflicts

4. International trade and underdevelopment: **(4 Lectures, 2 tutorials)**

Commodity question, unequal exchange and uneven development, accumulation on global scale, global value chain analysis

5. International Trading System: **(8 Lectures, 2 tutorials)**

From General Agreement on Tariff and Trade (GATT) to the World Trade Organisation (WTO); new areas brought under the trading system, GATS and TRIPS, the Doha Round conflicts

6. International Finance: **(4 Lectures, 2 tutorials)**

Capital account transactions, macro economic interdependence in open economies, the world of mobile finance, monetary integration and its consequences,

7. Issues in international financial architecture **(4 Lectures, 2 tutorials)**

Gold standard, Brettonwoods regime and postBrettonwoods arrangement; the development project in a world of mobile finance

Readings

1. Akyuz, Y (2003) Developing Countries and World Trade: Performance and Prospects, United Nations Conference on Trade and development, Geneva

2. Caprio, Gerard, Honohan, Patrick and Stiglitz, E Joseph (2001) Financial Liberalisatiojn: How Far, How Fast? Cambridge University Press

H 621: Topics in Experimental and Behavioural Approaches to Economic Development

Proposed by/instructor: New/Guest Faculty

Prerequisite: None

1. An overview of Concepts in Behavioural Economics (4 Lectures, 2 tutorials)

Cognition: Dual process of reasoning, judgment and decision making; Heuristics and Biases; Choice under Risk and Uncertainty ; Mental Accounting; Loss Aversion, Reference Dependence , Framing and Prospect Theory; Probabilistic Judgment; Time and Choice

2. An overview of Experimental Methods (4 Lectures, 2 tutorials)

Why experiments instead of field data? ; Natural experiments, quasi-experiments and controlled experiments; Methods and Methodological issues in experiments.

3. Behavioural and experimental methods for poverty and development (4 Lectures, 2 tutorials)

4. Applications in Labour Market Studies , (4 Lectures, 2 tutorials)

5. Applications in Caste and Gender Institutions , (4 Lectures, 2 tutorials)

6. Applications in Health and Education , (4 Lectures, 2 tutorials)

7. Applications in Micro Finance, Insurance and Credit market, (4 Lectures, 2 tutorials)

8. Applications in Public Policy , Governance and Corruption, (4 Lectures, 2 tutorials)

9. Applications in climate change , (4 Lectures, 2 tutorials)

References

Readings for Topic 1

1. Camerer, Colin F., George Loewenstein and Matthew Rabin (2003) Advances in Behavioral Economics,Princeton University Press

2. Mind, Behaviour and Society, World Development Report 2015, World Bank

Readings for Topic 2

2. Plott, Charles R & Smith Vernon L (2008) Handbook of Experimental Economics, North Holland

Readings for Topic 3

3. Abhijit V. Banerjee and Esther Duflo( ) The Experimental Approach to Development Economics http://economics.mit.edu/files/3159

4. Sendhil Mullainathan Development Economics through the lens of psychology, (mimeo).

5. Saugato Datta and Sendhil Mullainathan.(2012) "Behavioral Design: A New Approach to Development Policy." CGD Policy Paper 016. Washington DC: Center for Global Development. http://www.cgdev.org/content/publications/detail/1426679

6. Marianne Bertrand, Sendhil Mullainathan and Eldar Shafir (2004) A Behavioral-Economics View of Poverty, The American Economic Review, Vol. 94, No. 2, Papers and Proceedings of the One Hundred Sixteenth Annual Meeting of the American Economic Association San Diego, CA,January 3-5, 2004 (May, 2004), pp. 419-423

Readings for Topic 4

7. Azam, Mehtabul (2012) The Impact of Indian Job Guarantee Scheme on Labor Market Outcomes: Evidence from a Natural Experiment, IZA DP No. 6548, IZA, Germany

8. Jensen, Robert(2012) Do labor market opportunities affect young women's work and family decisions? Experimental evidence from India, The Quarterly Journal of Economics 127, 753–792. doi:10.1093/qje/qjs002

9. Abhijit Banerjee, Marianne Bertrand, Saugato Datta, Sendhil Mullainathan (2009) Labor market discrimination in Delhi: Evidence from a field experiment, Journal of Comparative Economics, 37 (2009) 14–27

10. Bertrand, M and Mullainathan, S (2004), "Are Emily and Greg More Employable than Lakisha and Jamal? A Field Experiment on Labor Market Discrimination," American Economic Review, 2004, 94(4), 991-1013

11. Sukhadeo Thorat, Paul Attewell, Firdaus Fatima Rizvi (2009)Urban Labour Market Discrimination, IIDS working paper series 111 No 1

12. Lori Beaman and Jeremy Magruder (2010) Who gets the job referral? Evidence from a social networks experiment, http://www.barcelonagse.eu/tmp/pdf/calvo2010-beaman.pdf

Readings for Topic 5

13. Fredrik Carlsson, Gautam Gupta and Olof Johansson-Stenman(2009) Keeping up with the Vaishyas? Caste and relative standing in India Oxford Economic Papers 61 (2009), 52–73

14. Fredrik Carlsson, Gautam Gupta and Olof Johansson-Stenman(2003) Choosing from Behind a Veil of Ignorance in India, Applied Economics Letters, 2003,, 825–827

15. Tarun Jain and Tulika Narayan (2010) Incentive to discriminate? An experimental investigation of teacher incentives in India, http://www.isid.ac.in/~pu/conference/dec_10_conf/Papers/TarunJain.pdf

16. Hoff, Karla, and Priyanka Pandey. 2006. "Discrimination, Social Identity, and Durable Inequalities." American Economic Review, 96(2): 206-211

17. Jensen, Robert (2012) Do Labor Market Opportunities Affect Young Women's Work and Family Decisions? Experimental Evidence from India, The Quarterly Journal of Economics (2012) doi: 10.1093/qje/qjs002 First published online: March 3, 2012

Readings for Topic 6

18. Rema Hanna, ,Esther Duflo and Michael Greenstone(2012) Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves, NBER Working Paper No. 18033 http://www.nber.org/papers/w18033

19. Banerjee, Abhijit, Esther Duflo, Rachel Glennerster, and Dhruva Kothari (2010) Improving Immunization Coverage in Rural India: A Clustered Randomized Controlled Evaluation of Immunization Campaigns with and without Incentives..British Medical Journal 340:c2220.

20. Banerjee, Abhijit, Shawn Cole and Esther Duflo Remedying education: evidence from two randomized experiments in India NBER Working Paper No. 11904, http://www.nber.org/papers/w11904

21. Muralidharan, Karthik and Venkatesh Sundararaman (2013) Contract teachers: experimental evidence from India, NBER Working Paper No. 19440, http://www.nber.org/papers/w19440

22. Karthik Muralidharan and Venkatesh Sundararaman (2011) Teacher Performance Pay: Experimental Evidence from India Journal of Political Economy, Vol. 119, No. 1 (February 2011), pp. 39-77.

Readings for Topic 7

23. Bauer, Michal, Julie Chytilová, Jonathan Morduch (2008)Behavioral Foundations of Microcredit: Experimental and Survey Evidence From Rural India, IES working paper 28/2008, Institute of Economic Studies, Faculty of Social Sciences, Charles University in Prague

24. Santosh Anagol , Shawn Cole , Shayak Sarkar (2013) Understanding the Advice of Commissions-Motivated Agents: Evidence from the Indian Life Insurance Market, Working Paper 12-055, March 7

25. Neeraj Sood, Eran Bendavid, Arnab Mukherji, Zachary Wagner , Somil Nagpal, Patrick Mullen (2014) , Government health insurance for people below poverty line in India: quasiexperimental evaluation of insurance and health outcomes, British Medical Journal 14;349:g5114 doi: 10.1136/bmj.g5114 .

Readings for Topic 8

26. Shawn Cole, Xavier Giné, Jeremy Tobacman, Petia Topalova, Robert Townsend and James Vickery (2012) Barriers to Household Risk Management: Evidence from India ,International Monetary Fund, WP/12/195 https://www.imf.org/external/pubs/ft/wp/2012/wp12195.pdf

27. Raghabendra Chattopadhyay and Esther Duflo (2004) Women as policy makers: Evidence from a randomized policy experiment in India, Econometrica, Issue Volume 72, Issue 5, pages 1409–1443, September 2004

28. Sujoy Chakravarty & Carine Sebi & E. Somanathan & Emmanuel Theophilus, 2013. "The Demographics of Cooperation: Evidence from a Field Experiment in the Gori-Ganga Basin," Journal of Economics and Management, College of Business, Feng Chia University, Taiwan, vol. 9(2), pages 231-269, July.

29. Marianne Bertrand Simeon Djankov Rema Hanna Sendhil Mullainathan (2007) Obtaining a driver's license in India: an experimental approach to studying corruption, The Quarterly Journal of Economics, , November

30. Banerjee, Abhijit V, Rukmini Banerji, Esther Duflo, Rachel Glennerster, Stuti Khemani Pitfalls of Participatory Programs: Evidence from a Randomized Evaluation in Education in India, http://righttoeducation.in/sites/default/files/pitfalls_0.pdf

H 622: Environmental Economics and Policy

Proposed by/instructor: New/Guest Faculty

Broad aspects of environmental economics (9 lectures and 3 tutorials)

Society and Environment: the Environmental Challenges and our Concerns and Current Environmental Issues., Mainstreaming Environment for Economic Development: the Issues and Problems; the Development Indices; Doomsday Scenarios- Limit to Growth Argument; and the Concept of "Another Development", Emergence of Environmental Economics: the Classical, Neo-Classical and Modern Economic Analysis; the Material Balance Approach; Optimal Depletion Path Argument; & its Perspectives, The Welfare Economics: the Ethical Foundations of Environmental Economics, Role of SBCA, and the Concept of Externalities
Sustainable Development: from Concept & Theory to Operational Principles and Strategies
Environmental Management: from Problems to Strategies, The Global Crisis in Human Settlement and the Environmental Movements in the World and the CPR dilemma

Environmental impact assessment (EIA) (9 lectures and 3 tutorials)

Why EIA?, Historical Development EIA; Organisation of EIA, Methodologies Adopted, Framework and Guidelines in EIA studies, Socio-Economic Aspects of EIA- the Approaches of Engineers, Economist and Social Scientists, EIA of Sectoral Development Projects, Status of EIA in different Countries vis-à-vis India, Case Studies of EIA

Environmental Legislations & Policies **(9 lectures and 3 tutorials)**

Role of U.N. and its Associate Bodies, Role of World Bank and its Associates , World Trade Organisation: Environmental Disputes and the Global Agenda: the North-South Perspectives, Environmental Policies/ Programmes and Protection Measures in India, Scope of Peoples' Participation in Management of Environment

Project Assignments **(6 lectures and 3 tutorials)**

The projects should primarily deal with some of the methodologies of EIA

References:

1 Barthwal, R.R.(2002), Environmental Impact Assessment", New Age International (P) Ltd. Publishers, New Delhi
2 Baumol, W.J. & Oates, W.E. (1975), *"The Theory of Environmental Policy: Externalities, Public Outlays and the Quality of Life",* Prentice Hall Inc.
3 Bromley, Daniel W. (1995), *"The Handbook of Environmental Economics",* Blackwell Publications Ltd.
4 Eccleston, Charles H (2001).*"Effective Environmental Assessments"*. Lewis Publishers, Washington,D.C.
5 Government of India (1998). *"India: Sustaining Development"*, Ministry of Environment and Forest, New Delhi.
6 Holdgate, Martin W. & White, G.F.(Ed), (1977), *"Environmental Issues",* John Wiley & Sons.
7 Kneese, Allan V. (1995), *"Economics of Natural Resources"*, Edward Elgar Publications Ltd.
8 Pearce, D.W. (1976), *"Environmental Economics",* Orient Longman Ltd.
9 World Bank, (1992). *"World Development Report, 1992: Development and the Environment",* Oxford University Press

Additional Readings

1. John O'Nell, Allan Holland &Andrew Light, (2008), "Environmental Values", Routledge
2. Rath, B. (1999), *"Environmental Economics: Issues, Policies, Strategies and Perspectives Part I*". Orissa Economic Journal, Vol. XXXI , No. 1 & 2, pp. 4-16.
3. Rath, B. (2000), *"Environmental Economics: Issues, Policies, Strategies and Perspectives, Part II* ". Orissa Economic Journal, Vol. XXXII , No. 1 & 2, pp.30-48.
4. Rath, B. ,(2008), " Impact Evaluation Study of *Biju Krushak Vikas Yojana & Pani Panchayat in all KBK Districts under RLTAP",* Submitted to Govt. of Orissa, Planning & Co-ordination Department.
5. Rath, B., (2008), *"Need Assessment Study for CSR of Auraiya Gas Power Station", AuGPP, NTPC Ltd, Dibiapur,Auraiya, Uttar Pradesh",*Submitted to NTPC Ltd, New Delhi
6. Rath, B (1998).'Rehabilitation and Resettlement in India: Approaches, Policies
and Remedial Action Plan'. mimeo, IIT Kanpur.
7. Ramakrishnan, K. & Rath, B.(2001), *"Power Project Development- Review of Social and Environmental Issues",* mimeo, IIT, Kanpur.
8. Singh, Sekhar (Ed) (1984), *"Environmental Policy in India".* Indian Institute of Public Administration, New Delhi.
9. Singh, Narindar, (1976), "Economics and the Crisis of Ecology", Oxford University Press, New Delhi
10. Senca,Joseph J. & Taussing, M.K., (1974), *"Environmental Economics",* Prentice Hall Inc.

ENGLISH

H 631. Humanities and the Institutional Space

Instructor/Proposed by: Joe Varghese Yeldho

Prerequisite: None

1. **Idea of Humanities (8 classes + 2 tutorials)**

History and Context. The speculative domain and the public sphere. Narrative accounts of 'knowing' as process.

2. **Justifying the Humanities (8 classes + 2 tutorials)**

Problems in method. The linguistic turn. Impact of institutional science.

3. **Notion of critique and it's history (8 classes + 2 tutorials)**

The aesthetics of social protest. Architecture and propaganda. Transient Space and poetics. Cultures of Technological determinism.

4. **The Institutional context (8 classes + 2 tutorials)**

Symbolism and institutional coda. Hierarchy and the history of resource allocation. Centring knowledge production. Education as consumption.

5. **The Humanities and the Natural Sciences8 classes + 2 tutorials)**

Conceptual value and frames of utility. Categorisation in science. Critical responses to the provenance of scientific 'fact' and 'evidence.'

References

Aristotle (1996). *Poetics*. London: Penguin.

Bourdieu, Pierre (1988). *Homo Academicus*. London: Polity.

Derrida, Jacques (2016). *Dissemination.*London: Bloomsbury.

Foucault, Michel (2010). *'Biopolitique:'Lectures*. London: Picador.

Freire, Paulo (2014). *Pedagogy of Hope.*London: Bloomsbury.

Heidegger, Martin (2008). *"On the origin of the work of art,"Basic Writings.* New York: Harper Collins.

Kant, Immanuel (2007). *Critique of Pure Reason*. London:Penguin.

Lefebvre, Henri (1991). *Production of Space.* Oxford: Blackwell.

Levinas, Emmanuel (2000). *Entre Nous.* New York: Columbia UP

Locke, John (2014). *An essay concerning human understanding.*London: Wordsworth.

Poovey, Mary (1998). *A History of the Modern Fact*.Chicago: University of Chicago press.

Ranciere, Jacques (1991). *The Ignorant Schoolmaster.*Redwood: Stanford UP.

Readings, Bill (1997). *University in Ruins*. Cambridge: Harvard UP.

Tafuri, Manfredo (1976). *Architecture and Utopia*. Cambridge: MIT Press.

H 632: The Modern European Novel

Instructor/Proposed by : Joe Varghese Yeldho

Prerequisite: None

1. Miguel de Cervantes – *Don Quixote* (5 classes + 1 tutorial)
2. Marcel Proust – *Swan in Love* (6 classes + 2 tutorials)
3. Nikolai Gogol – *Dead Souls* (5 classes + 1 tutorial)
4. Thomas Mann – *Dr. Faustus* (5 classes + 1 tutorial)
5. Jaroslav Hasek – *The Good Soldier Svejk* (5 classes + 2 tutorials)
6. Robert Musil – *The Man Without Qualities* (5 classes + 2 tutorials)
7. Joseph Roth- *The Radetsky March* (4 classes + 1 tutorial)
8. Italo Calvino- *If on a winter's night a traveler* (4 classes + 1 tutorial)

References

Agamben, Giorgio (2005). *State of Exception*. Chicago: Univ. of Chicago Press.

Badiou, Alain (2013). *Being and Event.* London: Bloomsbury.

Bakhtin, Mikhail (1988). *Dialogic Imagination.* Austin: Univ. of Texas Press.

Barthes, Roland. (1983). *A Barthes Reader*, ed. by Susan Sontag. New York; Hill and Wang.

Brink, André. (1998). *The Novel: Language and Narrative from Cervantes to Calvino.* New York: NYU Press.

Derrida, Jacques. (2006). *Spectres of Marx*. London: Routledge.

Freud, Sigmund (2010). *Civilization and its Discontents.*NY: W.W. Norton.

Kundera, Milan. (2003). *The Art of the Novel.* London: Penguin.

Lukács, Georg. (2002). *Studies in European Realism.* New York: Howard Fertig.

Mander, Jenny. (2007). *Remapping the Rise of the European Novel.* Oxford: Voltaire Foundation.

Nabokov, Vladimir. (2002). *Lectures on Literature*. NY: Mariner Books.

Nash, Christopher. (1988). *World-games: The Tradition of Anti-realist Revolt.* London: Routledge.

H 633: The Idea of the Nation in Indian English Fiction

Instructor/Proposed by: Joe Varghese Yeldho

Prerequisite: None

1. Rao, Raja. - *Kanthapura* (4 classes + 1 tutorial)
2. Narayan, R. K. - *Malgudi Days* (4 classes + 1 tutorial)
3. Anand, Mulk Raj. - *Untouchable* (4 classes + 1 tutorial)
4. Khanna, Balraj. - *A Nation ofFools* (4 classes + 1 tutorial)
5. Rushdie,Salman. - *Midnight's Children* (4 classes + 1 tutorial)
6. Ghosh, Amitav. - *The Shadowlines* (4 classes + 1 tutorial)
7. Das, Manoj. - *Cyclones* (4 classes + 1 tutorial)
8. Roy, Arundhati. - *God of Small Things* (4 classes + 1 tutorial)
9. Deb, Siddhartha. - *Surface* (4 classes + 1 tutorial)
10. Raj, M. C. - *Raachi* (4 classes + 1 tutorial)

References

Anderson, Benedict (1998). *Imagined Communities*. London: Verso.

Bates, Crispin (2006). *Beyond Representation:Colonial and Postcolonial Constructions of Indian Identity.* London: OUP.

Chatterjee, Partha (1993). *The Nation and its Fragments*. NJ: Princeton UP.

Hobsbawm, E.J. (2012). *Nations and Nationalism since 1780*. Cambridge: Cambridge UP.

Kedourie, Elie (1993). *Nationalism*. London: Blackwell.

Khair, Tabish. (2005). *Babu Fictions: Alienation in Contemporary Indian English Novels.* London: OUP.

Khilnani, Sunil (1999). *The Idea of India*. NY: Farrar, Strauss & Giroux.

Mukherjee, Meenakshi. (2001). *The Perishable Empire: Essays on Indian Writing in English.* London: OUP.

Mukherjee, Meenakshi. (1972). *The Twice Born Fiction*. Portsmouth: Heinemann.

Mukherjee, Meenakshi. (1996). *Realism and Reality: The Novel and Society in India.* London: OUP.

H 634: Black Intellectual Traditions and the Narratives of Race in America

Instructor/Proposed by: **Joe Varghese Yeldho**

Prerequisite: **None**

1. Frances E.W. Harper – *Iola Leroy* (4 classes + 1 tutorial)
2. F. Douglass- *Narrative of the Life of Frederick Douglass* (4 classes + 1 tutorial)
3. Booker T. Washington – *Up from Slavery* (4 classes + 1 tutorial)
4. W E B Du Bois - *The Souls of Black Folk* (4 classes + 1 tutorial)
5. Langston Hughes – *The Weary Blues* (4 classes + 1 tutorial)
6. Zora Neale Hurston - *Dust Tracks on a Road*(4 classes + 1 tutorial)
7. James Baldwin – *Go Tell it on the Mountain* (4 classes + 1 tutorial)
8. Ralph Ellison - *Invisible Man* (4 classes + 1 tutorial)
9. Harold Cruse - *The Crisis of the Negro Intellectual* (4 classes + 1 tutorial)
10. Angela Davis - *Blues Legacies and Black Feminism* (4 classes + 1 tutorial)

References

Boxill, Bernard R (1810). *Blacks and Social Justice*. NY: Rowman & Littlefield.

Edwards, Brent Hayes (2003). *The Practice of Diaspora: Literature, Translation and the Rise of Black Internationalism*. Cambridge: Harvard UP.

Gates, Henry Louis (1989). *The Signifying Monkey*. London: OUP.

Morrison, Toni (1993). *Playing in the Dark: Whiteness and the Literary Imagination*. NY: Vintage.

Napier, Winston (2000). *African American Literary Theory: A Reader*. NY: NYU Press.

Pittman, John P. (1996). *African American Perspectives and Philosophical Traditions*. London: Routledge

H 635: Writings of the South Asian Diaspora

Instructor/Proposed by : Joe Varghese Yeldho

Prerequisite: None

1. **Concept of Diaspora (8 classes + 2 tutorials)**

History and significance. Pluralism. Transnationalism. Social Networks. Cosmopolitanism.

2. **The Colonial Project (8 classes + 2 tutorials)**

Enlightenment and Imperialism. The inequity of Progress. Referencing South Asia.

3. **Notion of Exile (8 classes + 2 tutorials)**

Exile and its striations – Political, Social, Imaginary. The Migrant and the Refugee. Engaging the 'catastrophe'.

4. **Displacement Narratives (8 classes + 2 tutorials)**

Translating memory. Witnessing and trauma. The mimetic past. History as spatial metaphor.

5. **Neo Globalism and deterritorialization (8 classes + 2 tutorials)**

Gendering and the idea of Home. Unpacking the modern. Reconfiguring the Urban.

References

Baldwin, Shauna Singh (2009). *We Are Not in Pakistan*. New Delhi: Rupa.

Bose, Neilesh, Ed. (2009). *Beyond Bollywood and Broadway: Plays from the South Asian Diaspora*. Bloomington: Indiana University Press. (selected plays)

Diane McGifford, Ed. (1992). *Geography of Voice: Canadian Literature of the South Asian Diaspora*. Toronto: TSAR.

Kureishi, Hanif (1990). *The Buddha of Suburbia*. New York: Viking.

Mishra, Vijay (2007). *The Literature of the Indian Diaspora: Theorizing the Diasporic Imaginary*. London: Routledge.

Nasta, Susheila (2001). *Home truths: Fictions of the South Asian Diaspora in Britain*. London: Palgrave – Macmillan.

Paranjape, Makarand (2001). *In Diaspora: Theories, Histories, Texts*. New Delhi: Indialog Publications.

Pirbhai, Mariam (2009). *Mythologies of Migration, Vocabularies of Indenture: Novels of the South Asian Diaspora in Africa, the Caribbean and Asia-Pacific*. Toronto: Univ. of Toronto Press.

Refiq, Fauzia, Ed. (1995). *Aurat Durbar*: *Writings by Women of South Asian Origin*. Toronto: Second Story Press.

Rushdie, Salman (1992). *Imaginary Homelands: Essays and Criticism, 1981-91*. London: Penguin.

Said, Edward (2002). *Reflections on Exile*. Cambridge: Harvard UP.

H 636: Translation and Culture: Issues and Perspectives

Instructor/Proposed by: Joe Varghese Yeldho

Prerequisite: None

1. **Theory and Practice (8 classes + 2 tutorials)**

Transparency and Fidelity. Literal and Literary translation. Considering text and context(s) [O.V. Vijayan and Girish Karnad].

2. **Multiplicity of perspective (8 classes + 2 tutorials)**

Semantics and Semiotics. Film as visual rhetoric. Kurosawa and the optical metaphor.

3. Problematizing Identity and the process of 'othering'. (8 classes + 2 tutorials)

Social politics as method in translation. Reading *Six Acres and a Third* (Fakir Mohan Senapati)

4. Translation and Genre (8 classes + 2 tutorials)

Mapping text's and the ecology of seeing: Reading *Samskara* (U.R. Ananthamurthy) and *Godaan* (Munshi Premchand).

5. Translating Cultural Differences (8 classes + 2 tutorials)

Cultural Iconography. Experiencing the contemporary. Langauge and nuance.

References

Amos, F. R. R. (1973). *Early Theories of Translation*. New York: Octagon.

Anderman, G. (2005). *Europe on Stage: Translation and Theatre*. London: Oberon Books.

Bassnett, S. (1980). *Translation Studies*. London: Routledge.

Bassnett, S. and Lefevere, A. (1998). *Constructing Cultures: Essays on LiteraryTranslation*. Clevedon: Multilingual matters.

Bassnett, S. and Trivedi, H, eds. (1999). *Postcolonial Translation: Theory and Practice*. London: Routledge.

Bly, R. (1983). *The Eight Stages of Translation*. Boston: Rowan Tree.

Casetti, Francesco (1999). *Inside the Gaze*. Bloomington: Indiana UP.

Chaudhuri, S. (1999). *Translation and Understanding*. Delhi: Oxford University Press.

Cheyfitz, E. (1991). *The Poetics of Imperialism: Translation and Colonization from The Tempest to Tarzan*. London: Oxford University Press.

Cronin, M. (2003). *Translation and Globalization.* London: Routledge.

Katan, D. (2004). *Translating Cultures.* Manchester: St. Jerome.

Kothari, R. (2003). *Translating India*. Manchester: St Jerome.

Kreiswirth, M. and Cheetham, M. A., eds. (1990). *Theory Between theDisciplines: Authority / Vision / Politics.* Ann Arbor: The University of Michigan Press.

Lefevere, A. (1992). *Translation, Rewriting and the Manipulation of Literary Fame*. London: Routledge.

Mukherjee, Sujit (2012). *Translation as Discovery and other Essays*. New Delhi: Orient Blackswan.

Toury, G. (1980). *In Search of a Theory of Translation*. Tel Aviv: Porter Institute.

Venuti, Lawrence (2008). *The Translator's Invisibility*. London: Routledge.

PSYCHOLOGY

H651 - Organizational Behaviour

Instructor/Proposed by : Rooplekha Khuntia

Prerequisite: None

1. **Growth of Organizational Behaviour as a field of study: (8 lectures + 2 tutorials)**

Scientific management, Hawthorne studies, Industrial Psychology, Human Relations approach, other contributing disciplines.

2. **Individual level processes: (10 lectures+ 4 tutorials)**

Personality, values, attitude, emotions, perception, motivation, learning, decision making.

3. **Group level processes: (10 lectures + 4 tutorials)**

Communication, power and politics, leadership, groups, team dynamics, conflict and conflict resolution.

4. **Organizational system: (8 lectures + 2 tutorials)**

Organization structure, organizational culture, organizational effectiveness.

5. **Organizational Dynamics: (6 lectures + 2 tutorials)**

Organizational change, Stress management, human resource policies, challenges.

References :

[1] Organizational Behaviour by Margie Parikh and Rajen Gupta , 1st edn, Tata McGraw Hill.

[2] Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India

[3] Organizational Behaviour by Fred Luthans, 10th ed, McGraw-Hill International edition.

[4] Understanding Organizational Behaviour by U. Pareekh and S. Khanna, 3rd edn, Oxford University Press.

[5]Organizational Behaviour: human behaviour at work by J.W. Newstrom and K.Davis, McGraw Hill.

* Additional readings to be provided by the instructor as the course progresses.

H 652 - Leadership

Instructor/Proposed by : Rooplekha Khuntia

Prerequisites: none

1. **Introduction (2 lectures + 1 tutorial)**

What is leadership – the difference between leadership and management.

2. **Traditional theories of leadership (10 lectures + 4 tutorials)**

Trait approach, Behavioural approach, Situational approach.

3. **Contemporary theories of Leadership (10 lectures + 4 tutorials)**

Transactional and transformational leadership theory, charismatic leader, relational eadership, authentic leadership theory, servant leader, ethical leader, spiritual leaders.

4. **Power and leadership (6 lectures + 2 tutorials)**

Influence, empowerment, participation, trust.

5. **Role of leader in organizational change (6 lectures + 2 tutorials)**

Leadership tasks, patterns and techniques.

6. **Leadership in the Indian context: (2 lectures + 1 tutorial)**

Nurturant task leadership

7. **Leadership in a changing world : (2 lectures + 1 tutorial)**

Interdependence, diversity, group maintenance.

8. **Trends in leadership research. (2 lectures + 1 tutorial)**

References:

[1] Organizational Behaviour by K.Davis and J.W.Newstrom.

[2] Organizational Change Through Effective Leadership by R. Guest, P.Hersey and K.Blanchard

[3] The Cultural Context of Leadership and Power by J.B.P.Sinha

[4] Servant Leadership: A Journey into the Nature of Legitimate Power and Greatness by R.K.Greenleaf.

[5] Business Gurus Speak by S.N. Chary

[6] Business Maharajas by Gita Piramal

* Additional readings to be provided by the instructor as the course progresses.

H 653 - Organizational Change and Development

Instructor/Proposed by : Rooplekha Khuntia

Prerequisite: none

1. **Introduction: (4 lectures + 1 tutorial)**

Content of change, types of change, forces of change.

2. **Approaches to managing change: (6 lectures + 2 tutorials**

Communicating change, resistance to change, creating readiness for change.

3. **Understanding Organization as System: (4 lectures + 1 tutorial)**

Organization culture, Organization as sociotechnical system.

4. **Understanding Organizational Development:(6 lectures + 2 tutorials)**

Models of Organizational Development, diagnostic process.

5. **Implementing planned change: (15 lectures + 5 tutorials)**

Human process intervention, technostructural intervention, human resource intervention, strategic change intervention.

6. **Applications of Organizational Development:** **(6 lectures + 2 tutorials)**

Organizational development for economics, ecological and social outcomes.

References:

[1] An Experiential Approach to Organization Development by D.R. Brown and D. Harvey.

[2] Organization Development and Transformation by Wendell L. French, Cecil H. Bell, Jr. and Robert Zawacki.

[3] Managing Organizational Change: A Multiple Perspective Approach by I. Palmer, R. Dunford, and G Akin.

[4] Organizational Development and Change by T.G. Cummings and C.G.Worley

* Additional readings to be provided by the instructor as the course progresses.

H 654 - Positive Psychology

Instructor/Proposed by : Rooplekha Khuntia

Prerequisite: none

1. **Introduction:** **(8 lectures + 2 tutorials)**

What is Positive Psychology, History and background, models of positive psychology.

2. **Perspectives on Happiness and Wellbeing: (8 lectures + 2 tutorials)**

Defining happiness, meaning and measurement of happiness, methods of happiness research, determinants of happiness.

3. **Psychological capital:** **(10 lectures + 4 tutorials)**

Positive traits, identifying and assessing strengths, positive emotions, emotional intelligence, strength vs. weaknesses.

4. **Positive relationships:** **(10 lectures + 4 tutorials)**

Building meaningful relationship through empathy, forgiveness, gratitude, compassion, altruism, positive emotions etc.

5. **Applications of positive psychology: (6 lectures + 2 tutorials)**

Health, ageing, work, education, positive psychology and public policy, clinical applications.

References:

[1] Character Strengths and Virtues: A Handbook and Classification by C. Peterson and M.E.P. Seligman. American Psychological Association and Oxford University Press.

[2] Handbook of Positive Psychology by C. R. Snyder and S. J. Lopez.

[3] A Primer in Positive Psychology by C. Peterson.

[4] Introduction to Positive Psychology by William Compton.

[5] Positive Psychology: The Scientific and Practical Explorations of the Human Strengths by C. R. Snyder and S. J. Lopez.

[6] The Optimistic Child by M.E.P. Seligman, K. Reivich, L. Jaycox and J. Gilham.

* Additional readings to be provided by the instructor as the course progresses.

H 655 - Cross Cultural Psychology

Instructor/Proposed by : Rooplekha Khuntia

Prerequisite: Introductory course in Psychology

1. **Understanding cross cultural psychology: (6 lectures + 2 tutorials)**

Perspectives on culture, culture and human nature, nature vs. nurture.

2. **Research methods for cultural psychology: (8 lectures + 2 tutorials)**

Critical thinking, multicultural psychology, research and testing, world views.

3. **Culture and Cognition: (8 lectures + 2 tutorials)**

Sensation and perception, states of consciousness, self, intelligence, emotion, motivation.

4. **Development and Socialization: (6 lecture + 2 tutorials)**

Communication, cross cultural contact and the process of acculturation, social perception.

5. **Culture and health: (8 lectures + 2 tutorials)**

Cultural differences in the definition of health, psychosocial and sociocultural influences on health, culture and psychological disorders.

6. **Multicultural competency: (6 lectures + 2 tutorials)**

Identity development, attributions, work related values, workplace attitudes.

References:

[1] Cross-Cultural Psychology by Shiraev, E. & Levy, D. 4th ed,

[2] Cross-cultural Psychology: Research and Applications by Berry, J., Poortinga, Y.H., Segall, M.H., & Dasen, P.R. 2nd ed, Cambridge University Press.

[3] Human Behavior in Global Perspective: An introduction to cross-cultural psychology by Segall, Marshall H.Dasen, Pierre R.Berry, John W.Poortinga, Ype H. Elmsford, Pergamon General psychology Series, Vol. 160, NY, US: Pergamon Press. (1990)

[4] Handbook of Cross-cultural Psychology: Basic processes and human development by John W. Berry, Ype H. Poortinga, Janak Pandey, Allyn &Bacon.

[5] Understanding Cross Cultural Psychology: Eastern and Western Perspectives by Pittu D Laungani, Sage South Asia.

* Additional readings to be provided by the instructor as the course progresses.

H 656 - Business Ethics

Instructor/Proposed by: Rooplekha Khuntia

Prerequisite: none

1. **Introduction to Business Ethics: (10 lectures + 4 tutorials)**

Business ethics: an overview, Concepts and theories.

2. **Ethical theory and business: (10 lectures + 4 tutorials)**

Ethical Decision making in business- deontology and teleology, rights, fairness and justice. Ethical Dilemmas- sources and their resolution.

3. **Corporate Social Responsibility: (10 lectures + 4 tutorials)**

Business's environmental responsibilities, Employee responsibility, Moral rights in the workplace, Diversity and discrimination.

4. Managing Stakeholder Relations: (4 lectures + 1 tutorial)

Types of stakeholder relations, problems with stakeholder collaborations.

5. Globalization and business ethics: (5 lectures + 2 tutorials)

Doing business in a global marketplace, differing labor and environmental standards.

References:

[1] Ethics and the Conduct of Business, by John R. Boatright, 4th ed, Pearson Education.

[2] Business Ethics: An Indian Perspective, by A.C. Fernando, Pearson Education.

[3] Business Ethics: Concepts and Cases, by Manuel G. Velasquez, 6th ed, Prentice Hall India.

[4] Perspectives in Business Ethics, by Laura P. Hartman and Abha Chatterjee, 3rd ed, McGraw- Hill.

* Additional readings to be provided by the instructor as the course progresses.

SOCIOLOGY

H 671: Classical Sociological Theory

Instructor/Proposed by : Pranay Swain

Prerequisite: None

Course structure

1. **Theory and research** **(4 classes and 1 tutorial)**

Relation between theory and research, The nature and use of theory, Basic concepts

2. **Fundamental perspectives of society** **(4 classes and 1 tutorial)**

Conceptualization of social system, Social structure and culture, Various perspectives, Subjectivity vs Objectivity

3. **Comte, Spencer, and Marx** **(6 classes and 2 tutorials)**

Contending visions of a science of society

4. **Durkheim and his school** **(4 classes and 1 tutorials)**

Rules of Sociological Methods, Suicide, Division of Labour

5. **Conflict theory** **(8 classes and 3 tutorials)**

Marx: Dialectical Materialism; Frankfurt School and Critical Theory Jurgen :Habermas and Adono; Kant'sCritique of Pure Reason, Paul fayerabad

Modern Approaches: C Wright Mills; Postmodernism

6. **The theory of action** **(8 classes and 3 tutorials)**

structural-functionalism, and the course of American sociology

Talcott Parsons, The Structure of Social Action, Robert Merton, Social Theory and Social Structure

7. **Neo classical theories** **(8 classes and 3 tutorials)**

Exchange theory, Symbolic Interactionism, Phenomenology, Ethnomethodology, Structuration theory.

References

1. Tom Bottomore. 1978. "Marxism and Sociology," in Bottomore and Nisbet, eds., *A History of Sociological Analysis*, 118-130.

2. Coser, Lewis. 1975. Masters of Sociological Thought. NY: Harcourt, Brace, Jovanovich.

3. Giddens, Anthony. 1972. Emile Durkheim: Selected Writings. Cambridge, UK: Cambridge University Press.

4. Giddens, Antony. 2006. Sociology. Polity Press, New York.

5. Giddens, Anthony. 1992. Capitalism and Modern Social Theory. Cambridge University Press, Cambridge.

6. Marx, Karl. 1964. Selected Writings in Sociology and Social Philosophy. Translated by T. B. Bottomore. NY: McGraw Hill. [6]. Turner, Jonathan. 1994. The Structure of Sociological Theory. Belmont, CA: Wadsworth.

7. Parsons, Talcott. 1967. The Structure of Social Action, Free Press, 1967 , v. 1, Part I. Merton, Robert. 1968. Social Theory and Social Structure, enlarged edition, Free Press, 1968, 39-138.

8. Weber, Max. 1958. Essays in Sociology , Oxford University Press

H 672: Information and society (Theory)

Instructor/Proposed by : Debashis Pattanaik

Prerequisite: Introductory course on sociology and sociological theory.

Course structure

1. **Information & the idea of information society**(5 classes+1 tutorial)

2. **Classical tradition** (6 classes+2 tutorial)

Functional analysis, Functions and dysfunction, Political economy, Hegemony and Dialectical materialism

3. **Modern theory** (6 classes+2 tutorial)

Critical theory and socio-cultural tradition

4. **Post industrialist and late modern tradition** (8 classes+2 tutorial)

Neo evolutionism, Post industrial society, Information, Structure and Agency, Paradoxes of modernity, Surveillance

5. **Debates on information and advanced capitalism** (8 classes+2 tutorial)

Political economy, market criteria, class inequalities, objections to critical theory, Theories of Information manipulation, The public sphere, Information change, Public service institutions

6. **Information and post modernism** (8 classes+2 tutorial)

Regulation school, Globalization, Post fordism, Flexible specialization, Theories of network society

References

1. Anderson, Benedict. (1983). Imagined Communities: Reflections on the Origin and Spread of Nationalism , second edition. Verso, 1991.
2. Boudrillard, Jean (1985). The masses the implosion of the social in the media. New Literary History, 16 (3): 577-589.
3. Baudrillard, Jean. (1976). Symbolic Exchange and Death. Translated by Iain Hamilton Grant. Introduction by Mike Gane. Sage, 1993.
4. Bell, Daniel. (1973). The Coming of Post Industrial Society: A Venture in Social Forecasting Harmondsworth: Penguin, 1976.
5. Castells, Manuel. (1999). An introduction to information age. In Hugh Mackay and Tim O Sullivan (eds.) The Media Reader: Continuity and Transformation. London: Sage
6. Castells, Manuel. (1996). The Rise of the Network Society. Oxford: Blackwell.
7. Drucker, Peter F. (1993). Post -Capitalist Society. New York: HarperCollins.
8. Duff, Alistair S. (2000). Information Society Studies. Routledge.
9. Giddens, Anthony. (1991). The Consequence of Modernity. Cambridge: Polity
10. Habermas, Jurgen. (1974).The public sphere. New German Critique 3: 49-55.
11. Habermas, Jürgen (1962). The Structural Transformation of the Public Sphere: An Inquiry into a Category of Bourgeois Society. Translated by Thomas Burger with the assistance of Frederick Lawrence. Cambridge: Polity, 1989.
12. Jay, Martin (1973). The genesis of critical theory. In The Dialectical Imagination, Little, Brown & Co.
13. Karl Marx, Preface to Contribution to a Critique of Political Economy (1859).
14. Lasswell, Harold (1948). The Structure and Function of Communication in Society. In Schramm W. (Ed.), Mass Communication (2nd ed. 1960) Urbana, IL: University of Illinois.

15. Lash, Scott (2002). Critique of Information. Routledge.

16. Lunt, Peter and Livingstone, Sonia. (2013) Media Studies' fascination with the concept of the public sphere: critical reflections and emerging debates. Media Culture & Society, 35(1) 87-96.

17. McLuham, Marshall. (1964).The Medium is the message. In Understanding Media The Extension of Man Reprint 1994. MIT Press.

18. Schiller, Herbert (1991). Not yet the post-imperialist era. Critical Studies in Mass Communication 8.

19. Wright, Charles (1960). Functional analysis and mass communication. Public Opinion Quarterly 24.

H 673: Sociology of Development

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course structure

1. **Sociological perspectives** (4 classes + 1 Tutorial)

What is Development. Why does it matter?

Economic– human – social – sustainable – ecological notions of development

2. **Theories/models of development** (6 classes + 2 Tutorials)

Modernization theory (New modernization studies), Is development premised on underdevelopment? Dependence theory (New dependence studies), World system theory, Global system interdependence,

3. **Globalization and Modernization** (6 classes + 2 Tutorials)

What is Globalization, Role of Globalization in Economic Development. Can everyone catch up? Modernization Theory.

4. **Development- indicators** (4 classes + 1 Tutorial)

Human Development Index, Millennium Development Goals

5. **Sustainable Development** (6 classes + 2 Tutorials)

What is Sustainable Development? Factors of Sustainable Development, Participatory development. Environmental Issues and Ecological discourses

6. **Development reconsidered** (4 classes + 1 Tutorial)

Urbanization in Global system, Stakeholders approach

7. **Development induced social problems** (4 classes + 1 Tutorial)

Displacement, Regional Disparity, Social Eclusion, Unequal Distribution of Benefits

8. The Capabilities Approach (4 classes + 1 Tutorial)

Capabilities approach and its philosophical foundations and understanding of development, applications of capabilities approach to concrete social issues

9. Contemporary Issues in development (4 classes + 1 Tutorial)

Special reference to India: Health, Education and Livelihood . Case Studies and Contemporary debates. Rights of Future Generations, Reduce, Recycle and Reuse

References

1. Allen, T. and Thomas, A. 2000. Poverty and Development into the 21st century, Oxford: Oxford University Press
2. Bernstein, H., 1971. Modernization theory and the sociological study of development". Journal of 7 Development Studies, 7(2), pp.141-160.
3. Derze, Jean and Sen, Amartya. 1998. India: Economic Development and Social Opportunity. O.U.P, New Delhi.
4. Harrison, D. H. 1958. The Sociology of Modernization and Development. Routledge, London.
5. Heyter, Teresa. 1971. Aid as Imperialism, Pelican
6. Myrdal, Gunnar. 1989. The Equality Issue in World Development – The American Economic Review, vol 79, no 6, Dec 1989
7. Nussbaum, M. (2003) "Capabilities and Social Justice." International Studies Review, 4(2), pp. 123- 135.
8. Osorio, Leonardo et al (2005) "Debates on sustainable development: towards a holistic view of reality". Environment, Development and Sustainability 7: 501-518.
9. Planning Commission of India: various reports and working papers
10. Preston, P.W. 1982. The Theories of Development. Routledge, London.

11. Sen, A. (1999) "Development as Freedom" New York: Alfred A. Knopf. Introduction and chapters 1 and 2.

12. UNDP. Various Years. Human Development Report.

13. Wallerstein, Immanuel. 1992. "The Concept of National Development, 1917-1989: Elegy and Requiem." American Behavioral Scientist, 45(4/5): 517-529. Also published in: Wallerstein, Immanuel. 1995. After Liberalism. New York: The New Press, pp. 108-124. http://abs.sagepub.com/content/35/4-5/517.full.pdf

14. Webster, Andrew. 1984. Introduction to Sociology of Development. McMillan, London.

H674: Contemporary Social Theory

Instructor/Proposed by: Debashis Pattanaik

Prerequisite: Introductory course on sociology and sociological theory.

Course structure

1. **Exchange and rational choice theory**(6 classes + 2 tutorial)

Introduction, Social behavior as exchange, Exchange and power, Collective action

2. **Critical theory** (6 classes + 2 tutorial)

Mass media and mass society, Power structure, Life world vs System, Public sphere

3. **Middle range functionalism and neo functionalism** (5 classes + 1 tutorial)

Middle range functional analysis, Social structure, Functionalism to neo functionalism, Social action and social order

4. **Theories of institutions and networks** (6 classes + 2 tutorial)

Economic embeddings and social structure, Collective rationality, Structural holes

5. **Theories of modernity & post modernity**(8 classes + 2 tutorial)

Modernity and its consequence, Critique of modernity, World System, Crisis in modern world system, Globalization and nation state, Mass media and the simulation of reality, Enchanted consumption

6. **Theories of human agency, structuration and social system** (10 classes + 2 tutorial)

Agency, Social structure and system, Structuration, Morphogenic process, Models of Social system, Self Creation and self organization of social system.

References

1. Abbott, Andrew. (2001). The Chaos of disciplines. Pp. 3-33. In Chaos of Disciplines . Chicago: University of Chicago Press.

2. Alexander, J. C. (1998). Neofunctionalism and After. Basil Blackwell.

3. Archer, M. (1982). Morphogenesis versus structuration: On combining structure and action, The British Journal of Sociologygy 33(4): 455–83.

4. Baudrillard, Jean. (2008). Simulacra and Simulations. Pp. 230-234. In The New Social Theory Reader, Second Edition, edited by Steven Seidman and Jeffrey Alexander. New York: Routledge.

5. Bauman, Z. (1992). Imitations of Post Modernity. London: Routledge.

6. Burt, R. S. (2004). Structural holes and good ideas, American Journal of Sociology, 110 (2). 349-399.

7. Blumer, Herbert. (1969). Society as Symbolic Interaction. Pp. 78-89. In Symbolic Interactionism: Perspective and Method. Berkeley: University of California Press.

8. Craig Calhoun, C., Joseph G., Moody, James J. Pfaff, S. and Virk. I. (eds.) (2012). Contemporary Sociological Theory. UK: Blackwell.

9. D. Layder, (1994). Understanding Social Theory. London: Sage Publications.

10. Emirbayer, Mustafa and Jeff Goodwin. (1994). Network analysis, culture, and the problem of agency. American Journal of Sociology 99: 1411-54.

11. Goffman, Erving. (1959). The Presentation of Self in Everyday Life. New York: Doubleday. Selection: Pages 17-76.

12. Garfinkel, Harold. (1967). Studies of the routine grounds of everyday activities. Pp. 35-75. In Studies in Ethnomethodology . Cambridge: Polity Press.

13. Granovetter, Mark.(1985). Economic action and social structure the problem of embeddness. American Journal of Sociology, 91 (3).481-510.

14. Horkheimer, Max. (1989). Traditional and critical Theory. Pp. 171-178. In An Anthology of Western Marxism: From Lukacs and Gramsci to Socialist-Feminism, edited by Roger Gottlieb. New York: Oxford University Press.

15. Habermas, Jürgen. (1998). Civil Society and the Political Public Sphere. Pp. 359-387. In Between Facts and Norms: Contributions to a Discourse Theory of Law and Democracy Cambridge: MIT Press.

16. Habermas, Jürgen. (2009). Political Communication in Media Society: Does Democracy Still Have an Epistemic Dimension? The Impact of Normative Theory on Empirical Research. Pp. 138-183. In Europe: The Faltering Project. New York: Polity Press.

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18. Luhmann, N. (1995).Social Systems. Stanford: Stanford University Press.

19. Marcuse, Herbert. (1968/2000). Philosophy and critical theory. Pp. 357-362. In Social Theory: Roots and Branches, edited by Peter Kivisto. Los Angeles: Roxbury Publishing.

20. Schutz, Alfred. (1973). Some leading concepts of phenomenology. Pp. 99-117.In Collected Papers: The Problem of Social Reality, edited by Maurice Natanson. The Hague: Martinus Nijhoff.

21. Sewell, William H., Jr. (1992). A Theory of Structure: Duality, Agency, and Transformation. The American Journal of Sociology 98, 1 (July): 1-29.

H675: Qualitative Research Methods

Instructor/Proposed by : Pranay Swain

Prerequisite: None

Course structure

a. The Scientific Method and Sociological Inquiry(4 classes and 1 tutorial)

Qualitative versus quantitative research in the social sciences, Approaches to qualitative research,

b. Action Research (4 classes and 1 tutorial)

Action research/Participatory action research: The how and why of Action Research, Community mapping as a tool, Participatory Rural Appraisal

c. Qualitative Research Design (4 classes and 1 tutorial)

Designing qualitative research, Review of Literature and composing research questions, Site selection & sampling,

d. **Ethics in Qualitative Research** **(4 classes and 1 tutorial)**

Ethics in qualitative research, Dangers in the field: positioning yourself as researcher & ethnographic field work,

e. **Role of Researcher** **(4 classes and 1 tutorial)**

Getting in & getting along: Positioning yourself as researcher, Issues of data quality and applicability,

f. **Tools of Collecting Qualitative Data (8 classes and 2 tutorials)**

Triangulation, Observation/participant observation, Ethnography and naturalistic methods, Observation debriefing: introduction to in-depth interviews, Writing interview questions & practicing probes, Focus group interviews, Case studies

g. **Qualitative Data Analysis** **(6 classes and 2 tutorials)**

Content analysis, Computers and qualitative analysis, Mixing qualitative and quantitative research: possibilities and pitfalls

h. **Report Writing** **(6 classes and 2 tutorials)**

Making sense of qualitative data, Writing up qualitative findings, writing workshop

References

1. Bailey, Carol A. 2007. A Guide to Qualitative Field Research, (2nd ed.). Thousand Oaks, CA: Sage Publications.

2. Berg, Bruce L. 2007. Qualitative Research Methods for the Social Sciences, (6th ed.). MA: Pearson Education.

3. Esterberg, Kristin G. 2002. Qualitative Methods in Social Research. Boston, MA: McGraw-Hill Higher Education.

4. Mason, Jennifer. 2002. Qualitative Researching, (2nd ed.). Thousand Oaks, CA: Sage Publications.

5. Michael Q. Patton. 2002. Qualitative Evaluation and Research Methods, (3rd ed.). Newbury Park, CA: Sage Publications.

6. Morgan, David L. 1997. Focus Groups as Qualitative Research, (2nd ed.). Thousand Oaks, CA: Sage Publications.

7. Berg, B., and H. Lune. 2012. Qualitative Methods for the Social Sciences, pp. 61-87.

8. Stein, Arlene. 2010. “Sex, Truths, and Audiotape: Anonymity and the Ethics of Exposure in Public Ethnography.” Journal of Contemporary Ethnography 39(5) 554–568. A2L Topics: Ethical questions and controversies in conducting research.

9. Berg, B., and H. Lune. 2012. Qualitative Methods for the Social Sciences, pp. 196-216. Topics: Entering the field; doing observation.

H 676: Quantitative Research Methods –I

Instructor/Proposed by: Debashis Pattanaik

Prerequisite: Course on Research methodology 1

Course structure

1. **Introduction** (5 classes + 1 tutorial)

Research question and resources, Objectivity and Subjectivity: Debate on Values

2. **Measurement in social Science** (5 classes + 1 tutorial)

Operationalization, Variables, Measurement, Validity, Reliability

3. **Research design** (6 classes + 2 tutorial)

Survey research, Experimental design

4. **Introduction to statistical methodology & basic probability** (10 classes + 2 tutorial)

Frequency tables and histogram, Graphical methods, Measures of central tendency, Measures of dispersion, Coefficient of variation and Coefficient of dispersion, Probability, Probability rules, Permutation and combinations, Probability distribution, the binomial distribution, Normal distribution

5. **Sampling distribution of mean & estimation of population mean** (10 classes + 2 tutorial)

Population distribution, Central limit theorem, Standard error of the Mean, Z distribution, Student’s t distribution, Assumptions for t distribution, Estimation vs hypothesis testing, Point estimate, Confidence Intervals for a Single Population Mean, Z and t statistics for two independent samples, Confidence Intervals for the Difference between Means from Two Independent Samples: variance known- and variance unknown.

6. **Test of Hypotheses** (6 classes + 2 tutorial)

Terminology, Neyman–Pearson Test Formulation, Test of a Mean: Population Variance Known, est of a Mean : Population Variance Unknown, One-Tailed Versus Two-Tailed Tests, *p*-Values, Type I and Type II Errors.

References

1. Babbie, E. R. (2009). The Practice of Social Research. New York:Wadsworth Publishing.
2. Booth, W. (2003) The Craft of Research. London: The University of Chicago Press.
3. Black, T. R.(1999). Doing Quantitative Research in Social Sciences: An Integrated Approach to Research Design, Measurement and Statistics. London: Sage Publications.
4. Cooper, R. A. and Weekes, A. J. (1983), Data, Models and Statistical Analysis. New Jeresy: Barnes and Noble Books.
5. Fowler, F. J. (2009). Survey Research Methods (Applied Social Research Methods). London: Sage Publications.
6. Gupta, S. C. and Kapoor V. K. (2014). Fundamentals of Mathematical Statistics. New Delhi: S. Chand.
7. Graham, Kalton. (1983). Introduction to survey sampling. Newbury Park: Sage.
8. Henry, G. T. (1995). Graphing Data - Techniques for Display and Analysis. Thousand Oaks, CA: Sage Publications.
9. Healey, J. F. (2005). Statistics: A Tool for Social Research. Belmont: Wadsworth Publishing.
10. Huck, S. W. (2007). Reading Statistics and Research. Boston: Allyn and Bacon.
11. Maxim, P. S. (1999). Quantitative Research Methods in the Social Sciences. Oxford: Oxford University Press.
12. Nachmias, C. Frankfort and Leon-Guerrero. (2006) A. Social Statistics for a Diverse Society, Thousand Oaks, CA: Pine Forge Press.
13. Shadish, W. R. and Cooke, T. (2011) Experimental and Quasi-Experimental Designs for Field Research. London: Routledge Academic, London.
14. VanLeeuwen, T. and Jewitt, C. (eds.) (2001). Handbook of Visual Analysis. London: Sage Publications.
15. Wagner, William E. (2014).Using IBM SPSS Statistics for Research Methods and Social Science Statistics. Sage Publications.

H 677: Social Network Analysis I

Instructor/Proposed by : Debashis Pattanaik

Prerequisite: Prerequisite: Course on Research methodology 1 and social theory.

Course structure

1. **Introduction to social network analysis** (5 classes+1 tutorial)

History of social network research, General trends in the field of social network study, Patterns of networks, Basics of Graph theory

2. **Basic network concepts** (8 classes+2 tutorial)

Network terminology, Sociological questions and relationships, Patterns and distributions, Roles and positions

3. **Analysis I** (10 Classes+2 tutorial)-28

Complete network, Local network and Relations through associations

4. **Analysis II** (10classes+2 tutorial)-40

Sentiments and Friendship, Balance theory, Structural balance, Social capital, Small world problem

5. **Social frameworks I** (5classes + 1 tutorial)

Traditional network and kinship relationship, Reciprocity, Patron client network, Organizations and network, Dark network

6. **Social frameworks II** (5 Classes + 1 tutorial)

Information, Knowledge and network, Social media and network

References

1. Barabasi, Albert Laszlo. (2002) Linked: The New Science of Networks*. New York: Perseus Books.*

2. Breiger, R. L. (XXXX). The duality of person and groups. Social Forces, Vol. 53:181-190.

3. Burt, R. (2004). Structural holes and good ideas. American Journal of Sociology 110:349-400.

4. Carrington, P., Scott, J. and Wasserman, S. (2005) Models and Methods in Social Network Analysis, Cambridge: Cambridge University Press.

5. Davis, J. A. (1963). Structural balance, mechanical solidarity and interpersonal relations. American Journal of Sociology 68:444-62.

6. Doreian, P. (1980). On the evolution of group and network structure. Social Networks, 3. 235-252.

7. Flandreau, Marc and Jobst, Clemens. (2005). The ties that divide: A network analysis of the international monetary System, 1890-1910. The Journal of Economic History, 65: 977-1007.

8. Granovetter, Mark. (1973). The strength of weak ties. The American Journal of Sociology, Vol. 78, No. 6: 1360-1380.

9. Knoke, D. and Yang, S. (2007). Social Network Analysis. Thousand Oaks, California: Sage.

10. Marsden, Peter: (1987). Core discussion networks of Americans. American Sociological Review Vol. 52, No. 1: 122-131.

11. Levi strauss, C. (1963). Structural Anthropology. New York: Basic Books.

12. Moody, James. (2004). The structure of a social science collaboration network. American Sociological Review 69: 213-264.

13. Scott, J. (2000). Social Network Analysis: A Handbook, Second Edition. London: Sage.

14. Shalins, Marshal. (2012).What Kinship Is and Is Not. Chiago: University of Chicago Press.

15. Suitor, J. J., Wellman, B. and Morgan, D. L. (1997). It's about time: How, why and when networks change. Social Networks 19(1).

16. Uzzi, B. and Spiro, J. (2005) Collaboration and creativity: The small world problem. American Journal of Sociology 111: 447-504.

17. Wasserman, S. and Faust, K. (1994). Social Network Analysis: Methods and Applications, Cambridge: Cambridge University Press.

18. Watts, Duncan J. (1999). Network dynamics and the small world phenomenon. American Journal of Sociology. 105, 2: 493-527.

CHEMICAL SCIENCES

Programme Code: CHEM04

Programme Outcome:

- Foundation in the fundamentals of core chemical sciences fields including those in Analytical, Inorganic, Nuclear and Physical Chemistry.
- Skill development in critical thinking and problem solving applied to scientific problems.
- Development of skills to clearly communicate the results of scientific work in oral, written and electronic formats to both scientists and the public at large.
- Development of skill set necessary for starting a research career in chemical sciences and allied areas
- Appreciate the central role of chemistry in DAE programmes and apply these to take up research in key issues such energy, health and medicine.

List of Courses

Course Structure Under BARC:

Sr. No.	Old Course Code	New Course Code	Subject Title	Hours	Credits	Marks
CORE COURSES						
1	CYJRF-101	01-CHEM04-601-C	Inorganic chemistry	30	4	
2	CYJRF-102	01-CHEM04-602-C	Physical chemistry	30	4	
3	CYJRF-103	01-CHEM04-603-C	Organic chemistry	30	4	
4	CYJRF-104	01-CHEM04-604-C	Radiochemistry	30	4	
5	CYJRF-105	01-CHEM04-605-C	Analytical chemistry	30	4	
6	CYJRF-106	01-CHEM04-606-C	Health physics and safety in chemical labs	20	2	
			CORE TOTAL	**185**	**24**	
ELECTIVES - *Any 5*						
Group A (Any one)						
7	CYJRF-201	01-CHEM04-701-E	Radioisotopes and radiations in industry	30	4	
8	CYJRF-202	01-CHEM04-702-E	Actinide chemistry	30	4	
9	CYJRF-203	01-CHEM04-703-E	Radiopharmaceuticals	30	4	
10	CYJRF-204	01-CHEM04-704-E	Radiation detection and measurements	30	4	
Group B (Any one)						
11	CYJRF-205	01-CHEM04-705-E	Advanced materials chemistry	30	4	
12	CYJRF-206	01-CHEM04-706-E	Polymers science and technology	30	4	
13	CYJRF-207	01-CHEM04-707-E	Renewable energy harvesting and storage	30	4	
14	CYJRF-208	01-CHEM04-708-E	Fundamentals of environmental chemistry	30	4	
Group C (Any one)						
15	CYJRF-209	01-CHEM04-709-E	Advanced spectroscopy	30	4	

16	CYJRF-210	01-CHEM04-710-E	Computational chemistry	30	4	
17	CYJRF-211	01-CHEM04-711-E	Radiation and photochemistry	30	4	
18	CYJRF-212	01-CHEM04-712-E	Materials for cancer therapeutics and diagnostics	30	4	
Mandatory						
19	CYJRF-301	01-CHEM04-713-E	Numerical methods and computer programming	30	4	
20	CYJRF-302	01-CHEM04-714-E	Chemistry of nuclear fuel cycle	30	4	
21	CYJRF-303	01-CHEM04-715-E	Research methodologies	30	4	
			ELECTIVES TOTAL	**150**	**20**	
NON-SUBJECT ASSIGNMENTS						
22		01-CHEM04-601-PR	Mini Project 1		8	
23		01-CHEM04-602-PR	Mini Project 2		8	
			NON-SUBJECT ASSIGNMENTS TOTAL		**16**	
			TOTAL	**335**	**60**	

CORE COURSES

CYJRF-101: Inorganic Chemistry (30 Hours / 4 Credits) (01-CHEM04-601-C)

Course Outcomes:

- Description of specific crystal structures by applying basic crystallographic concepts
- Understanding different types of defects and their effect on the functional properties
- Understand the general characteristics of the d and f block elements
- Thorough knowledge of the different theories to explain the bonding in coordination compounds
- Idea about different synthesis methods for nano-materials useful for research work

Course Details:

Co-ordination Chemistry:

Werner's Coordination theory, Valence Bond Theory, Crystal Field Theory, Jahn Teller effect, Thermodynamic effects of crystal field, Coordination chemistry of lanthanide and actinide ions, Application of group theory for d-d transition, Electronic spectra of complex ions, Absorption probability, Allowed transitions and selection rules, Tanabe Sugano diagram, Nephelauxetic effect, Ligand metal orbital overlaps, Magnetic properties of complex ions, f-f transitions in lanthanides. Molecular orbital theory, Molecular orbital diagram from concepts of group theory, MO's for Sigma bonding in AB_6 molecules, Tetrahedral AB_4 case, MO's for pi bonding in AB_6 molecules, Metal organic framework materials. Dissociative & associative reaction mechanism of ligand replacement in octahedral and square planar complexes, trans-effect and its implications.

Materials Science:

Basic solid-state chemistry: Crystalline and amorphous materials, Close packed structures, Basic structure types, Silicate structures, Perovskites, Pyrochlores, Spinels, Structure of common nuclear materials (oxides, metallic, carbides), Co-ordination number, Bonding, Radius ratio rules, Lattice energies, Bond energies
Defects in Solids: Defects and defect equilibria, Classifications of defects, point/line/surface/volume defects, Techniques to study defects, Solid solutions, Phase transitions and their classifications, Thermodynamic classification of phase transitions, Martensitic phase transitions, Equilibrium and metastable phases
Nanomaterials: General properties, Difference between nano and bulk materials, Gradation in properties with variation in particle size with examples
Electrical Materials: Ionic conductors, Solid electrolytes, Electronic conductors, Band structures of metals, Insulators and semi-conductors, Controlled valency semiconductors, Dielectrics and concept of polarizability, Ferroelectrics, piezo and pyroelectric materials (concept, examples, applications), Thermoelectric materials, Thomson, Peltier and Seeback effects, Thermocouples, Hall effect
Magnetic materials: Behaviour of materials in magnetic field, Diamagnetic, Ferromagnetic, Anti-ferromagnetic, Paramagnetic materials with examples, Effect of temperature on magnetic materials, Application of magnetic materials
Optical materials: Phosphors, Photoluminescence, Electroluminescence, Thermoluminescence, Characteristics of host matrix, Sensitizers, Activators, Excitation and emission spectra, Energy transfer, Defect-induced luminescence, Quantum yield, Application of phosphors, Materials for LASERS (examples: Ruby and Nd lasers)

Techniques for synthesis of materials

General concepts, Equipment/materials required with few typical examples, Scope and limitations of different synthesis techniques: Solid state synthesis, Hydrothermal synthesis, Ultrasonication and Microwave synthesis, Metathesis, *chimie douce* (polyol, co-precipitation, ion exchange), Gel combustion and sol-gel synthesis, High pressure synthesis, Techniques for growing single crystals and thin films

Diffraction Techniques for Phase Identification

Concept of diffraction techniques, X-ray diffraction, Reciprocal space, Structural and scattering factors, grain / particle size effects, Different techniques of recording diffraction patterns, Indexing of diffraction patterns, Neutron diffraction, Electron diffraction.

Reference Books:

1. Solid State Chemistry and its Applications by A. R. West
2. Material Science and Engineering by V. Raghavan
3. New Directions in Solid State Chemistry by C. N. Rao and J. Gopalakrishnan
4. Solid State Chemistry: An Introduction by Smart and Moore
5. Introduction to Solid State Physics by Charles Kittel
6. Advanced Techniques for Materials Characterization" Eds. A. K. Tyagi, M. Roy, S. K. Kulshreshta, S. Banerjee, Trans Tech Publications Ltd, Switzerland (2009)
7. Advanced Inorganic Chemistry, 6th Edition by F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann
8. Inorganic chemistry by Shriver & Atkins, 5th edition
9. Inorganic Chemistry: Principles of Structure and Reactivity, 4th edition, by J. E. Huheey, E. A. Keifer, R. L. Keifer, O. K. Medhi

CYJRF-102: Physical Chemistry (30 Hours / 4 Credits) (01-CHEM04-602-C)

Course Outcomes:

- Analyze thermal effects on a chemical process
- Understanding the phase diagrams
- Understanding basics of quantum mechanics to understand the difference between classical and quantum phenomena
- Develop expertise in molecular orbital theory that helps in understanding structure of polyatomic molecules
- Understanding kinetics of chemical reactions and reaction dynamics
- Learn difference between chemical kinetics and dynamics, and their applications in real systems
- Expertise developed in carrying out research in relevant area of chemical physics with acquired knowledge

Course Details:

Thermodynamics:

Laws of thermodynamics, Carnot cycle, Concept of entropy, Fundamental equations and thermodynamic functions, Chemical potentials, Thermodynamics of solutions, ideal and regular solution models. Chemical Equilibrium**:** Solid-gas equilibrium, Ellingham diagram. Statistical mechanical interpretation of laws of thermodynamics, Entropy and probability, Partition function and equilibrium.

Chemical potential of an ion in solution; Activity and activity coefficients of ions in solution, Quantitative aspects of Faraday's laws of electrolysis, Nernst equation, Standard electrode (reduction) potential and its application to different kinds of half-cells. Binary and ternary phase diagrams, Degree of freedom rule and lever-rule, Calculation of simple binary phase diagrams from thermodynamic properties, Chemical potential variations across phase diagrams.

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Chemical Kinetics:

Rates of chemical reaction, rate equation, methods of determination of rate and order of a chemical reaction, complex reaction, Collision and transition state theories of chemical reaction, Potential energy surfaces and reaction dynamics. Application to unimolecular and Bimolecular reactions, Chemical oscillations and nonlinear dynamics.

Quantum Chemistry:

Postulates of quantum mechanics, Classes of operator: Linear and Hermitian, Physical significance of eigen value in quantum mechanics; Boundary value problem in quantum mechanics; Exactly solvable problems: Particle in a box and ring; simple harmonic oscillator; rigid rotor and hydrogen atom; Approximation methods: Variation method; perturbation theory for time-independent and time dependent systems; Many-electron systems: Hartree-Fock theory and beyond; Chemical binding in simple molecular systems: Valence bond and molecular orbital theories; Concept of LCAO and introduction to ab-initio and semi-empirical molecular orbital calculations of molecules; Extended systems: From bonds to bands; Applications to few simple molecules.

References:

1. Fundamentals of Thermodynamics by Sonntag, R.E, Borgnakke, C & Van Wylen
2. Principles of Thermodynamics Hardcover by Jean-Philippe Ansermet, Sylvain D. Brechet
3. Chemical kinetics, by Keith J. Laidler
4. Atkins' Physical Chemistry by Julio de Paula and Peter Atkins
5. Quantum Chemistry by R. K. Prasad
6. Molecular Quantum Mechanics by Peter Atkins
7. Quantum Chemistry 7^{th} Ed, Levine

CYJRF-103: Organic Chemistry (30 Hours / 4 Credits) (01-CHEM04-603-C)

Course Outcomes:

- Knowledge about synthetic design, and to enable a student to devise a synthetic route for a target molecule
- Knowledge about the various strategies in organic synthesis
- Knowledge about the most recent advancements in organic synthesis
- Understanding of important spectroscopic methods and their application for structure elucidation of organic molecules

Course Details:

Strategy and Design of Organic Synthesis:

Brief history of organic synthesis, Retro-synthesis analysis and synthetic-strategy, Stepwise synthesis vs. domino synthesis, Linear and convergent synthesis, Practice of total synthesis, Enantio- and diastereo-selective synthesis, Concept of double diastereo-selection-matched and mismatched pair; Solid phase synthesis, Concepts in combinatorial synthesis, Diversity oriented synthesis and their applications in various fields in chemistry including drug development, Catalysis and materials development.

Carbon-Carbon and C-X Bond Formation:
Various C-C and C-X coupling methods including single, double and triple bonds viz. Heck reaction, Cross coupling reactions (Suzuki, Stille, Negishi, Kumada, Hiyama, Sonogashira, Buchwald-Hartwig), Fischer carbenes, Schrock carbenes, Olefin metathesis, Various types of metathesis and application to organic synthesis, Dotz benzoannulation, Pauson-Khand reaction and [2+2+2] cycloadditions, Organo-catalyzed organic reactions and enantio-selective organo-catalysis, Umpolung and N-heterocyclic carbene-application in catalyzed general and asymmetric synthesis, Functionalization by catalytic selective C-H activation and metal free hydrogenation equivalents.

Organic Spectroscopy:
Importance of spectroscopic methods in the structural elucidation of organic molecules**,** Organic absorption spectroscopy, Use of IR and UV in Organic Chemistry, examples of IR and UV spectra of simple organic molecules, nuclear spin and resonance, chemical shifts, factors that influence ^{1}H chemical shifts, spin-spin coupling, coupling patterns and resonance multiplicities, coupling to chemically equivalent spins, weak and strong coupling, chemical and magnetic equivalence, 1H spin couplings and chemical structure, geminal, vicinal and long-range couplings, chirality and NMR, chiral solvating agents, ^{13}C NMR spectroscopy, NMR instrumentation, Fourier transform NMR, interpretation, Concepts and applications of methods behind Mass Spectrometry and the interpretation of spectra

Reference books:
1. Organic Chemistry by Jonathan Clayden, Nick Greeves and Stuart Warren
2. Organic Chemistry by Jerry March
3. Modern Physical Organic Chemistry by Eric V. Anslyn and Dennis A. Dougherty
4. Organic Spectroscopy by William Kemp
5. Organic Synthesis: The Disconnection Approach by Stuart Warren

CYJRF-104: Radiochemistry (30 Hours / 4 Credits) (01-CHEM04-604-C)

Course Outcomes:
- Explain the different kinds of radioactive decay and interpret a radioactive decay series, apply radiotracer principles
- Understand the basic concepts in fission and the production yields of different radioactive isotopes during fission
- Expertise to choose a particular detector for a specific application
- Knowledge base to understand safety aspects while working with radioactivity
- Basic knowledge to develop need-based measurement systems

Course Details:

Fundamentals of Radiochemistry

Radioactivity: Nuclear stability, Binding energy, Natural radioactivity, Decay series, Induced radioactivity, Radioactive decay laws, Concept of half-life and radioactive equilibria
Radioactive decay modes: α-decay, β decay, γ - deexcitation – basics
Nuclear models: Liquid drop model, Shell model, Basic concept of spin, parity electric and magnetic moments, Isomerism
Artificial radioactivity: Transmutation – concept of cross section, Energy thresholds, Fission and radioactivity formed in fission, Nuclear fusion, Basics of reactors and accelerators

Production and chemical properties of transuranic elements – Variable oxidation states, Redox behavior, Production of trans-actinides and fast radiochemical separations

<u>Radiotracers, dating and basic principles of nuclear analytical techniques</u>

Radiation interaction and detection: Interaction of heavy charged particles and electrons with matter, Stopping power, Bethe equation, Braggs's curve, range, interaction of X-/γ-rays and neutrons,
Detectors: Ionization chamber, Proportional counter, GM counter, NaI(Tl) detector, HPGe detector, Silicon detectors for charged particles, Detection efficiency, Energy resolution, Dead time, Counting Statistics

References:

1. Nuclear and Radiochemistry (1981) – G. Friedlander, J. Kennedy, J. M. Miller and J. W. Macias
2. Manmade elements (1963) – G. T. Seaborg
3. Essentials of Nuclear Chemistry (1982) – H. J. Arnikar
4. The Chemistry of Transuranium Elements (1971) – C. Keller
5. Fundamentals of Radiochemistry, IANCAS Publication, 2007.
6. Radiation detection and measurement, G.F. Knoll, John Wiley & Sons

CYJRF-105: Analytical Chemistry (30 Hours / 4 Credits) (01-CHEM04-605-C)

Course Outcomes:

- Acquaintance with various analytical techniques
- Idea on how to tackle an analytical problem, pertaining to DAE and other industries
- Acquaintance with theories of various matrix separation techniques
- Acquaintance with statistical treatment of analytical data
- The course gives sufficient expertise leading to enhanced employability

Course Details:

Separation/Purification and Detection Technique
Solvent extraction: - Conventional, Liquid membranes, Bulk, Supported and emulsified; Solid Phase Extraction (SPE); Ion Exchange: - Conventional, Membranes. Chromatography: **-**Gas Chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion Chromatography (IC), Super critical extraction chromatography, Capillary electrophoresis. Retention, Band spreading, resolution, Application of chromatographic techniques.

Electrochemical Methods
Potentiometry, Ion Selective Electrodes (ISE), Membrane ion selective electrodes, Voltammetry & Polarography, Cyclic, Pulse and Stripping Voltammetry, Electrochemical kinetics, Coulometry and Amperometry, AC voltammetric Techniques, Electrochemical impedance spectroscopy, Charge transfer and diffusivity, spectro-electrochemistry.

Spectrochemical Methods
Atomic Absorption Spectrometry: - Flame (FAAS), Electrothermal (ETAAS), Cold Vapor (CVAAS), Hydride Generation (HGAAS); Optical Emission Spectrometry (OES): - with Inductively Coupled Plasma (ICPOES), Glow Discharge (GDOES).

Mass Spectrometry
Mass Analysers:- Magnetic, Quadrupole, Time of Flight (TOF), Ion Cyclotron Resonance; Detectors:- Faraday Cup, Channeltron, Daly; Ion Sources:- Thermal Ionization (TI), Electron Impact, ICP, GD, Laser Ablation (LA-ICP), Secondary Ionization (SI), Resonance Ionization (RI), Matrix Assisted Laser Desorption and Ionization (MALDI).

Thermal Methods
Thermogravimetric Analysis (TGA); Derivative Thermogravimetric Analysis (DTG); Differential Thermal Analysis (DTA); Differential Scanning Calorimetry (DSC); Evolved Gas Analysis (EGA); Dilatometry; applications in Polymers Catalysis, Cement, Coal, etc.

Nuclear Methods
Neutron Activation Analysis (NAA); Charged Particle Activation Analysis (CPAA); X-ray fluorescence (XRF) spectrometry; K_0 method of analysis.

Statistics in Chemical Analysis
Accuracy, Precision, Errors in quantitative analysis, Propagation of errors, Treatment of errors, Tests of Significance and Confidence Limits, Reporting of analytical results.

Reference Books:
1. Encyclopaedia of Analytical Chemistry: Applications, Theory and Instrumentation, Editor R. A. Meyers, John Wiley & Sons Ltd. (2000).
2. Fundamentals of Analytical Chemistry, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
3. Principles of Instrumental Analysis, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
4. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).
5. Solvent Extraction of Metals, A. K. De, S. M. Khopkar and R. A. Chalmers, Van Nostrand, Reinhold (1970).

CYJRF-106: Health Physics and Safety in Chemical Labs (20 Hours / 2 Credits) (01-CHEM04-606-C)

Course Outcomes:
- Basic knowledge of handling hazards of various radioactive materials
- Knowledge of radiation protection aspects in nuclear and radiation facilities
- Develop an understanding of the principle of chemical/radiochemical safety
- Inculcate a culture of safety which shall benefit the organization
- Awareness about various emergencies and the need of emergency preparedness plans

Course Details:

<u>Health Physics</u>

Fundamentals of Radiation Protection:
Radioactivity, Ionizing radiation, Radiation quantities and units**,** Basis and structure of the system for radiation protection, System of radiological protection for human, natural radiation.

Basic Radiation Physics and Radiation Dosimetry Aspects
Interaction of radiation with matter, External and internal radiation hazards in nuclear and radiation facilities, Radiation dosimetery: basics, concepts and definitions, External radiation dosimetry and dosimetry of internally deposited radio nuclides, Radiation detection principles, Monitoring instruments and Personnel monitoring devices

Operational Monitoring and Safety Aspects of Facility Design
Exposure situations as per ICRP-103 recommendations, Control of external and internal radiation hazards, Radiation dose limits and its basis, General principles and techniques of radiation monitoring, air activity and area contamination, Assessment and control of radiation hazards in nuclear fuel cycle facilities with special reference to metallurgical, radiochemical and radioisotope facilities and fuel reprocessing plants, Criticality safety aspects, Environmental safety aspects during operation of nuclear and radiation facilities, Industrial hygiene and safety aspects during operation of nuclear and radiation facilities.

Radiological Safety Aspects in Design of Radio-Chemical Laboratories
Safety aspects of design of radiochemical laboratory, its types and operational aspects, Partial containment/confinement systems and ventilation system in a laboratory.

Safety in chemical labs
Definition of chemical safety and its assessment, general chemical safety awareness, Classification of chemicals: Corrosive, Flammables, explosives, toxics, pyrophoric, carcinogen. Chemical which create lachrymation and smoke, Entry of such chemicals into human/biological system and its consequences, precautionary and safe methods for handling such chemicals, Compatibility issues with chemicals, Understanding the Safety Data Sheets (Material Safety Data Sheets) for different chemicals. Storing different chemicals, incompatible chemicals, making inventory of chemicals, labelling chemicals depending upon its nature, safe disposal of chemicals, precautions and safe operating procedures (SOP) to be taken into consideration for chemical spills, chemical protective clothing, chemical accidents and their classification and consequences, Emergency Procedures during chemical accidents, Personal Protective equipment from chemical exposure, precautions to be taken with chemical which need to be refrigerated. Safe practices while using vacuum lines and laser. Fire safety and different types of fire extinguishers.

ELECTIVE COURSES

GROUP A

CYJRF-201: Radioisotopes and Radiations in Industry (30 Hours / 4 Credits) (01-CHEM04-701-E)

Course Outcomes:

- Knowledge of different processes employed for the production and radiochemical processing of important artificially produced radio-nuclides
- Understanding of emergence of the radiation and radioisotopes as an essential tool in various industries
- Applications of various radiotracers in industries
- Understand the concept of radionuclide generator with some relevant examples
- Understanding of various radiation processing techniques
- Appreciate that radiation and radioisotopes are boon for the development of nation and mankind

Course Details:

Production of Radioisotopes

General Introduction and Decay Schemes of Some Important Radioisotopes
Isotopes and radioisotopes, Naturally obtained and artificially produced radioisotopes, Need for radioisotope production, Basics of radioisotope production, Decay scheme, Simplified decay schemes of some important radioisotopes: ^{60}Co, ^{64}Cu, ^{68}Ge, ^{90}Y, ^{99}Mo, ^{131}I, ^{153}Sm, ^{177}Lu.

Production of Radioisotopes in a Nuclear Reactor
Production of radioisotopes in a nuclear reactor - Various processes, Calculation of activity of radioisotope produced, Concept of specific activity, 'No-carrier-added' and 'carrier-added' radioisotopes, Importance and methodologies for obtaining high specific activity radioisotopes, Preparation of targets for irradiation in a nuclear reactor - Chemical form, Encapsulation material, Quantity, Concept of flux depreciation and its impact on radioisotope production, Introduction to Szilard-Chalmer reaction and Bateman equation, Radiochemical processing of the irradiated targets - various techniques, Radioisotope production in Dhruva reactor - Tray rods, Positions available for target irradiation, Neutron flux, Power, Operation schedule, Production routes and radiochemical processing for some important reactor radioisotopes: ^{60}Co, ^{99}Mo, ^{125}I, ^{131}I, ^{153}Sm, ^{192}Ir and ^{177}Lu.

Production of Radioisotopes in a Cyclotron
Principles of production of radioisotopes in a cyclotron - Coulomb barrier, Q value, Nuclear reaction cross-section, Excitation function, Calculation of yield of radioisotopes produced in a cyclotron, Target preparation for production of radioisotopes in a cyclotron - Concept of internal and external targets, Methodologies for target preparation, Target temperature and need for cooling, Considerations for target window foil materials, Production and radiochemical separation of some important cyclotron produced radioisotopes: ^{18}F, ^{44}Sc, ^{64}Cu, ^{68}Ge, ^{89}Zr, ^{123}I, ^{124}I, ^{211}At and ^{225}Ac.

Radionuclide Generators
Concept and applications of radionuclide generators, Separation methodologies used in generators - Column chromatography, Solvent extraction, Electrochemical separation, 'Gel' based systems, Sublimation and Thermo-chromatography. Advantages and limitations of each separation methodology, Calculation of elution yield and t_{max}, Shelf-life of generator, Examples of some clinically relevant radionuclide generator systems: ^{99}Mo/^{99m}Tc, ^{68}Ge/^{68}Ga, ^{90}Sr/^{90}Y, ^{188}W/^{188}Re, ^{225}Ac/^{213}Bi generators.

Applications of Radioisotopes & Radiation in Industry

Radiotracer Applications
Basic principle of radiotracer technology, Advantages of radiotracers, Selection of a radiotracer for a particular study, Injection of radiotracers, Detection of radiotracer, Radiotracer data treatment and analysis.

Applications of Radiotracers in Industry with Case Studies
Leak detection using radiotracers, Flow rate measurements using radiotracers, Residence time distribution measurements, Sediment transport investigations, Radiotracer applications in oil fields, Wear and corrosion rate measurements, Adsorption studies.

Sealed Source Applications in Industry - Principle and Applications
Radiometric measurements, Radiography, Tomography, Nucleonic gauges.

Applications of Isotope Hydrology
General principle of hydrology, Measurement techniques, Source and mechanism of recharge, Interconnection between water bodies, Determination of age of ground waters, Pollution studies.

Radiation Processing Applications
Application of electron beam for processing of materials, Application of gamma radiations for processing of materials.

Reference Books:
1. Manual for Reactor Produced Isotopes. IAEA-TECDOC-1340, IAEA, 1999.
2. Dynamic Mechanical Analysis: A Practical Introduction. K.P. Menars, CRC Press, Boca Raton, 1999.
3. Industrial application of radioisotopes. G. Foldiak.
4. Guide Book on Radioisotope Tracers in Industry - Tech. Rep. Series 316, IAEA, Vienna, 1990.
5. Environmental Isotopes in Hydrogeology. Ian Clarke and Peter Fritz, Lewis Publishers, NY, 1997.

CYJRF-202: Actinide Chemistry (30 Hours / 4 Credits) (01-CHEM04-702-E)

Course Outcomes:
- Understanding of the fuel cycle operations including reprocessing and waste management
- Idea about environmental aspects of actinide migration in case of accident
- Pursue further areas of study such as transactinides and 'atom at a time chemistry'

Course Details:

Position in periodic table: Electronic configuration, The Actinide Concept, Transuranium elements

Actinide Spectroscopy: Electronic states, Atomic properties, UV-visible absorption and emission spectroscopy.
Time resolved fluorescence spectroscopy (TRFS), Photo-acoustic spectroscopy (PAS), X-ray absorption spectroscopy
(EXAFS/ XANES) and their application in actinide speciation.

Electronic structure and bonding: Introduction to '*f*' orbitals and their splitting in the ligand field. Relativistic effect and its consequences. Modern techniques for understanding the bonding in actinide compounds

Co-ordination chemistry: Ionic radii, Coordination number, Hydration Energy, Complexation with inorganic / organic igands, Complexation with crown ethers, cryptands, calixarenes.

Redox behaviour: Redox potentials, Eh-pH diagrams, Variable oxidation states, Ionic species, Unusual oxidation states in actinides and their stabilization, Thermodynamic/ kinetics of redox reactions, Disproportionation.

Hydrolysis of actinides: Hydrolysis, Polymerization / Depolymerization,

Auto-radiolysis: Auto-radiolytic effects in aqueous solutions, Auto-radiolysis effects in solid compounds of actinides.

Actinide separations relevant in nuclear fuel cycle: Ion-exchange, Solvent extraction methods for actinides (inter and intra-group separations), Actinide partitioning, Lanthanides-actinide separation, SANEX processes.

Analytical chemistry of actinides: CQC of nuclear fuels, Davies & Gray method for U analysis, Drummond & Grant method for Pu analysis, Analytical chemistry of transplutonium elements

Actinides in the environment: Natural abundance of actinides, Oklo phenomenon, Actinide speciation in aquatic environment, Complexation with naturally occurring organics such as humic acid and fulvic acid, Sorption and Migration, Interaction with rock, clay, mica etc. Formation and migration of radiocolloids.

Biochemistry of actinides: Actinide-microbe interaction, Actinide migration in the food chain, Fixation in human, Pu in blood, Intra-cellular uptake of Pu, Sequestering using chelation therapy, Bioremediation of nuclear wastes.

Transactinide: Production, Rapid separation techniques, Atom-at-a-time chemistry. Chemistry of elements 104, 105, 106, 108

Reference Books:

1. J.J. Kratz, G.T. Seaborg and L.R. Morss; The Chemistry of Actinide Elements, 2nd Edition, Vol. 1&2, Chapman & Hall, New York (1986).
2. J. J. Katz, L.R.Morss, J.Fuger, and N.M.Edelstein, Chemistry of Actinide and Transactinide Elements, 3rd edition, Springer, Berlin Volume 1-5, (2006).
3. J.C. Bailar, H.J. Emelius, R. Nyholm and A.F. Trotman-Dickenson; Comprehensive Inorganic Chemistry, Vol. 5, Press, Oxford (1973).
4. A. J. Freeman and C. Keller (Eds.); Handbook of Chemistry and Physics of the Actinides, Vol. 1-6, North Holland Publishers, Amsterdam (1986).
5. G.R. Choppin and M.K. Khankhasayev; Chemical Separation Technologies and Related Methods of Nuclear Waste Management, Kluwer Academic Publishers, Netherlands (1999).
6. G.R. Choppin and J. Rydberg; Nuclear Chemistry, Theory and Application, Pergamon Press, Great Britain (1980).

CYJRF-203: Radiopharmaceuticals (30 Hours / 4 Credits) (01-CHEM04-703-E)

Course Outcomes:

- Understanding the importance of nuclear medicine in human healthcare
- Knowledge about application of radiation and radioisotopes for diagnosis and treatment of various human ailments specifically cancer
- Knowledge about theranostics
- Comprehension of various nuclear imaging techniques and their application in nuclear medicine
- Understanding of preparation and quality control of radiopharmaceuticals

Course Details:

Nuclear Medicine and Radiopharmaceuticals

Nuclear medicine and its importance in human healthcare, Concept of tracer and its application in nuclear medicine, Radiopharmaceuticals, Classification of radiopharmaceuticals, Characteristics of diagnostic and therapeutic radiopharmaceuticals, Metal essential and metal non-essential radiopharmaceuticals, Target-specific radiopharmaceuticals, Mechanism of uptake of radiopharmaceuticals.

Preparation of Radiopharmaceuticals

Design and preparation of radiopharmaceuticals, Characteristics of diagnostic and therapeutic radionuclides, Carrier moieties for radiopharmaceuticals, Methods of radiolabeling, Isotopic and non-isotopic labeling, Direct and indirect labeling, Labeling using BFCA (Bi-Functional Chelating Agent), Characteristics of an ideal BFCA, Concept of pre-labeling and post-labeling, Radiolabeling with Technetium and Rhenium, Various cores of Technetium, Radiolabeling using novel cores such as Tricarbonyl, HYNIC, Nitride and '4+1' chemistry, Radiolabeling with Lanthanides, Gallium, Yttrium, Copper etc., Concept of radio-protector and stabilizing agent.

Quality Control of Radiopharmaceuticals
Need for quality control of radiopharmaceuticals, Types of quality control tests, Physico-chemical quality control tests, Methods for determining Radiochemical Purity, Radionuclidic Purity and Chemical Purity of radiopharmaceuticals, Biological quality control tests, Sterility test, Bacterial Endotoxin Test (BET), Quality control methods for some important radiopharmaceuticals (SPECT as well as PET) followed in hospital radiopharmacy.

Formulation of Patient Dose of Radiopharmaceuticals
Concept of centralized nuclear pharmacy and hospital radiopharmacy, Formulation of patient dose in centralized nuclear pharmacy and hospital radiopharmacy, Concept of freeze-dried kit, Formulation of freeze-dried kits, Advantages and disadvantages of using freeze-dried kits for patient dose formulation.

Nuclear Imaging Techniques
Nuclear medicine imaging vs. other contemporary imaging techniques, Concept of tomography, Gamma camera, SPECT, PET and Hybrid imaging (SPECT-CT, PET-CT, SPECT-MRI, PET-MRI), SPECT vs. PET.

Some Important Radiopharmaceuticals
Some important organ-specific diagnostic (SPECT as well as PET radiopharmaceuticals) - Contemporary agents for Myocardial imaging, Brain imaging, Renal imaging, Hypoxia imaging, Tumor and inflammation imaging, Infection imaging, Receptor-specific imaging agents etc., Therapeutic radiopharmaceuticals for some specific applications - Bone pain palliation, Radiation synovectomy, Targeted radionuclide therapy, Peptide Receptor Radionuclidic Therapy (PRRT), Radioimmunotherapy (RIT), Targeted Alpha Therapy (TAT).

Concept of Thernostics and Personalized Medicine
Concept of theranostics, Applications and advantages of theranostics in nuclear medicine, Theranostic radionuclides, Types of theranostic agents, Concept of personalized medicine.

Reference Books:
1. Fundamentals of Nuclear Pharmacy, G.B. Saha, Springer-Verlag, 1984.
2. Radiopharmaceuticals: Chemistry and Pharmacology, Adrian D. Nunn. Marcel Dekker, 1992.
3. Radionuclides in Therapy, R.P. Spencer, R.H. Sievers, A.M. Friedman. CRC Press, Boca Raton, 1987.
4. PET in Oncology: Basics and Clinical Applications, J. Ruhlmann, P. Oehr, H.J. Biersack. Springer-Verlag, 1998.
5. Fundamentals of Radiochemistry. D.D. Sood, A.V.R. Reddy, N. Ramamoorthy. Indian Association of Nuclear Chemists and Allied Scientists, 2004.

CYJRF-204: Radiation Detection and Measurements (30 Hours / 4 Credits) (01-CHEM04-704-E)

Course Outcomes:
- Development of understanding of general interaction of radiation with matter
- Appreciate the difference in radiation-matter interaction based on characteristics of matter and radiation

- Understanding the functioning of various radiation detectors based on concepts of radiation-matter interaction
- Application of this knowledge to develop measurement systems as required

Course Details:

Interaction of Radiation with Matter

Interaction of Heavy Charged Particle with matter
Ionization in gaseous medium, Bragg curve, stopping power, Bethe Equation for stopping power, Range of heavy charged particles and straggling, Range energy relationship
Interaction of Fast Electrons with Matter
Comparison with heavy charged particle, LET for electron, Bremsstrahlung radiation, Bethe Equation, path length and range of electrons, Attenuation and absorption of β particles, Backscattering of β- particles
Interaction of Electromagnetic Radiations (γ, X-Rays) with Matter
Photoelectric Effect, Compton Scattering, Pair Production. Variation of cross section for different process with γ energy and Z of the medium, Attenuation and Absorption of gamma rays.
Interaction of neutrons with matter
Elastic and Inelastic Scattering of neutrons and slowing down, nuclear reactions
Radiation Detectors
Principle of Radiation Detectors: Pulse height spectrum, Counting Characteristics, plateaus, Detection efficiency, Energy resolution, Dead time, Counting Statistics.
Gas filled Detectors: Ionization Chamber, Proportional counter, GM counter,
Scintillation Detectors: Organic and Inorganic scintillators, Liquid scintillation counter, NaI(TI) detector
Semiconductor Detectors: p-n junction, HPGe detector for gamma ray spectroscopy, Si(Li) for x-ray spectroscopy, Si surface barrier detector for alpha spectroscopy
Neutron Detectors: BF_3, ^3He gas filled counters.

Solid State Nuclear Track Detectors (SSNTD)
Instrumentation for nuclear techniques
PMT and photo diodes, Single Channel Analyser, ADC, Multi-Channel Analyser, basic coincidence circuit, determination of life time using coincidence system, Positron Annihilation Spectroscopy: Instrumentation and Applications, Perturbed angular correlation measurement: Instrumentation and Applications

References:
1. Radiation detection and measurement, G.F.Knoll, John Wiley & Sons

GROUP B

CYJRF-205: Advanced Materials Chemistry (30 Hours / 4 Credits)

(01-CHEM04-705-E)

Course Outcomes:
- Appreciate the importance of developing advanced materials
- Knowledge about various classes of advanced materials such as carbon, carbides, nitrides essential for future research career
- Understanding of various characterisation techniques based on X-rays
- Knowledge about important DAE-relevant materials
- Knowledge of application of ion beams to characterise materials

Course Details:

Nuclear materials
Structure of common nuclear materials: Oxides (UO_2, PuO_2, ThO_2), metallic (U, Pu, Zr and its alloys, steel), carbides etc. Non-stoichiometry in nuclear materials and its significance, Concept of surrogates for nuclear materials, Materials relevant to back end of nuclear fuel cycle, Glasses and ceramics for waste immobilisation, Structure of components of SYNROC, Behavior of materials under irradiation (examples from front end and back end of nuclear cycle), dpa, Difference between effects of low and high energy irradiation.

Carbon-based materials
Classification: Diamond, Graphite, graphite oxide, fullerenes, Carbon nano-tubes, Graphene, Glassy carbon, Diamond like carbon; Structural and thermodynamic basis of classification; **Synthesis methods:** Natural diamond, Synthetic diamond (HPHT and CVD methods), Graphite (natural and lab-made graphite, nuclear-grade graphite), fullerenes and CNT, Graphene synthesis; **Properties:** Physical and chemical properties (Structural-basis of origin of these properties), Unique properties of each carbon-form, Property-application correlation; Current applications and futuristic technological potential

Thermoelectric Materials: Thermoelectric materials, Thomson, Peltier and Seeback effects, Thermocouples, Hall effect, Materials used for thermoelectric energy conversion, Thermal conductivity and factors affecting it, Concepts of thermoelectric energy conversion, Figure of merit and factors governing it, Applications of thermoelectric materials

Chemistry of Carbides, Borides, Nitrides: Synthesis, bonding, structure, properties and applications

Materials Characterisation Techniques:
(a) Diffraction Techniques for Structural Analysis: Brief description of diffraction techniques with some examples for indexing XRD patterns. Comparison of Powder and Single crystal X-ray diffraction, Neutron diffraction, Electron diffraction.

(b) Electron microscopic techniques: Electrons and their interactions with the specimen, Fundamentals of electron microscopy with emphasis on SEM and TEM, Overview of the instruments, Magnetic lenses and deflectors, Electron guns, Lens aberrations and basic operation modes: Bright field and dark field imaging, Diffraction modes, Different electron microscopy techniques and applications, Image analysis using SEM and TEM, Introduction to advanced microscopic techniques: EDX, HAADF-STEM, EELS, electron tomography etc.

(b) Advanced Techniques for Materials Characterisation: Different characterization techniques based on X-rays and electrons: XRF, EPMA, XPS, AES, EELS, EXAFS and their application with examples, Concept and examples of Characterisation Techniques based on Nuclear Reactions and Ion Beams: Rutherford Back Scattering Spectrometry (RBS), Elastic Recoil Detection Analysis (ERDA), Nuclear Reaction Analysis (NRA), Particle Induced X-ray Emission (PIXE) and Particle Induced Gamma-ray Emission (PIGE), Techniques employing Nuclear Probes: Positron annihilation spectroscopy (PAS): Lifetime spectroscopy, Doppler broadening spectroscopy, Age momentum correlation, Applications with examples, Perturbed angular correlation (PAC) techniques and their applications with examples.

Reference Books:
1. Solid State Chemistry and its Applications by A. R. West
2. Material Science and Engineering by V. Raghavan
3. New Directions in Solid State Chemistry by C. N. Rao and J. Gopalakrishnan
4. Solid State Chemistry: An Introduction by Smart and Moore
5. Introduction to Solid State Physics by Charles Kittel

CYJRF-206: Polymers Science and Technology (30 Hours / 4 Credits) (01-CHEM04-706-E)

Course Outcomes:

- Exhaustive understanding of chemistry of polymers and polymer processing
- Understanding of techniques required for polymer characterisation
- Application of radiation to polymer processing and its relative merits and demerits
- Introduction to special purpose polymers developed for specific applications

Course Details:

Fundamentals of Polymer Science

Historical background of macromolecules, Introduction to concepts such as monomer, functionality and physical state, Classification of polymers on the basis of source, Chemical structure, Composition and stereoregularity, Polymer nomenclature and classification of polymers as Thermoplastics, Thermoset, Fibers and Elastomers. Comparison of polymers with metals and ceramics and applications where polymers have significant advantages, Examples of common thermoplastics, fibers, thermoset and elastomers polymers.

Chemistry of Polymers

Chemistry of polymerization, Brief introduction to addition polymerization, Condensation polymerization, Ring opening polymerization, Redox polymerization, Living radical polymerization, Factors affecting polymerization, Emerging approaches of polymerization, High energy radiation, Plasma and photo polymerization, Electrochemical polymerization, MMP, RAFT and ATRP. Chemistry of copolymerization, Copolymerization kinetics and copolymer structures, Chemical modification of polymers, Cross-linking, Degradation, Grafting, Imprinted polymers and functionalization, Separation and purification of polymers.

Basics of Polymer Processing

Introduction to polymer synthesis: Bulk, Solution, Precipitation, Suspension, Emulsion, Condensation, Addition, Interfacial, Solid phase and Gas phase Polymerization, Introduction to polymer mixing and processing techniques, Effect of composition, Stabilization and coagulation in polymer compounding, Open mill mixing, Internal and continuous mixers and extruders, Compression molding, Injection molding, Blow molding, Melt spinning, Dry spinning, Wet spinning, Electro spinning and Drawing of fibers.

Polymer Characterization and Structure - Property Correlations

Basic concepts of polymer structure, Chain length, Branching, Copolymer arrangement (block, random or graft), Conformation, Degree of crystallinity and degree of orientation, Effect of polymer structure on functional properties, Effect of molecular weight and molecular weight distribution on crystallinity, Glass transition and mechanical properties, Functional group identification and characterization by UV-VIS, IR and NMR spectroscopy of polymers, Physical and mechanical properties of polymers (Impact strength, Tensile strength, Flexural strength, Hardness), Polymer viscoelasticity and principles of TMA and DMA, Thermal analysis of polymers, Heat of fusion, Heat capacity, Thermal conductivity, Glass transition temperature and Degree of crystallinity, Estimation of thermal stability of polymers from TGA and DSC, Polymer microstructure evaluation of by polarized light microscopy, TEM, SEM, AFM, WAXS and PALS.

Nanotechnology in Polymer Science

Introduction to nanoparticles and nanocomposites, Synthesis of nano-polymers, Types of nanofillers used in polymer nanocomposites, Synthesis of polymer nanocomposite by melt intercalation, Compounding and in-situ polymerization and surface modification of nanofillers, Factors affecting properties of polymer-filler composites, Dispersion of nanofillers in polymers, Polymer-nanoparticles interface, Role of filler geometry and size, Characterization of polymer nanocomposites: TEM, AFM, SEM and Optical microscopy, Mechanical properties, Dynamic mechanical analysis, Tensile properties, Flexural properties, Impact strength, Heat distortion temperature, Thermal stability, Fire retardant properties, Gas barrier properties, Conductivity, DMTA and Melt-rheology. Applications of nano-polymers and polymer nanocomposites.

Polymer Blends, Composites, Membranes and Emulsions
Introduction to polymer blends and composites, Classification of polymer blends and composites, Principle of polymer compatibility, Polymer-polymer interaction, Thermodynamics of polymer-polymer mixing, Solubility parameter and blend morphology, Types of polymer composites and reinforcement theory, Applications of polymer blends and composites, Classification of membranes, Polymer selection for development of membranes and common processes for making polymer membranes, Applications and uses of membranes, Chemistry of polymer emulsions, Emulsion types and applications.

Radiation Processing of Polymers
Basic radiation chemistry and physics of polymers, Time scale of energy deposition, Interaction of radiation with monomers and polymers, Energy transfer and radiolysis, Overall effect of radiation on properties of polymers and factors that can affect the overall radiochemical yield of a process, Theory of swelling in cross-linked polymers, Charlesby-Pinner and cross-linking density analysis of irradiated polymers, Polymer structure and cross-linking density correlations, Mechanical, Thermal and Spectroscopic evaluation of radiation processed polymers, Role of EPR and NMR in quantifying radical yield and radiolytic transformations, Radiation grafting; Types of radiation grafting, Kinetics and characterization of grafting yield, Factors affecting polymer degradation by radiation, Applications of radiation cross-linking, Grafting and Degradation, Comparison of radiation and chemical processes, Basic aspects of UV based process and a comparison with high-energy radiation based processes.

Specialty Polymers and Advanced Applications of Polymers
Brief introduction to special purpose polymers, Structure-property correlations in radiation resistant polymers, Heat and fire resistant polymers, Electro active polymers, Electro-chromic polymers and piezo-resistive polymers, Concepts and applications of Thermoplastic Elastomers, Gels, Micro-gels and hydrogels, Functionally graded polymer blends and smart adhesives, Key examples of emerging/established applications of polymers in areas such as Sensors, Radiation stability, EMI shielding, Catalysts, Electrostatic discharge devices, Solar cells, Drug delivery, Hydrogel, Biomaterials, Desalination and Environmental remediation.

Reference Books:
1. Textbook of Polymer Science by Fred W. Billmeyer, Publisher: Wiley, Third edition (2007) ISBN-10: 9788126511105.
2. Polymer Science by Vasant R. Gowariker, N. V. Viswanathan, Jayadev Sreedhar New Age International, 1986-11030.
3. Applied Radiation Chemistry: Radiation Processing by Robert J. Woods, Alexei K. Pikaev Publisher: Wiley-Interscience; ISBN-10: 0471544523.
4. Radiation Processing of Polymer Materials and Its Industrial Applications by Keizo Makuuchi, Song Cheng ISBN: 978-1-118-16279.

CYJRF-207: Renewable Energy Harvesting and Storage (30 Hours / 4 Credits) (01-CHEM04-707-E)

Course Outcomes:
- Appreciation of renewable energy-based research
- Knowledge about alternative sources of energy
- Understanding relevance of energy storage and conversion

- Development of understanding of hydrogen energy and related research
- Knowledge base for carrying out research in energy materials and allied fields

Course Details:

Basic Definitions and Classification
Energy and development, Units, Dimensions and measurement systems, Conventional and non-Conventional Sources of energy, Energy from fossil fuels: Coal, Oil, Natural gas and Nuclear resources, Basics of Solar, Wind, Hydro, Tidal, Ocean thermal and Other renewable energy sources, Impact of energy on environment, Environmental pollution due to energy.

Energy Conversion Systems
Basics of photovoltaic (PV) and PV systems, Thermochemical conversion through pyrolysis, Gasification and esterification, Bio-oil, Basics of hydrogen fuel, Fundamentals of fuel cells, Energy storage technologies, Chemical storage and electrical storage, Details of Pb-acid battery, Ni-Cd-alkaline battery.

Generation of Hydrogen
Energy conversion and energy storage in photosynthetic organisms, Efficiency of photosynthesis, Thermochemical cycle for generation of hydrogen, Semiconductor materials, Metal oxide nano composites and their properties, Photochemical and Photoelectrochemical generation of hydrogen, Hydrogen storage materials.

Batteries, Supercapacitors and Fuel Cells
Cathode/anode materials, Electrolytes, Membranes, Chemical and Electrochemical processes in different batteries (Li ion, Na ion), Supercapacitors and fuel cells, Determination of fundamental parameters for characterization of the efficiency of batteries, Supercapacitors and fuel cells, Introduction to redox flow battery and different types of redox flow batteries, Hybridization of various energy storage systems such as battery-supercapacitors, Battery-fuel cell and Battery-supercapacitor-fuel cell for different applications.

Reference Books:

1. Sustainable Energy without the hot air by David J. C. MacKay.
2. Solar energy engineering, Processes and systems, S. A. Kalogirou, 2nd Edition.
3. Solar Energy handbook, Michael Boxwell, 2017 Edition.
4. Photoelectrochemical Water Splitting: Materials, Processes and Architectures (Energy and Environment Series) 1st Edition, Hans-Joachim Lewerenz, Laurie Peter.
5. Advances in Photoelectrochemical Water Splitting: Theory, Experiment and Systems Analysis, Editors S David Tilley, Stephan Lany, Roel van de Krol.
6. Lithium ion batteries: Basics and applications, Editor R. Korthauer, Springer.
7. Supercapacitor: Instrumentation, Measurement and Performance Evaluation Techniques, Satyajit Ratha, Aneeya K. Samantara and, Springer.
8. Nanomaterials in Advanced Batteries and Supercapacitors, David J. Lockwood, Springer.

CYJRF-208: Fundamentals of Environmental Chemistry (30 Hours / 4 Credits) (01-CHEM04-708-E)

Course Outcomes:

- Understanding of different types of pollution and related problems
- Understanding of technologies related to mitigation of water, air and terrestrial pollution
- Knowledge of green chemistry, green solvents and zero waste technologies
- Understanding of different types of wastes and their management

Course Details:

Basic Concepts of Environmental Chemistry
Environmental Segment, Natural cycle of environment, Composition of the atmosphere, Chemical and photochemical reaction in atmosphere, Hydrosphere, Lithosphere, Geo-sphere and Geochemistry, Soil property, Biosphere, Ecology and Ecosystem, Atmospheric aerosols, Chemical toxicology, Concept of Green Chemistry.

Water Pollution and Waste Water Treatment Chemistry
Aquatic environment, Water pollutant, Eutrophication, Water quality guidelines, Drinking water supplies, Water quality parameters and Standards, Sampling, Protocols for heavy metal analysis in potable water, Chemical speciation, Waste water and its treatment, Advance microbiological processes in waste water treatments, Use of sorbents for waste water remediation, Isotherm and kinetic modeling.

Air Pollution Control Technologies and Devices
Source and type of air pollutant, Fate and transportation of air pollutant, Global and regional air pollution issues, Control of gaseous pollutants by adsorptions and condensation, Air pollution sampling and analysis: Ambient and Stack sampling, Air quality standards, Noise pollution and its standards.

Terrestrial Environment
Soil formation, Soil composition, Soil organisms, Soil reactions, Macro and micro nutrients in soil, Soil properties, Sources of soil pollution, Type of soil pollutant, Soil sampling, Solid waste in soil, Speciation of metal ions in soil.

Toxic and Hazardous Waste Management
Classification and categorization of hazardous waste, Disposal methodologies of hazardous waste, International and national guidelines for solid waste disposal. Management of Radiation, Noise, Thermal, Oil and e-wastes: Recycling of waste. Biosorption - Biotechnology and heavy metal pollution in terrestrial environment.

Green Chemistry
Basic principle of green chemistry, Green reagent & reaction, Green methodologies & analysis, Zero waste technology, Designing of biodegradable products, Catalytic methods in green synthesis, Safer chemicals; Selection of auxiliary substances (solvents, separation agents), Green solvents, Solvent less processes.

Reference Books:
1. Environmental chemistry: A global perspective by Gary W. Vanloon and Stephen J. Duffy
2. Environmental chemistry by A. K. De
3. Essential of environmental studies by Kurien Joseph and R. Nagendran
4. A Textbook of Environmental Chemistry by V. Subramanian
5. Environmental particles by Jacuues Buffle and Herman P. Van Leeuwen

GROUP C

CYJRF-209: Advanced Spectroscopy (30 Hours / 4 Credits) (01-CHEM04-709-E)

Course Outcomes:

- Develop understanding of various advanced spectroscopic
- techniques for analyzing complex compounds

- Thorough knowledge of the fundamentals of microwave, infrared, Raman, electronic and magnetic resonance spectroscopy, X-ray photoelectron spectroscopy
- Thorough understanding of application of suitable spectroscopic techniques to various research problems
- Equipped with sufficient knowledge about spectroscopy for employability

Course Details:

Vibrational Spectroscopy

Infra-Red Spectroscopy
Harmonic oscillator and the rigid rotator spectroscopic model, Harmonic oscillator (Hooke's Law), Hermite polynomials, Anharmonic oscillator, Selection rules, Rigid rotator, Rotating diatomic model, Vibrating diatomic molecule, Diatomic vibrating rotator, Vibro-Rotational spectrum for simple molecules, Born-Oppenheimer approximation (BOA), Vibrations of polyatomic molecules, Symmetry of molecules and vibrational spectroscopy, Influence of rotation on polyatomic spectra, Techniques and instrumentation for FT-IR, Analysis of functional groups by IR, 2D-IR.

Raman Spectroscopy
Basic concept of Raman Spectroscopy, Quantum mechanical model of Raman scattering, Rayleigh scattering, Stokes and anti-Stokes scattering, Polarizability of the molecules, Selection rules for rotational Raman spectra of diatomic molecules, Rotational Raman spectra, Vibrational Raman spectra, Raman spectra of polyatomic molecules, FT-Raman, Instrumentation and techniques, Enhanced Raman Spectroscopy (SERS, TERS).

Spin Spectroscopies

Nuclear Magnetic Resonance (NMR)
Nuclei with intrinsic spin Angular momentum, Magnetic moments interaction with magnetic fields, P- NMR, (n+1) rule, First order spectra, Spin-spin coupling, Multiplets in NMR spectroscopy, Spin-Spin Coupling between chemically equivalent, Second order spectra and vibrational method, Nuclear OverHauser Effect, C13-NMR, 2D and Correlated 2D NMR spectroscopy, Chemical Shift Anisotropy (MAS-NMR), Solid state NMR- Si29-NMR, F19NMR etc.

Electron Paramagnetic Resonance (EPR)
A brief review of theory, Analysis of ESR spectra of systems in liquid phase, Radicals containing single set, Multiple sets of protons, Triplet ground states, Transition metal ions, Rare earth ions, Ion in solid state, Double resonance techniques: ENDOR in liquid solution, ENDOR in powers and non-oriented solids.

Mossbauer Spectroscopy
Basic physical concepts, Spectral line shape, Isomer shift, Quadrupole splitting, Magnetic hyperfine interaction, Interpretation of Mossbauer parameters of ^{57}Fe, ^{99}Ru, ^{101}Ru, ^{195}Pt, ^{193}Ir and ^{110}Sn, General applications of Mossbauer like - Solid state reactions, Thermal decomposition, Ligand exchange, Electron transfer, Isomerism, Surface studies and biological applications etc.

Photo Electron Spectroscopy
XPS, AES and UPS: Background to electron beam techniques, XPS and AES processes, UHV conditions, X-Ray Sources, Electron Sources, Ion Sources, Spectral Interpretation, Nomenclature (j-j & L-S coupling), Elemental detection, Electron-excited secondary electron spectrum-AES, XPS-Primary, Secondary Structure, Angular effects, Time dependent spectra, Depth profiling, Data analysis: Curve fitting, Co-ordination number, Surface states, Ultraviolet Photoelectron Spectroscopy (UPS).

Electronic Spectroscopy
Intensity of electronic transitions, Rules governing the transition between two states, Excited electronic states of atoms and molecules, Types of electronic transitions in organic molecules, Potential energy diagrams, Absorption band and Frank-Condon Principle, Emission spectra, Excited state-dipole moment, Photo physical pathways, Internal conversion and Interstate crossing, Emission property, Fluorescence, Phosphorescence, Photoluminescence Spectroscopy, UV-Vis spectra for solids, Band gap determination, Kubelka- Munk theorem.

Reference Books:
1. Organic Spectroscopy. William Kemp. McMillan Publications.
2. Spectrometric Identification of Organic Compounds. Francis X. Webster, Robert M. Silverstein. Wiley Publications.
3. Fundamentals of Molecular Spectroscopy. CN Banwell EB Mccash.
4. Physical Chemistry: A Molecular Approach. Donald A. McQuarrie. John D. Simon.

CYJRF-210: Computational Chemistry (30 Hours / 4 Credits) (01-CHEM04-710-E)

Course Outcomes:
- Calculation of transition state structure and understand reaction mechanism
- Interpretation of IR and UV-Vis spectra of a system
- MD simulation and analysis of simulation results
- Planning theoretical calculation to explain experimental results and predict molecular properties
- Band structure calculations of solids and analyze results

Course Details:

Electronic Structure Theory of Molecules
Introduction, Revision to classical mechanics and quantum mechanics, Optimization techniques, Electronic structure methods: Self Consistent Field Theory, Restricted & unrestricted HF, Semi-empirical methods, Electron correlation methods: Configuration interaction Methods, Multi Configuration Self-Consistent Field, Many body perturbation theory, Couple cluster method, Basis sets, Density functional methods, Wave functional analysis & Molecular properties

Theory of Solids
Geometry of crystal and symmetries in solids, Concept of reciprocal space and its use in solid state research and band structure, Introduction of energy bands in solids & Density of States, Determination of band structure (Kronig-Penny Model- analytical solution), Comparison of band structures (Metal (bcc, fcc, hcp), Insulators and Semi-conductors)

<u>Molecular Dynamics Simulation</u>

Multi-scale material modelling (MMM): Overview, Different length scales and associated timescales relevant to different computational methods, Atomistic modeling of materials: Why computer simulation of a many-body system at finite temperature, Born Oppenheimer (BO) approximation and the origin of different Molecular Dynamics (MD) methods such as B.O. MD, CPMD and classical MD.

Interatomic Potentials : Introduction to interatomic potentials, Expressing many-body potentials into suitable tractable form, Simplification due to homogeneous, isotropic approximation, Characteristics of potential, Obtaining potential function for a particular system, Different forms of Empirical potential functions such as Hard Sphere Potential, Lennard-Jones Potential, Morse Potential etc., Many-body potentials such as Embedded Atom Potential, Glue potential etc.

Molecular Dynamics Simulations: An algorithm, Initialization, Boundary Conditions: Periodic Boundary Condition and Minimum Image Condition, Force Calculation & force subroutine, Integrating the Equations of Motion: Verlet, Velocity-Verlet& Leap Frog Algorithm

Statistical Mechanics and Molecular Dynamics simulation: Multi-dimensional phase-space and time averaging, Ensemble and Ensemble averaging, Ergodicity and the equivalence of time and ensemble averages, Judging Equilibration

Application of Statistical Mechanics to get different average equilibrium properties from the microscopic quantities of the simulation: How to get different equilibrium properties, Temperature and Pressure, Radial Distribution functions and structure factor, Time Correlation function and different dynamical quantities from equilibrium simulations, How to calculate Diffusivity, Thermal conductivity, electrical conductivity, viscosity etc

Reference Books

1. An Introduction to computational chemistry by Frank Jensen (Wiley)
2. Quantum chemistry by I R Levine
3. Solid State Physics by M A Wahab
4. Computer simulation of liquids by Allen & Tildesley
6. Advanced Techniques for Materials Characterization"; Eds. A. K. Tyagi, M. Roy, S. K. Kulshreshta, S. Banerjee; Trans Tech Publications Ltd, Switzerland (2009)
7. Nuclear and Radiochemistry (3rd edition 2013) by G. Friedlander, J. Kennedy, J. M. Miller and J. W. Macias.
8. Ion Beam Analysis: Fundamentals and applications by Michael Nastasi, James W. Mayer, Yongqiang Wang.
9. Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM, Springer, 1st ed. 2005
10. R. Haynes, Optical Microscopy of Materials, Springer, 1984

CYJRF-211: Radiation and Photochemistry (30 Hours / 4 Credits) (01-CHEM04-711-E)

Course Outcomes:

- Awareness of radiation induced reactions and its applications
- Expertise to analyse and quantify radiation/photochemical induced chemical reactions
- Trained man power for using various radiation and photochemical sources and state-of art experimental facilities
- Hands-on experience and research training during project work
- Knowledge development in the DAE relevant activities and planning for future R&D programs

Course Details:

Radiation Chemistry

Overview of interaction of high-energy radiation with matter (Photoelectric effect, Compton effect, Pair production, Photonuclear reactions, Coherent scattering), Attenuation and absorption coefficients, Electrons, Radiation sources, Spatial and temporal distribution of energy and primary products, G-values, Track entities, Time scales of events in radiation chemistry, Ion-pairs, Ion-molecule reactions.
Radiolysis of water, radical and molecular yields, Material balance, Dosimetry (Fricke), Radiolysis of non-polar solvents, Geminate recombination, Comparative aspects of radiolysis of liquids, Solids and gases.

Detection of primary species and free radicals using pulse radiolysis coupled with optical absorption and conductivity, Evaluation of absolute rate constants, One-electron redox potentials.
Radiation chemistry in polymer development.
Radiation chemistry of biological systems and use of radiation chemistry in development of antioxidants, Radioprotectors and nanoparticles.

Photochemistry
Laws of photochemistry, Electronic transitions, Properties of electronically excited molecules, Franck-Condon principle, Absorption, De-excitation processes - Fluorescence, phosphorescence, Delayed emission, Heavy atom effect, Quantum yields of photo-processes.
Kinetics and mechanism of collisional quenching, Stern-Volmer equation, Rate constants and lifetime of reactive energy states (Processes like electron transfer, Energy transfer, Proton transfer).
Steady-state absorption and fluorescence techniques, Time-resolved absorption and fluorescence techniques like time-correlated single photon counting, nanosecond laser flash photolysis.
Fundamentals of Lasers, Applications of optical probes in biology, Stimuli responsive supra-molecular complexes, Luminescent materials and sensors.

Reference Books:
Radiation Chemistry
1. An introduction to Radiation Chemistry. J. W. T. Spinks and R. J. Woods; Wiley Interscience, New York, 1990.
2. Radiation Chemistry: An Introduction. A. J. Swallow; Longman, London, 1973.
3. The Study of Fast Proccesses and Transient Species by Electron Pulse Radiolysis. Editors: J. H. Baxendale and F.Busi; Reidel, Dordrecht, Holland, 1982.
Photochemistry
1. K. K. Rohatgi-Mukherjee, Fundamentals of Photochemistry; Wiley Eastern: New Delhi, 1978.
2. J. B. Birks, Photophysics of Aromatic Molecules. Wiley Interscience, New York, 1970.
3. J. R. Lakowicz, Principle of fluorescence spectroscopy, 3rd ed.; Springer: New York, 2006.
4. J. Turro, Modern Molecular Photochemistry, Benzamin, Menlo Park, CA, 1978.

CYJRF-212: Materials for Cancer Therapeutics and Diagnostics (30 Hours / 4 Credits) (01-CHEM04-712-E)

Course Outcomes:
- Concept behind methodologies adopted for cancer treatment and diagnosis
- Understanding of functioning mechanism of cancer drugs
- Understanding of application of nanoparticles in cancer therapy
- Knowledge about cancer therapeutics to enable to pursue research in cancer therapeutics and diagnostics.

Course Details:

Introduction
Types of cancer, Chemotherapeutic drugs, Limitations in current treatment, Personalized treatment of cancer, Nanodrugs and Nanocarriers - advantages, Challenges and Current status, Advanced nanomaterials for cancer therapy such as Magnetic nanoparticles, Noble metal nanoparticles, Up conversion nanoparticles, Quantum dots, Carbon based nanostructures, Polymeric nanoparticles, Lipid and amphiphile based carriers. General methods of preparation and characterization.

Magnetic Nanoparticles in Cancer Therapy

Magnetic properties of materials, Diamagnetism, Paramagnetism, Ferro and Ferrimagnetism, Hysteresis, Domain and domain walls, Superparamagnetism, Magnetic fluid hyperthermia, MRI contrast agents, Parameters to assess heating efficiency, Specific loss power and intrinsic loss power, Mechanism of heat dissipation, Synthesis and functionalization of MNPs. Structural characterization and coating strategies.

Photodynamic Therapy (PDT) and Radio sensitisation

Photosensitisers and light sources for PDT, Photophysics and photochemistry, Mechanism of PDT mediated cytotoxicity, Cytoprotective mechanism, Anti-vascular effect of PDT, PDT and immune response, Combination therapy. Nanomaterial based radio-sensitization, High Z materials, DNA damage mechanisms. ROS generation through photocatalysis and chemocatalysis, Depletion of intracellular GSH, Improving tumor oxygen level and cell cycle regulation, Combination with Chemotherapy and PDT.

Interfacial Phenomena in Colloidal Drug Delivery

Interfacial forces and energetics, Adhesion and Cohesion, Wetting, Capillarity, Pressure across curved surfaces, Adsorption, Surface active agents, Static and dynamic interfacial tension. Experimental methods, Data analysis, Colloids - Definition, Classification, Properties, Lyophilic and lyophobic colloids. Kinetics of particle formation, Stabilization of colloids, Association colloids, Micelles, Liposomes, Microemulsions and Emulsions, Types and means of detection, Settling and control of emulsion stability, emulsifying agents, Breakdown of droplets, Pickering emulsions, Colloid characterization, Microscopy, Light scattering, SAXS, SANS and Zeta potential, Pharmaceutical applications of colloids.

Rheology of Polymeric Drug Delivery Systems

Introduction, Elastic solids, Newtonian and Non-Newtonian fluids, Empirical equations and models, Rheological measurements, General viscometers and rheometers, Capillary viscometer, Falling ball viscometer, Rotational viscometry and rheometry, Non-Newtonian corrections, Dynamic rheological analysis of Gels, Overlap concentration and Cross-link density estimation. Viscoelastic parameters. Theory of gelation.

Targeted Drug Delivery

Routes of drug delivery, Comparison and transdermal permeability, Factors affecting permeability, Nucleic acid therapeutics, Aptamers, Gene delivery and viral vectors, Synthetic non-viral vectors, Passive targeting, Mononuclear Phagocyte System (MPS) and Enhanced Permeation and Retention (EPR) effect, Active targeting, Prodrugs and receptors, Folic acid directed targeting, Antibodies, Peptides and Other cell surface receptors, Gene directed enzyme prodrug therapy, Membrane transporters. Stimuli sensitive delivery systems.

Basic Pharmacokinetics and Pharmacodynamics

Concentration vs. time profile, Pharmacokinetic models, Rate equations, Multiple dose administration, Statistical moments, Pharmacokinetic parameters derived from statistical moments, Organ specific clearance, Bioavailability and bioequivalence assessment, Peak height concentration, Time of peak concentration and area under the curve, Criteria for bioequivalence.

Cellular & Molecular Biology of Cancer

Introduction of cells, Types of cells, Basic architecture of cells, Transformation of normal cell in to cancer cells (carcinogenesis), Classification and staging of cancer, Hallmarks of cancer, Cellular metabolism and cancer, Genomic instability/mutation and cancer, Tumor suppressor proteins, Cancer metastasis, Caner angiogenesis, Enhanced Permeation Retention (EPR), Mechanisms of cancer cell death, Mechanisms of acquired drug resistance in cancer cells, Cancer cell imaging, Tumor immunology.

Introduction to Cancer Diagnostics
Overview of the current methods, Histopathology, Cancer biomarker detection, Imaging techniques, Research on cancer diagnostics-approach, Cell line studies, Mice model studies, Validation in human subjects, Cancer biomarkers - Types of biomarkers, Clinical test for biomarkers, Novel methods for biomarker detection.

Biosensors and Sensor Materials
Electrochemical sensors: Classification based on bioreceptor, Aamperometry, Voltammetry, Impedance based methods, Sensor characteristics, Surface Plasmon Resonance (SPR) biosensors - SPR principle, biomolecular interaction using SPR, Nanoparticle for LSPR sensing, Surface modification strategies, Diagnostic applications, Sensor materials: Carbon based, Metal nanoparticles, Metal oxides, Organic-inorganic hybrids, Biopolymers, Conducting polymers (CP), CP-conduction mechanism, Doping, Synthesis of CPs, Properties of CPs, Application of CP for diagnostics.

Recent developments in Biosensors
Microfluidic devices, Nanopatterning, Lab-on-chip devices.

Reference Books:
1. Nanostructures for Cancer Therapy Edited by A. Ficai and A. M. Grumezescu. Elsevier (2017)
2. Remington Essentials of Pharmaceutics Edited by Linda A. Felton, Pharmaceutical Press (2012)
3. Colloids In Drug Delivery, Edited by Monzer Fanun, CRC Press, Taylor and Francis Group, LLC (2010)
4. The Biology of Cancer by Robert A. Weinberg, Norton & Co. (2013)
5. Biosensors and Molecular Technologies for Cancer Diagnostics Ed. Keith E. Herold, Avraham Rasooly. CRC Press Taylor and Francis Group, LLC (2012)

MANDATORY

CYJRF-301: Numerical Methods and Computer Programming (30 Hours / 4 Credits) (01-CHEM04-713-E)

Course Outcomes:
- Conceptualizing the basics of mathematical methods and the relevant modeling techniques
- Thorough understanding of FORTRAN and its usage
- Skill enhancement for solving the problems associated with physical and chemical sciences by developing computer algorithms through FORTRAN

Course Details:

Numerical Methods
Approximation and errors in numerical computation, Truncation and rounding errors; Fixed and floating-point arithmetic, Absolute and relative error, Error propagation.
Interpolation and polynomial approximation, Newton forward/backward interpolation, Lagrange's and Newton's divided difference interpolation, Cubic-spline interpolation, Gaussian quadrature.
Differentiation and integration, Differentiating continuous and tabulated functions, Higher order derivatives, Richardson's extrapolation, Integrations using Trapezoidal rule, Simpson's 1/3 rule, Euler-Maclaurin methods, Romberg's integration.
Solution of a system of linear equations, Gauss-Jordan elimination, Matrix inversion, LU decomposition, Gauss-Seidel Iterative method.
Solution of nonlinear systems of equations, Bisection method, Regula-Falsi method, Newton-Raphson method, Muller's method for complex and multiple roots.

Eigenvalues and Eigenvectors, Elementary similarity transformation, Inverse Iteration.
Solution of ordinary differential equation, Initial value problem, Runge-Kutta method, Gear algorithm, Stability analysis, Boundary value problem, Finite difference method.
Partial differential equation, Finite difference approximation, Relaxation methods, Stability analysis.
Modeling of data, Linear regression, Polynomial regression, Least squares, Nonlinear regression and Fourier Approximation Methods, Confidence limits.

II. Basics of Computer Programming

Introduction to computer programming, Computers and evolution of FORTRAN program, Program organization.
Arithmetic statements, Constants and variables, Arithmetic expressions, Computer arithmetic.
Logical variables and expressions, Hierarchy of operations.
Numerical Input/Output, Introduction to formatting, Fields.
Transfer of control, Conditional statements, Logical IF statement; Algorithms.
Implementing loops, Nested Do Loops, Exiting from a DO Loop.
Arrays, DIMENSION statements, Implied Do Loops;
Functions and subprograms, Arithmetic statement functions, Calling subprograms
Miscellaneous features of FORTRAN, Common, equivalence, DATA statements, External.
Design, Documentation, and Coding Style.

References

1. Numerical Methods for Scientists and Engineers, by R. Hamming, Dover Publications (2012).
2. Numerical Methods for Scientific and Engineering Computation, by M. K. Jain, S. R. K. Iyengar and R. K. Jain, New Age International Publishers (2004).
3. Computer Oriented Numerical Methods, by V. Rajaraman, Prentice-Hall of India (2018).
4. Classical FORTRAN: Programming for Engineering and Scientific Applications, by Michael Kupferschmid, CRC Press (2009).

CYJRF-302: Chemistry of Nuclear Fuel Cycle (30 Hours / 4 Credits)

(01-CHEM04-714-E)

Course Outcomes:

- Knowledge of processes involved in recovery of nuclear material from ores
- Understanding of fabrication and quality control of nuclear fuel
- Understanding of reprocessing of spent fuel and waste management
- Knowledge in physico-chemical characterization of nuclear fuel, irradiation behaviour
- Understanding the chemistry involved in different stages of nuclear fuel cycle

Course Details:

Chemistry of Fuel Materials

Separation and purification of uranium, thorium and zirconium from their ores, Principles and processes of isotope separation and enrichment of ^{235}U and deuterium, Conversion processes for preparation of UO_2, $(U,Pu)O_2$, $(U,Th)O_2$, and advanced fuel materials like UC, (U,Pu)C, UN (U,Pu)N, metals and alloys.

Nuclear Reactors and Related concepts

Classification of reactors on the basis of neutron energy and reactor components, different reactors types like PHWR, BWR, PWR, AHWR, High Temperature Reactors, Molten salt reactor concept etc., Introduction of fusion reactor concept, Physico-chemical behaviour and properties of oxide, nitride and carbide fuels, Fuel fabrication processes & chemical quality control of fuel materials, Behaviour of nuclear fuels (thermal/fast) during irradiation, Post irradiation studies, fuel clad chemical interaction, Burn-up etc.

Chemistry of Back End of Nuclear Fuel Cycle

Reprocessing of thermal reactor fuel using PUREX process, THOREX process, reprocessing of fast reactor fuel, Classification of waste, Treatment practices of gaseous waste, low and intermediate level liquid waste, Partitioning of actinides from high level liquid waste, separation of valuable isotopes, vitrification, immobilization matrices and transmutation.

References:

1. D. R. Olander, "Fundamental Aspects of Nuclear Reactor Fuel" USERDA Report TID-26711 (1976).
2. D. Wilson, "The Nuclear Fuel Cycle, From Ore to Waste", Oxford University Press Inc. New York (1996).
3. Source book of Atomic Energy (1969) S. Glasstone.
4. R. L. Murray and J. A. Powell, "Understanding Radioactive Waste" 4th Edition, Columbus : Battelle Press (1994).
5. E. Glueckauf, "Atomic Energy Waste: Its Nature, Treatment and Disposal", Interscience Publishers Inc. New York (1961).

CYJRF-303: Research Methodologies (30 Hours / 4 Credits) (01-CHEM04-715-E)

Course Outcomes:

- Demonstrate knowledge of research processes (reading, evaluating, and developing)
- Perform literature reviews using print and online databases
- Identify, explain, compare, and prepare the key elements of a research proposal/report
- Knowledge of writing reports and thesis Idea about following ethical practices in research

Course Details:

Objectives and types of research: Motivation and objectives - Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem - Literature review – Primary and secondary sources - reviews, treatise, monographs-patents - web as a source - searching the web - Critical literature review - Identifying gap areas from literature review - Development of working hypothesis.

Research design and methods - Research design – Basic Principles - Need of research design - Features of good design – Important concepts relating to research design - Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Value of Statistics; Errors and Statistics - Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results - students's t test; F-test; Chi Square test; propagation of errors.

Reporting and thesis writing – Structure and components of scientific reports - Types of report - Technical reports and thesis - Significance - Different steps in the preparation – Layout, structure and Language of typical reports - Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation - Planning - Preparation - Practice - Making presentation - Use of visual aids - Importance of effective communication -Computers in Chemistry, Usage of packages such as, Excel, AIM2000, ChemCraft, etc. Manuscript drafting based on 'Experimental data and Literature Survey'.

Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialisation - Copy right - Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights - Reproduction of published material - Plagiarism - Citation and acknowledgement - Reproducibility and accountability.

References

1. Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction to Research Methodology, RBSA Publishers.
2. Kothari, C.R., 2000, Research Methodology: Methods and Techniques. New Age International.
3. Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Publications (2 volumes)
4. R. Paneer Selvam - Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
5. Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
6. Day, R.A., 1992.How to Write and Publish a Scientific Paper, Cambridge University Press.
7. Vogel's Text Book of Quantitative Inorganic Analysis, ELBS.

NON-SUBJECT ASSIGNMENTS

Mini Project 1 (18 credits) (01-CHEM04-601-PR)

Course Outcomes:

- To evaluate the understanding of subject
- To train the students on hands-on experience on a number of instrumental techniques

Mini Project 2 (18 credits) (01-CHEM04-602-PR)

Course Outcomes:

- Idea about how to do literature survey on a given topic
- Idea about planning and execution of an experiment
- Data analysis
- Writing project report
- Presentation of data and results

BACK TO MAIN

Homi Bhabha National Institute
(A university established under Section 3 of the UGC Act. 1956)
Indira Gandhi Centre for Atomic Research
Kalpakkam – 603 102 Tamil Nadu, India

Ph.D. in Chemical Sciences
Courses under IGCAR
(Program Code: CHEM04)

Homi Bhabha National Institute
(A university established under Section 3 of the UGC Act. 1956)
Indira Gandhi Centre for Atomic Research
Kalpakkam – 603 102 Tamil Nadu, India

Chemical Sciences Courses offered in HBNI & Course coordinators

CH-1 : Mathematics and Computational methods (6 credits)

CH-2 : Chemical Thermodynamics (6 credits)

CH-3 : Electrochemistry and Corrosion Science (4 credits)

CH-4 : Introduction to Materials Science and Engineering (6 credits)

CH-5 : Analytical Chemistry for Nuclear Fuel Cycle (6 credits)

CH-6 : Chemical Instrumentation and Laboratory Techniques (6 credits)

CH-7 : Health Physics and Radiation Sciences (6 credits)

CH-9 : Chemistry of Fuel Cycle-I(6 credits)

CH-10 : Chemistry of Fuel Cycle-II: Actinide chemistry and separation science (6 credits)

CH-11 : Materials for Nuclear Reactors and Fuel Cycle Processing Systems (6 credits)

CH-12 : Nuclear and Radiochemistry (6 credits)

CH13 : Corrosion Science and Engineering (6 credits)

CH-14 Quantum Chemistry & Group Theory (6 credits)

CH-15 : Molecular Spectroscopy (6 credits)

CH-16 : Lasers and Application (6 credits)

CH-17 : Nanomaterials and Advanced Chemical Sensors (6 credits)

CH-RM: Course on Research Methodology (3 credits)

CH-1: Mathematics, computational methods, numerical analysis and computer programming

Course content

1. **Differential Equations & Integral Transforms:** Linear differential equations: Series method of solution; Legendre, Lagurre and Hermite differential equations. Use of ladder operators for solutions to differential equations; applications to quantum chemistry.

Orthogonal Polynomials and Special functions – Dirac Delta function, gamma function, error function. Introduction to Fourier series, Fourier transform and Laplace transform – applications in quantum chemistry and spectroscopic techniques – FT-NMR, FT-IR.

Convolutions of functions, use of Fourier transforms in convolution, Applications in chemistry.

2. **Vectors:** Vector differentiation and integration: Concepts of gradient, divergence and curl and their physical significance. Orthogonal vectors, Gram-Schmidt process – applications in quantum chemistry. Vector fields in space – Gauss and Stokes theorem with applications.

3. **Matrix Algebra:** Elementary operations and elementary matrices. Rotation matrices, Similarity transformations; Applications of numerical techniques in matrix algebra to evaluate eigenvalues and eigenvectors; Diagonalization and inversion of matrices. Applications in chemistry.

4. **Numerical Methods:** Newton-Raphson method for finding roots, differentiation, integrations by quadrature techniques, solutions of differential equations.

Book suggested

1. Advanced Mathematics for Engineers and Scientists, M.R. Spiegel, Schaum's Outline Series(1983).
2. Mathematical Methods for Physics Engineering, K.F. Riley, M.P. Hobson and S.J. Bence, Cambridge University Press (1998).
3. Theory and Problems of Vector Analysis, M.R. Spiegel, Schaum's Outline Series (1981).
4. Computer Oriented Numerical Analysis, V. RajaRaman, Prentice Halls India, 3rd ed. (1999)
5. Mathematical Physics, E. Butkov, Addison-Wesley Publishing Company, California (1968).

CH-2: Chemical Thermodynamics

Course content

1. **Laws of Chemical Thermodynamics:** Thermodynamic laws, thermodynamic properties of the system, criterion for equilibrium, Heat engines, Helmholtz energy, Gibbs energy, Closed system, Maxwell's equations, Gibbs-Helmholtz equation.

2. **Behaviour of Gases:** Gas laws, ideal gas and deviations from ideality, Vander Waal's equation, equation of state, critical phenomena,Thermodynamic treatment of non-ideal gases, gas mixtures.

3. **Solutions:** Raoult's and Henry's laws, activity of a component in solution, Gibbs-Duhem equation, Properties of Raoultian ideal solutions, Colligative properties, Non ideal and regular solutions, Partial and Integral thermodynamic property evaluation, alpha function, Gibbs free energy of formation of regular solutions, Criteria for stability of regular solutions, Miedema's model, associated solution model, sub-regular solutions, Models for ternary systems such as Colinet's model.

4. **Phase Equilibria:** Phase rule, Gibbs Free energy as a function of temperature and pressure, Equilibrium between a vapor and a condensed phase in a single component system, Graphical representation of phase equilibria in a single component system, Gibbs energy and thermodynamic activity, phase diagrams- single component, binary and ternary diagrams, simple calculation of thermodynamic properties from phase diagram, pressure-composition diagrams, CALPHAD and models for optimization of phase diagrams.

5. **Reactions in Gases and Condensed Phases:** Reaction equilibria in homogeneous and heterogeneous media, effect of temperature and pressure on equilibrium constant, Le Chatlier's principle, Reaction equilibria in H2/ H2O, CO/CO2 systems, Ellingham diagrams, Effect of phase transformation, use of different standard states for representing reactions in condensed phases, phase stability diagrams, application of phase diagrams in material systems.

6. **Statistical Thermodynamics:** Entropy and disorder in an atomic scale, concept of microstate, most probable microstate, influence of temperature, Boltzmann equation, partition functions, configurational entropy and thermal entropy.

7. **Experimental Thermodynamics:** Calorimetry - classification of calorimeters, different types of calorimeters, heat capacity measurements, thermochemical calorimetry, estimation of thermodynamic quantities.

Vapor pressure measurements- static methods, transpiration, boiling point method, isopiestic method, Knudsen effusion method , Langmuir evaporation method, role of mass spectrometry for study of vaporization reactions, second and third law methods, Gibbs energy functions from spectroscopy data, measurements at very high temperatures.

Galvanic cell EMF methods for activity measurements, - solid electrolyte and molten salt EMF methods.

Measurement of oxygen and carbon potentials – gas equilibration/ EMF methods

Determination of phase diagrams- spot technique, thermal analysis, enthalpies of transformations, transformation temperature, order of transformation, DTA, TGA, thermal expansion, resistivity- as a function of temperature , thermal diffusivity, measurement of thermal diffusivity and thermal conductivity.

Books Suggested:

1. Physical Chemistry, G W Castellan, Addison Wesley, 1971
2. Introduction to Metallurgical Thermodynamics, David R Gaskell, McGraw Hill, 1973.
3. Physical Chemistry, P W Atkins, 7th Ed, Cambridge University Press, 2004.
4. Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering, K Denbigh, Cambridge University Press, 1981.
5. Chemical and Process Thermodynamics, 2nd Ed, B G Kyle, Prentice Hall, 1992.
6. Thermodynamics, G N Lewis, M Randall, revised by K S Pitzer and L Brewer, McGraw Hill, 1961.
7. Differential Scanning Calorimetry: An Introduction for Practitioners, G W H Hohne, Springer Verlag, 1996.
8. Characterisation of high temperature vapours, Ed by J L Margrave, John Wiley, New York, 1967.
9. Physicochemical Measurements in Metal Research, Ed by R F Bunshah, Wiley Interscience, New York, 1970.

CH-3: Electrochemistry

Course content

1. Electrolytes – Different electrolyte systems (aqueous, ionic melts and solid electrolytes) and their conductivities; Debye-Huckle theory, Techniques for measuring electrical conductivities - DC and AC techniques

2. Electrochemical cells - Electrochemical potentials, Nernst equation and electrochemical series, Molten salt and solid electrolyte based cells

3. Electrode processes and kinetics – Diffusion layers & characteristics of the diffusion layers, over potentials, Butler-Volmer and Tafel equations, polarisable and non-polarisable electrodes, reference electrodes, voltammetric techniques, polarography, Cyclic Voltammetry, rotating electrodes and micro-electrodes, chronpotentiometric and chronoamperometric techniques, elucidation of mechanisms of electrochemical reactions.

4. Applications of electrochemical principles - Electro-analytical techniques and electrochemical sensors; energy conversion and storage systems (fuel cells and batteries); thermochemical data measurements.

Reference Books:

1. "Electrochemical Methods: Fundamentals and Applications**",** AJ Bard & LR Faulkner, Wiley, New York, 1987.
2. "Electrode Dynamics**",** AC Fisher, Oxford University Press, Oxford, 1996.
3. "Electrochemistry", **P**.H. Reiger, Prentice-Hall International, Englewood Cliffs, 1995.
4. "Solid electrolytes and their Applications", (Ed) E.C.Subba Rao, Plenum, New York, 1980.
5. "Electrochemistry", C. M. A. Brett and A. M. O. Brett, Oxford University Press, 1993.
6. "Laboratory Techniques in Electroanalytical Chemistry", 2nd Ed., by P. T. Kissinger and W. R.Heineman, Marcel Dekker, 1996.
7. "Chemical Sensor Technology", Vol.2, (ed) T.Seiyama, Kodansha Ltd., Tokyo, 1989.
8. "Chemical Sensor Technology", Vol.3, (ed) N.Yamazoe, Elsevier, Amsterdam, 1991.
9. "Solid State Gas Sensors", P.T.Mosley and B.C.Toefield, Adam Hilger, Bristol, 1987.
10. "Advances in Electroanalytical Chemistry", Vol.2, A.J.Bard, Macel Dekker, New York, 1967.
11. "Fuel Cell Systems", L.J.M.J.Blowmen and M.N.Mugerwa, Plenum Press, New York, 1993.

CH-4: Introduction to Materials Science & Engineering

Course content

1. **Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.

2. **Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.

3. **Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.

5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.

6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.

7. **Phase Diagrams & Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley & Sons, N.Y., 2003.

7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

CH-5: Analytical Chemistry for Nuclear Fuel Cycle

Course content

1. **Instrumental Methods – Principles and Applications:**

Spectrochemical Methods: Detectors- Photomultiplier Tube (PMT), Charge Coupled Device (CCD), Charge Injection Device (CID), Spectrometers – Czerny Turner, Echelle, Sample Introduction Devices – Flame, Electrothermal, Laser Ablation, Direct Sample Insertion Devices, Interferences, detection limits, sensitivity, Absorption Spectrometry – Flame Atomic Absorption Spectrometry, (FAAS), Electrothermal Atomic Absorption Spectrometry (ETAAS), Optical Emission Spectrometry (OES) with Inductively Coupled Plasma (ICPOES), Glow Discharge (GDOES), Fluorescence Spectrometry – Laser Induced Fluorescence (LIF), Recent advances – Continuum Source (CS-AAS), Single Atom Detection.
Mass Spectrometry: Mass Analysers – Magnetic, Quadrupole, Time of Flight (TOF), Ion Cyclotron Resonance, Features – Resolution, Dispersion, Abundance, Sensitivity, Detectors – Faraday Cup, Channeltron, Daly, Ion Sources –Thermal Ionisation (TI), Electron Impact, ICP, GD, Laser Ablation (LA-ICP), Secondary Ionisation (SI), Resonance Ionisation (RI), Matrix Assisted Laser Desorption and Ionisation (MALDI), Hyphenated Technique – ICP-MS, HPLC-MS, GC-MS.

Thermal Methods: Thermogravimetric Analysis (TGA), Derivative Thermogravimetric Analysis (DTG), Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Evolved Gas Analysis (EGA).

Nuclear Methods: Activation Analysis – Neutron Activation Analysis (NAA), Charged Particle Activation Analysis (CPAA), X-ray fluorescence (XRF) spectrometry, Ion Beam Analysis – Backscattering Spectrometry (BS), Particle Induced γ-ray Emission (PIGE), Nuclear Reaction Analysis (NRA), Elastic Recoil Detection Analysis (ERDA), Particle Induced X-ray Emission (PIXE).

2. **Separation Techniques – Principles and Applications:**

Solvent Extraction Technique: Conventional, Liquid Membranes – Bulk, Supported and Emulsified, Solid Phase Extraction (SPE).

Ion Exchange: Conventional and Membranes.

Chromatography: Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Ion chromatography (IC).

3. **Statistical Methods in Chemical Analysis:** Methods of sampling and associated errors, Classification of errors, Propagation of errors, treatment of errors, Normal distribution, Tests of Significance and Confidence Limits. Method of Least squares – linear and non-linear, weighted least squares formalism, constrained least squares fitting

4. **Laboratory Experiments (any 5):**

Determination of trace impurities in high purity materials by AAS.

Application of Electroanalytical Methods to trace analysis

TGA and DTA study of inorganic compounds

Neutron Activation Analysis of trace constituents in a complex matrix

Analysis of an alloy sample by EDXRF

Anion analysis by ion selective electrode.

Chromatographic separation and measurement of the components in a mixture

Isotopic Analysis by Mass Spectrometry

Books suggested:

1. Fundamentals of Analytical Chemistry, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
2. Principles of Instrumental Analysis, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
3. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).
4. Statistics for Analytical Chemistry, J. C. Miller and J. N. Miller, 2nd Edition, Wiley (1998).

CH-6: Chemical Instrumentation and Laboratory Techniques

Course content

1. **Passive Circuit Elements and Configurations:** Circuit behaviour of resistors,inductors and capacitors; the potential divider and the wheatstone Bridge (resistive and capacitive), R-L-C-circuits as filters and resonance circuits.

2. **Electronic Devices and Their Role in Power Conversion and Amplification:** The junction diode, SCR, triacs and their role in rectification and AC power control; bipolar transistor and IGBT and their role in linear/switched mode power supplies and in amplification of signals; constant current power supplies Inverter circuits; issues in measurement of signals - Concept of input impedence and the role of J-FETs and MOSFETs.

3. **Operational Amplifiers and their Various Functionalities:** The basic OP-AMP and its desired characteristics; the inverting amplifier, the non-inverting amplifier, summing configuration;

The differentiator and integrator circuits; comparator; precision rectifier; waveform generation.

4. **Fundamental Issues Related to Chemical Instrumentation:** Role of chemical instrumentation in the nuclear fuel cycle, with relation to selectivity, sensitivity and automation amenability.

The basic anatomy of excitation with energy source-interaction with analyte-detection of the effect produced; issues related to selectivity; sensitivity and detection limits; sources of noise and measures to minimize the effect; boxcar integrator, lock-in-amplifier.

5. **UV-VIS-IR Instruments:** Phenomenon of resonant absorption and Beer's law of photometry; implementation of Beer's law in a spectrophotometer; compensation for spectral response of the detector; slit servo mechanism for compensation of optical emission.

Atomic absorption spectrophotometer-flame ionization, compensation for molecular absorption, hollow cathode lamp excitation for high specificity.

Atomic emission spectrometry-principles, instrumentation and data interpretation

Laser fluorescence spectrometry-laser basics, three stage power supply for flash lamp excitation.

Non dispersive spectrometer- FTIR - principle, data collection scheme.

6. **X-Ray Spectrometry:** Generation of X-Rays, The X-Ray tube, setting the energy and intensity; Bragg's law; X-Ray fluorescence, X-Ray diffraction, ESCA for surface analysis.

7. **Mass Spectrometry:** Ion sources-thermal ionization, Knudsen effusion and electron impact ionization, inductively coupled plasma source, Laser induced vapourisation, spark source.

Magnetic analysers, quadrupole analysers, time-of-flight analysers.

Detectors-faraday, SEM, Channeltron.

Mass scanning, peak centering, signal handling and digitization and counting.

8. **Thermal Analysis:** Thermal excitation - furnaces, temperature profiling and furnace power control.

Thermal effects - TGA, DTA, DSC, dilatometry.

Thermal measurements - thermocouples, RTDs, signal conditioning and handling.

9. **Additional Methods of Analysis:** Gas chromatography - mobile and stationary phases; separation on the basis of retention time; TCD and FID detectors.

Instrumentation for pH meters and conductivity meters; automated titro-processors and applications of coulometry.

Radioactive assay based on multi-channel gamma ray spectrometry.

10. **Digital Electronics:** Logic gates; flipflops, counters, astable and monostable multivibrators; decoders; logic families; data conversion-various types of ADCs and DACs.

Microprocessor systems-processor architecture, memory circuits, I/O subsystems; interfacing techniques; assembly language programming.

11. **Laboratory Techniques:** Machine Drawings Projections: orthographic – 1st & 3rd Angles
pictorial; Oblique: Perspective. Conventional representation of common features and sections;
Dimensioning and tolerancing; Scales, lines and lettering; Threads; Fastenings. Brief Introduction of AutoCAD and its use, common drawing and edit commands.

Vacuum systems - equipment for vacuum generation - rotary pumps, diffusion pumps, ion pumps, turbo molecular pumps; Generation of high temperatures, measurement of vacuum and temperatures, centrifuges, chemicals and laboratory safety.

12. **Vacuum Generation and measurements:** Kinetic theory of gases – Velocity distribution – Mean free path – Monolayer formation – vacuum units – Viscous and molecular Flow regimes – Reynold's and Knudsen Numbers viscosity and thermal conductivity of gases – Gas release from solids – vaporization – out gassing – diffusion – permeation – Vacuum pumps – Titanium Sublimation pumps – Ion pumps – Cryogenic pumps and maters for construction of Vacuum chamber.

Gauges: Thermal conductivity, cold cathode, hot cathode ionization gauges and their Principle of operation.

Books suggested:

1. Principles of Instrumental Analysis, D. A. Skoog and J. Leary, McMillan Publishers,
2. Instrumental Methods of Analysis, H. H. Willard, L. L. Merritt, Jr., J. A. Dean, F. A. Settle, Jr. CBS Publishers and Distributors, New Delhi 1986.
3. A text book of Quantitative Analysis, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).

CH-7: Health Physics and Radiation Sciences

Course content

1. **Interaction of Radiation With Matter:** Ionization in gaseous medium, Bragg's curve, stopping power, Bethe equation, range of particles and straggling, LET, attenuation and absorption of beta particles, backscattering, photoelectric, compton and pair production processes for gamma radiation, variation with gamma energy and Z of medium, attenuation and absorption of gamma rays, elastic and inelastic scattering of neutrons.

2. **Radiation Detection and Measurement:** Principles of radiation detectors, counting characteristics, detection efficiency and energy resolution, dead time and counting statistics, Gas filled detectors, scintillation processes and detectors, organic and inorganic scintillators, NaI(Tl), LaBr3, semiconductor detectors, p-n junctions, germanium and silicon detectors, room temperature semiconductors, neutron detectors including bubble detectors, solid state nuclear track detectors, nuclear probes - positron annihilation, perturbed angular correlation, mossbauer effect.

3. **Shielding and Dose Calculations:** Shielding (beta, gamma and neutron sources).

Shielding from mixed sources; calculation of dose for point, line and volume sources.

4. **Dosimetry:** Definition of various dosimetric terms (exposure, absorbed dose, equivalent dose, effective dose, concept of radiation and tissue weighting factors and their importance, Activity, Specific activity (SI units and Old units), radiological, biological and effective half-life and their relation and the concept of the same and their importance. Concept of ALI and DAC.

5. **Radiation Protection Principles:** Radiation protection philosophy, objectives and principles of radiation protection, Dose limits to occupational workers and members of public, Dose constraints, Investigation limits. Types of exposure (natural, occupational, medical and public).

External and internal exposures; routes of intake of radioactive material. Use of personal dosimeters (Film badge, TLDs, pocket dosimeters). Calculation of internal dose, Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given), exposure-dose relationship, Bragg-Gray principle.

Fundamentals of ICRP respiratory model, entry through ingestion, GI track model, wholebody counting and bioassay techniques.

6. **Radiation Protection Procedures:** Procedures followed in radiation work places, supervised and controlled areas, work permits, contamination control methods (air-borne, surface and personnel), swipe samples, and rubber areas, spill pack (gloves + absorbing paper), decontamination and de-corporation techniques; bore wells and inspection chambers; precautions during radioactive source storage and handling.

Types of radiation monitors / radioactivity measurement methods adopted for radiation protection. Personnel monitoring, area monitoring and stack monitoring.

7. **Waste Management:** Radioactive waste classification and management – An overview.

8. **Emergency Preparedness:** Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, counter measures.

9. **Nuclear Fuel Cycle Applications:** Radiological aspects and environmental impact of FBRs. Criticality safety and Radiological aspects in nuclear cycle facilities.

10. **Regulatory Details:** Atomic Energy Act, National and International regulatory bodies, their role and responsibilities, Radiation Protection Rules, Nature of duties and responsibilities of Radiation Safety Officer / Health Physicist, radio toxicity and classification of laboratories, design of lab for radioactive work, Safe handling of radioisotopes, Transport of radioactive materials.

11. **Basic Radiobiology:** Interaction of ionizing radiation with living cells, Ionizing radiations, excitation and ionization process, basic structure and components of cell, chemical and biological consequences of radiation action, radicals and reactions in cell killing, direct and indirect effect and relevant biological damage.

12. **Molecular and Cellular Effects of Radiation:** Radiation action and organizational level in cell, Damage to DNA, single and double structural breaks in units membrane dose and survival curve, cellular radioactivity, radiobiological effectiveness and linear energy transfer Dzz dose, rate effect, dose fractionation, Mitotic delay, chromosome aberration and mutations by radiation action on cells.

13. **Modification of Biological Effects of Radiation:** Oxygen effect, OER, Chemical radio sensitizers, Chemical radio protectors, Mechanisms of action and importance in nuclear research programme.

14. **Radiobiology and Radiotherapy:** Radiation and cancer, cell cycle and radiosensitivity, rationale of using radiation for tumor cell kill, problems.

15. **Basics of Radiation Chemistry:** Interaction of high energy radiation with matter, G-values, radiation induced reactions in solids, liquids and gases.

Laboratory Experiments:

1. Plancheting, alpha counting and spectroscopy
2. Counting characteristics of gas detectors
3. Half life determination and attenuation coefficient determination
4. High resolution gamma spectrometry
5. Dose Measurements: Whole Body Counting laboratory, Bio-dosimetry laboratory, TLD personnel monitoring services laboratory.

Demonstrations:

1. **Use of Personnel Protective Equipment (PPE):** Proper checking and wearing of gloves, and other plant dresses (shoe covers, boiler suits, overcoats etc).

Respirators (dust, gas mask, self contained breathing apparatus, and fresh air-line) TLD, Film badge, neutron film, criticality badge and bubble detector

2. **Use of Radiation Monitoring Equipment: Installed and Portable Radiation Monitors:** AGM (audio and visual alarm, setting up of alarm limits); staplex air sampler (estimation of air-borne activity-both alpha and beta-gamma), different types of survey meters (low to high range), ALSCIN and GM based contamination monitors (side window and end window, hand and foot monitor, cloth monitor), continuous air monitor, criticality alarm system.

Books suggested:

1. Introduction to Health Physics by Herman Camber
2. Biological Effects of Radiation by J. E. Coggle
3. Radiobiology for Radiologist by Eris J. Hall
4. Detection and Measurement of Radiation - Glenn T Knoll.

CH-9: Chemistry of Fuel Cycle-I

Course content

1. Recovery of the starting compounds bearing U, Pu or Th from their primary and secondary sources. Mining, beneficiation, pre-concentration, purification and recovery.

2. **Oxide Fuels:** Preparation of UO2, PuO2, MOX and ThO2. Physical and chemical properties, phase diagrams of relevance, control of phase composition and stoichiometry, fuel fabrication flow sheet and quality control.

3. **Advanced Ceramic Fuels:** Carbides U-C, Pu-C, U-Pu-C, U-Pu-C-O and U-Pu-C-O-N, Nitrides U-N, Pu-N, U-Pu-N. Physical and chemical properties, phase diagrams of relevance, control of phase composition and stoichiometry, fuel fabrication flow sheet and quality control.

4. **Advanced Fuel Fabrication Techniques:** Oxides, Methods based on sol-gel and novel techniques. Carbides; sol-gel method, direct pressing and arc casting.

5. Preparation of U, Pu and Th.

6. **Alloy Fuels:** Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-RM, U-Pu- MA), dispersions and composites – Salient physical and chemical properties, relevant phase diagrams, fabrication and quality control.

7. **Inert Matrix Fuels for Partitioning and Transmutation:** A brief account on the current developments.

8. **Fuel – Clad Interaction:** Significance of FCCI and FCMI. Specifics pertaining to oxide, carbide and metallic fuels. Role of chemical thermodynamics in the prediction and understanding of Fuel clad chemical compatibility.

9. **In Pile Behaviour of Fuels:** Chemistry and redistribution of fission products, role of chemical potentials of the constituents in the breach of clad in oxide, carbide and alloy fuel pins and detection mechanisms.

Books suggested:

1. Donald R. Olander, Fundamental aspects of nuclear reactor foel elements fundamental aspects of nuclear reactor foel elements, Springfield, BTIS, 1985.
2. H. J. Matzke, Science of Advanced LMFBR fuels, North Holland, Amsterdam, 1986.
3. M. Benedict and T.H. Pigford, Nuclear Chemical Engineering, Mc Graw Hill, New York, 1957. (Specific journal articles and other references will be cited during the lectures)

CH-10: Chemistry of Fuel Cycle–II

Course content

1. **Actinide Chemistry:** Discovery of actinide elements, electronic structure, oxidation states, inter-conversion of oxidation states, complexes of actinide ions, actinide contraction, comparison of actinides with lanthanides. Actinides in environment.

Purification of actinides using techniques such as ion-exchange, Solvent Extraction, Liquid membranes and Chromatographic Methods.

Hydrolysis, colour, spectroscopy and magnetic properties of actinides, nuclear properties of actinides, decay modes.

Thorium: isotopes, occurrence and production; Uranium: isotopes, occurrence, resour0ces and production.

Transuranium Elements: production of transuranic elements, Neptunium, Plutonium, Americium and Curium; Actinide synthesis by heavy ion reactions.

Fission Product Chemistry.

2. **Aqueous Reprocessing:** Introduction to nuclear fuel reprocessing; Need for reprocessing; PUREX, TRUEX, THOREX.

Latest developments. Solvent extraction for actinide purification; basic principles, introduction to extractants, classification of extractants.

Purification of uranium, plutonium; lanthanide actinide separations.

3. **Pyrochemical Reprocessing:** Introduction to non aqueous reprocessing: Objectives and advantages of non aqueous reprocessing in fast reactor fuel cycle, Advanced fuel cycle flowsheets involving non aqueous reprocessing, Recent trends in pyrochemical reprocessing of oxide and metallic fuels.

Oxide electrowinning flowsheet, Pyrochemical reprocessing of metallic fuels (IFR process) - Integral Fast Reactor Concept, Differences in electrorefining and electrowinning.

4. **NUMAC:** Importance of Nuclear Material Accounting; techniques used for analysis of nuclear materials.

NUMAC with techniques such as Potentiometry, Coulometry, Amperometry.

Mass Spectrometry, Calorimetry, Gamma counting, neutron counting etc. Advantages and drawbacks of individual methods.

5. **Post Irradiation Techniques:** Introduction to post-irradiation examination methods of nuclear reactor fuels; importance of PIE methods, burn-up measurements; NDE testing of fresh fuel pins.

Non-destructive evaluation of irradiated fuels (X-ray and neutron radiographic examination of fuel pins, Fission gas analysis, Metallographic examinations).

6. **Nuclear Waste Management:** Introduction - industrial waste, nuclear waste & its speciality, generation of radioactive wastes, radioactivity in the environment, Solid, liquid & gaseous wastes, international classification. Basic philosophy & methods of radioactive waste management, environmental monitoring. HLW & spent fuel waste. Radioactive waste immobilization matrices & their ultimate disposal.

Reference Books

1. “**Handbook of Physics and Chemistry of Rare Earths: Lanthanides Actinides**” G.T. Seaborg, Vol.18,(Eds., K.A. Schneider, Jr., L. Eyring, G.R. Choppin and G.H. Lander), Elsevier Science, Amsterdam (1994).
2. “**The Chemistry of Actinide Elements**”, J.J. Katz, G.T. Seaborg and L.R. Morss, Vol. 1 and 2, 2nd Ed., Chapman and Hall, New York (1986).

3. “**Handbook of Physics and Chemistry of Actinides**”, A.J. Freeman and C. Keller,North Holland Amsterdam, Vol.3 (1985), Vol.4 (1986), and Vol.6 (1991).

4. “**The Chemistry of Transuranium Elements**”, C. Keller,Verlag Chemie GmbH, Germany (1971).
5. “**Summary of the Properties of Lanthanide and Actinide Elements**” G.T. Seaborg and D’E.Hobart in ‘Frontiers in Nuclear Chemistry’, Eds. D.D. Sood, A.V.R. Reddy and P.K. Pujari, IANCAS publication, Mumbai (1996)
6. “**The Chemistry of Plutonium**” J.M. Cleveland, Gordon and Breach Science Publishers, Newyork, 1970

7. “**Solvent Extraction of Metals**”, A. K. De, S. M. Khopkar and R. A. Chalmers, Van Nostrand, Reinhold (1970).
8. “**Ion Exchange and Solvent Extraction : A Series of Advances**”, Editors J. A. Marinsky and Y. Marcus, Marcel Dekker Inc. (1998).
9. “**Ion Exchangers**”, F. Helfferich, McGraw Hill (1962).
10. “**Introduction to Modern Liquid Chromatography**”, L. R. Snyder and J. J. Kirkland, 2nd Edition, Wiley (1979).
11. “**Analytical Chemistry**”, R.V.Dilts, Van Nostrand (1974).
12. “**Modern Practice of Gas Chromatography**”, by R.L.Grob and E.F.Bary, 4th Edition, Wiley-Interscience.
13. “**Practical Supercritical Fluid Chromatography and Extraction**”, M. Caude, D. Thiebaut, Eds.) Harwood Academic Publishers (1999).
14. “**Supercritical Fluid Extraction**”, M.A.Mchugh and V.J.Krukonis, Butterworth Heinemann, 2nd Edition, 1994
15. “**Fundamentals of Analytical Chemistry**”, D.A. Skoog, D. M. West, F. J. Holler, S.R. Crouch, 8th Edition, Thomson (2004).
16. “**Principles of Instrumental Analysis**”, D.A. Skoog, F. J. Holler, T. A. Niemann, 5th Edition, Saunders College Publishing (1998).
17. “**A text book of Quantitative Analysis**”, A.I. Vogel, 5th Edition Revised by G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denney, ELBS (1989).

CH-11: Materials for Nuclear Reactors and Fuel Cycle Processing Systems

1. Fundamentals of reactor physics and different reactor systems

a) Fission reactors: Thermal reactor, fast reactor, advanced reactor, b) Fusion reactors: Thermonuclear reactor

2. Health Physics and Radiation Sciences

Interaction of radiation with matter, Radiation detection and measurement – use of gas filled detectors, scintillators, semi-conductor detectors, neutron detectors, Radiation Units and Limits.

Hazards Control and Evaluation, Biological effects of radiation, Dose and dose limits for occupational workers and members of public, Radiation Protection Procedures, Dosimeters.

Transport and release, Classification of nuclear waste and their management –Emergency Preparedness, Radiation Chemistry, G-values, radiation induced reactions in solids, liquids and solids.

3. Introduction to Reactor Materials

Moderators (Requirements, properties of D_2O and graphite), C**ontrol rod materials (**Requirements, properties), **Coolants** (Requirements, properties and handling - water, liquid sodium, lead-bismuth alloys, helium, CO_2), **Cover gas (**Cover gas purification, monitoring for hydrogen, fission gases)

4. Introduction to Coolant chemistry:

Na, Pb-Bi and Pb-Li chemistry: Monitoring and maintaining purity of coolants, on-line monitoring using EC monitors, sampling and analysis.

Water chemistry (Introduction to fast reactor water chemistry, condenser cooling and process water chemistry, de-mineralising plant and condensate polishing unit chemistry, on-line monitoring, biological shield cooling water chemistry, related analytical techniques, Chemical aspects of corrosion in liquid metal coolant systems

5. Fuel reprocessing: Chemistry of Actinides with respect to reprocessing, Aqueous methods - Purex, Thorex, use of novel extractants, Non-aqueous methods - pyrochemical processes.

Books Suggested:

1. S. Glasstone, Source Book on Atomic Energy, Allied East-West Press Pvt. Ltd., NewDelhi.
2. S. Glasstone and Sesonske, Nuclear Reactor Engineering, Chapman Hall, London, 1994.
3. H.U. Borgstedt and C.K. Mathews, Applied Chemistry of the Alkali Metals, Plenum Press, 1987.
4. C.C. Addison, The Chemistry of the Liquid Alkali Metals, John Wiley and Sons, 1984.
5. Power Plant Chemistry: A practical guide, Buecher Braid, Penwell, Oklahoma, 1997.
6. Modern Power Station Practice, III Edition, Pergamon, NY, 1992.

CH-12: Nuclear and Radiochemistry (CH12)

Course content

1. **Nuclear Properties:** Concept of nucleus, nuclear spin, parity, electric and magnetic moments, isomerism, nuclear mass and binding energy, elemental abundance, radioactive decay laws, radioactive equilibria, Bateman's equation, liquid drop and shell models.
2. **Nuclear Structure and Decay Modes:** Nuclear force, structure of complex nuclei, liquid drop, shell and collective models, nucleon emission, beta decay, gamma de-excitation and internal conversion, selection rules.
3. **Nuclear Reactions and Accelerators:** Basic principles and energetics, cross sections, nuclear fission, charge and mass distribution in fission, compound nucleus reactions, direct reactions, types and details of accelerators.
4. **Radiochemical Separations:** Concepts of traces, chemical yields, radiochemical purity, applications.
5. **Nuclear Techniques:** Nuclear probes, PAC, NDA and on-line monitoring.
6. **Radio-isotope Production:** Basic principles of isotope production in both reactors and accelerators, Szilard - Chalmers effect and its utility, concept of generators, Moly generators.
7. **Applications of Radioisotopes:** Concepts of nuclear medicine and radio-pharmaceuticals, SPECT, PET, brachytherapy and and teletherapy Radio-immuno assay, industrial, agricultural and biological applications.

Laboratory Experiments:

1. Fission product separation and transient equilibrium.
2. Separation of actinides using ion-exchange or solvent extraction
3. Neutron activation analysis.

Books Suggested:

1. Nuclear and Radiochemistry (1981) - G. Friedlander, J. Kennedy, J.M. Miller and J.W. Macias
2. Atomic Nuclear (1955) - R.D. Evans
3. Source book of atomic energy (1969) - S. Glasstone
4. Essentials of Nuclear Chemistry (1982) - H.J. Arnikar
5. The chemistry of Transuranium Elements (1971) - J. Keller
6. G.R. Chopin and Rydberg: Nuclear Chemistry, Theory and Applications, Pergamon Press, Great Transuranium elements and transactinides.
7. Manual for reactor produced isotopes, IAEA-TECDOC-1340 (1999)
8. Radionuclides in therapy - R.P. Spencer, R.H. Sievers, A.M. Friedman. CRC Press (1987
9. Radioimmunoassay: Principles and Practice, M.R.A. Pillai and S.D. Bhandarkar, 2nd Edition, BARC, 1998
10. Industrial applications of radioisotopes - G. Foldiak

CH-13: Corrosion Science and Engineering (CH13)

Course content

1. **Thermodynamics of Aqueous Corrosion:** Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.

2. **Kinetics of Aqueous Corrosion:** Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.

3. **Forms of Corrosion:** General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion.

Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.

4. **Corrosion in Reactor and Reprocessing Plants:** Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.

5. **Prevention and Control of Corrosion:** Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.

6. **Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.

7. **Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, “Corrosion and corrosion control – An introduction to corrosion science and engineering”, Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, “Corrosion Engineering”, Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.
4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, “Corrosion and corrosion protection handbook”, USA, 1983.

CH-14: Quantum Chemistry and Group Theory

1. Fundamental principles

Brief review of the fundamentals of quantum mechanics – postulates, measurements, operators, de Broglie equation, Heisenberg principle, Schrodinger Equation.

2. Exactly solvable problems

Particle in a box with walls at infitine and finite potential; Double box potential, tunneling, effect of barrier height on splitting of degenerate energy levels and its application in understanding double well potential. Particle in a ring. Simple harmonic oscillator, rigid rotor, hydrogen atom problem solution using both the power series method and ladder operators.

3. Approximation methods

Variation method, perturbation theory for time-independent and time dependent systems; Many-electron systems: Hartree-Fock theory and beyond; Chemical binding in simple molecular systems: Valence bond and molecular orbital theories; Concept of LCAO and introduction to ab-initio and semi-empirical molecular orbital calculations of molecules.

4. Group Theory

Symmetry elements and operations, point groups, matrix representation, reducible and irreducible representations, the Great Orthogonality theorem, direct product representation, projection operators.

5. Applications of Group Theory in Chemistry

Vibrational problem, hybridization, SALC, ligand field theory.

Reference Books

1. **"**Quantum Chemistry", I. N. Levine, Allyn & Bacon, Inc. (Boston) 5ed. (2000).
2. "Introduction to Quantum Chemistry", F. S. Levine, Cambridge Univ. Press (2002).
3. "Quantum Chemistry", W. Kauzmann, Academic Press (1957).
4. "Chemical Applications of Group Theory", F. A. Cotton, Wiley Eastern Limited, (1989).
5. "Group Theoretical Techniques in Quantum Chemistry", C. D. H. Chisholm, Academic Press (1976).

CH-15: Molecular Spectroscopy

1. Vibrations and rotations of diatomic molecules, selection rules, nuclear spin statistics.

2. Electronic spectroscopy of diatomic molecules, coupling of angular momentum, Hunds coupling cases, term states of molecules, potential energy functions – analytical and numerical (e.g. RKR), Dissociation energy, Franck Condon principle, numerical methods to evaluate Franck Condon factors.

3. Vibrations of polyatomic molecules – classical mechanics of vibrations, symmetry and normal vibrations – applications of group theory.

4. Experimental techniques in spectroscopy: Fourier transform spectroscopy (FTIR, FT-RAMAN), time resolved FTIR and its applications in absorption and emission studies. Laser based experimental methods, Introduction and application of Terahertz spectroscopy.

5. Studies on ultrafast processes: Nanosecond and picosecond laser flash photolysis, fluorescence time domain spectroscopy with special emphasis on energy transfer and electron transfer reactions and studies on excited state properties**.**

6. NMR & ESR: Basics of NMR and ESR, Multipulse techniques in NMR, FTNMR, 2D-NMR. Time domain ESR, Electron Nuclear Double Resonance (ENDOR)-principle and applications.

Reference Books:

1. “Introduction to Lasers Physics”, K. Shimoda, Springer Verlag, 1984 Berlin
2. “Laser Spectroscopy basic concepts and Instrumentation”, W. Demtroder, Springer 2003, Berlin.
3. “Molecular Spectroscopy”, C. N. Banwell, 4 Edn, Tata McGraw Hill, Delhi.
4. “Infra red spectra of Inorganic and coordination compounds”, K. Nakamoto, 5 Ed, John Wiley 1978, NewYork.

CH-16: Lasers and Their Applications

Introduction to Lasers

1. Rate equation for absorption, induced and spontaneous emission, Einstein's A and B coefficients – Concepts of laser action and population inversion – rate equations for two, three and four level systems.

2. Laser and its sub-systems – Optical amplifier – optical resonator – excited state pump – Properties of laser beams – Spatial and temporal coherence.

3. Different types of passive resonators, modes of a passive resonator – Active resonators – Gain & Threshold condition for lasing actions – laser modes – Gain saturation and mode competition – spatial and velocity hole burning.

4. Wavelength and Intensity stabilization of lasers – turning of wavelength of lasers – prisms, grating and elations – controlled wavelength turning – Selection of axial modes, Experimental realization of single mode.

5. Generation of short pulses – Q-switching and mode locking – active and passive methods

6. Principles of various types of lasers – UV, vis & IR lasers, metal vapour lasers, solid state lasers, Gas lasers, Dye lasers, Semiconductor-diode laser and free electron laser

Laser Spectroscopic Techniques:

Important features of lasers useful for spectroscopy – monochromaticity, directionality, high intensity, tunability, short pulses etc. Advantages of lasers for spectroscopy – high sensitivity and selectivity. Short review of spectral line broadening mechanisms.

Doppler-limited spectroscopy
a) High sensitivity methods of Absorption – frequency modulation, intracavity absorption.
b) Photoacoustic spectroscopy; c) Resonance ionization spectroscopy combined with mass spectrometry – multiphoton processes; d) Optogalvanic spectroscopy

Laser Induced Fluorescence: a) Molecular Spectroscopy by LIF; b) Experimental aspects and advantages of LIF (c) LIF in supersonic molecular beams

Laser Raman Spectroscopy: (a) Linear Raman Spectroscopy; (b) Non-linear Raman Spectroscopy – Stimulated Raman scattering (c) Coherent Anti-Stokes Raman Spectroscopy (CARS)

Analytical applications of lasers: a)Laser induced break down spectroscopy, cavity ring down spectroscopy; (b) Atmospheric measurements with LIDAR

Laser material interactions: a) Vaporization, desorption and ablation. b) Surface modification; c) Laser cooling (d) Laser Induced Chemical Reactions/ Laser Isotope Separation

Reference Books:

1. “Introduction to Lasers Physics”, K. Shimoda, Springer Verlag, 1984 Berlin
2. “Laser Spectroscopy basic concepts and Instrumentation”, W. Demtroder, Springer 2003, Berlin.
3. “Principles of lasers”, O. Svelto and D. C. Hanna, Plenum, 1989, New York
4. “Chemical and biochemical applications of lasers-vol I & III”, C.B. Moore, (Ed) Academic Press, New York (1974)
5. “Lasers”, P.W. Milonni and J.H. Eberly, World Scientific, Singapore (1981)

CH 17 - Nano materials and advanced chemical sensors

Introduction

Nanoscale– its importance, definitions, nanomaterial science- One dimension, Two dimensions (carbon nanotubes, inorganic nanotubes, nanowires, biopolymers), Threee dimensions (nanoparticles, fullerenes C-60, dendrimers, quantum dots) properties (electrical, optical, mechanical & chemical)

Synthesis and characterization

Synthesis -Chemical methods (precipitation, sol-gel, CVD, ion-exchange, dispersion), Physical methods (milling, PVD, pyrolysis, ion-implantation). Consolidation of nanopowders – sintering introduction, theories of sintering, sintering of nanomaterials, novel methods for consolidation of nanopowders. Characterization – X-ray techniques, spectroscopic techniques, electron beam techniques, optical methods

Applications

Structural and functional ceramics, coatings, sensors, power sources, additives and catalysts, composites, lubricants, magnetic materials, medical implants & nuclear ceramics. Sintering – introduction, theories, methods for consolidation and sintering of nanostructured materials

Introduction to chemical sensors

Fundamental definitions and principles; rationale of sensor design and operation; basic theoretical considerations

Electrochemical Sensors

(Potentiometric sensors, Voltammetric and Amperometric sensors)
Ion selective electrodes(ISEs) – principles, solid (glass and fast ion conductor based) and liquid membrane based electrodes, Electrochemical gas sensors, Semiconductor devices (ISFETs, MOSFETs), Conductance gas and vapour sensors based on metal oxides, semiconductors and conducting polymers. Biosensors- oxygen and glucose biosensors; mediated enzyme electrodes and enzyme field effect transistors (ENFETs).

Piezoelectric Sensors

Piezoelectricity and mechanical resonance: stress, strain and polarization; constitutive relationships; equations of wave motion and wave representation.

The transverse-shear mode sensor, or quartz crystal microbalance: application to gas- and liquid-phase sensing; applications to VOC sensing, immunosensing and biosensors.

Optical Sensors

IR and UV sensors - semiconductors - optical irradiation – recombination - Quantum efficiency - p-n junctions - IV characteristics - forward bias and reverse bias - applications.

Micro Electro Mechanical System (MEMS) based sensors and electronic noses

Cantilever based sensors – Sensing Principles, types of cantilevers, use of different detection techniques, examples and applications

Chemometrics as applied to chemical detection and identification; Olfaction and electronic noses; Salient features

Sensor fabrication methods

Sensor configurations and geometries, Use of nano-materials in sensors

Thin/thick film formation techniques (physical, chemical and LB film formation techniques), MEMs based sensor fabrication

Surface analysis and characterization

Practicals

Testing of a solid electrolyte based potentiometric oxygen sensor
Testing of an amperometric sensor for oxygen
Fabrication and testing of a thick-film hydrogen sensor

References

1. Fundamentals of Nanostructured materials, Eds. D. Fiorani (World Scientific, Singapore, 1994)
2. Nanoparticles and Nanostructured Films: Preparation, Characterization and Applications, Ed. J.H. Fendler (Wiley-VCH, New York, 1998)
3. Chemistry of Nanomaterials Vol 1 and 2, Eds. C.N.R. Rao, A. Muller, A.K. Cheetam, (Wiley-VCH, Weinheim, 2004)
4. Nanoscience and Nanotechnology (Ed.) B.S. Thomar, IANCAS Bull., Vol. VI, No.2, April 2007.
5. J. Janata, Principles of Chemical Sensors, Kluwer Academic Publishing Plenum, Dordrecht, 1989.
6. T. Seiyama Ed. , Chemical Sensor Technology, Vol. 1 and 2 Elsevier, Amsterdam, 1988.and 1990
7. Chemical Sensor Technology, Vol. 3, (N. Yamazoe Ed.)Elsevier, Amsterdam, 1991.
8. Chemical Sensor Technology, Vol. 4 (S. Yamauchi Ed), Elsevier, Amsterdam, 1992
9. H. Baltes, W. Gopel, J. Hesse Eds. , Sensors Update Volumes 1 to 6 , Wiley-VCH, Weinheim, 1996.
10. W. Gopel, J. Hesse, J.N. Zemel Eds., Sensors, A Comprehensive Survey, Vol. 7, Wiley-VCH, Weinheim, 1993.
11. R.W. Cattrall, Chemical Sensors, Oxford Univ. Press, Oxford, 1997.
12. K.T.V. Grattan, B.T. Meggitt Eds. , Optical Fiber Sensor Technology, Vol. 4: Chemical and Environmental Sensing, Kluwer Academic Publishing, Dordrecht, 1999.
13. ‘Solid State Gas Sensors’, (eds. P.T. Moseley, B.C. Toefield), 1987, Bristol, Adam Hilger.
14. S.R. Morrison: ‘The Chemical Physics of Surfaces’, 1; 1978, New York, Plenum Press.

CH-RM: Course on Research Methodology

Unit-I - Objectives and types of research: Motivation and objectives – Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Unit-II - Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem – Literature review – Primary and secondary sources – reviews, treatise, monographs-patents – web as a source – searching the web - Critical literature review – Identifying gap areas from literature review - Development of working hypothesis.

Unit-III - Research design and methods – Research design – Basic Principles- Need of research design — Features of good design – Important concepts relating to research design – Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Unit-IV – Value of Statistics; Errors and Statistics – Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results – students's t test; F-test; Chi Square test; propagation of errors.

Unit-V - Reporting and thesis writing – Structure and components of scientific reports - Types of report – Technical reports and thesis – Significance – Different steps in the preparation – Layout, structure and Language of typical reports – Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation – Planning – Preparation – Practice – Making presentation – Use of visual aids - Importance of effective communication –.Computers in Chemistry, Usage of packages such as, Excel, AIM2000, ChemCraft, etc. Manuscript drafting based on "Experimental data and Literature Survey". **Unit-VI** - Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialisation – Copy right – Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights – Reproduction of published material – Plagiarism - Citation and acknowledgement - Reproducibility and accountability. [7 hrs]

REFERENCES

1. Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction to Research Methodology, RBSA Publishers.
2. Kothari, C.R., 2000, Research Methodology: Methods and Techniques. New Age International.
3. Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Ess Publications (2 volumes)
4. R. Paneer Selvam – Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
5. Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
6. Day, R.A., 1992.How to Write and Publish a Scientific Paper, Cambridge University Press.
7. Vogel's Text Book of Quantitative Inorganic Analysis, ELBS.

BACK TO MAIN

Courses of Study

For PhD Program

SCHOOL OF CHEMICAL SCIENCES

SYLLABUS FOR

Ph.D. in Chemical Sciences

(Program Code: CHEM04)

National Institute of Science Education and Research Bhubaneswar

(An Off-Campus Center of Homi Bhabha National Institute – a deemed to be University, Anushkati Nagar, Mumbai)

With effect from the Academic Year 2018

Detailed course PhD program

Number of compulsory courses – Theory (Credit assigned)	Number of elective courses (Credits assigned)	Total credit/semester (Credits assigned)
03	03	36
12 (Research Project)	12 (Research Project)	24

List of Compulsory Courses

Course No	Credits	Course Name
C606	06	Physical Methods in Chemistry I
C601	06	Physical Methods in Chemistry II
C604	06	Coordination Chemistry
C605	06	Chemical Binding
C665	06	Advanced Organic Chemistry

List of Elective Courses

Course No	Credits	Course Name
C602	06	Chemical Rate Processes
C603	06	Chemistry of Heterocycles and Natural Products
C651	06	Molecular Modeling
C653	06	Classics in Molecules
C652	06	Solid State Chemistry
C654	06	Crystallography
C655	06	Principles of Drug action
C656	06	Advanced Bio-inorganic Chemistry
C657	06	Nuclear Magnetic Resonance
C658	06	Advanced Functional Materials
C659	06	Supramolecular Chemistry
C660	06	Chemistry of Nanomaterials
C662	06	Polymer Chemistry
C663	06	Molecular Reaction Dynamics
C664	06	Theory of Molecular Spectroscopy
C666	06	Catalysis: Reaction Mechanisms and Applications
C667	06	Advanced Main group Chemistry
C668	06	Advanced Fluorescence Spectroscopy
C669	06	Biomacromolecules
C670	06	Advanced Heterocyclic Chemistry
C671	06	Statistical Mechanics
C751	06	Photochemistry
C752	06	Pharmaceutical Chemistry
C753	06	Group Theory and Molecular Spectroscopy

List of Research Projects Courses

Course No	Credits	Course Name
C754	12	Organic Chemistry Project-1
C755	12	Organic Chemistry Project-2
C756	12	Inorganic Chemistry Project-1
C757	12	Inorganic Chemistry Project-2
C758	12	Physical Chemistry Project-1
C759	12	Physical Chemistry Project-2

Lab Course (Research Project) code: Course name), Credits
Organic Chemistry Project-1 (C754), Credit 12, (12h/week)
Organic Chemistry Project-II (C755), Credit 12, (12h/week)
Inorganic Chemistry Project-I (C756), Credit 12, (12h/week)
Inorganic Chemistry Project-II (C757), Credit 12, (12h/week)
Physical Chemistry Project-I (C758), Credit 12, (12h/week)
Physical Chemistry Project-I (C759), Credit 12, (12h/week)

DETAILED SYLLABUS

Compulsory Courses

C606: Physical methods in Chemistry I

General introduction to spectroscopy: Electromagnetic radiation and its interaction with atoms and molecules. Holistic view of spectroscopy. [2]

Ultraviolet Spectroscopy: Electronic Transition; definitions of related terms and designation of UV-absorption band.

Studies of conjugated and extended conjugated systems. WoodwardFieser rules. Analytical use of UV-spectroscopy. [8]

Infrared and Raman Spectroscopy: Molecular Vibrations, instrumentation of iR and Raman spectroscopic techniques. Interpretation of infrared and Raman spectra, Identification of functional groups, hydrogen bonding, Complexity of IR spectra, Utility of iR spectroscopy in structural elucidation. Raman spectroscopy in material science; SERS. [8]

Fluorescence spectroscopy: Phenomena of fluorescence. Photochemical laws, general characteristics, Quantum yield and its measurements. Radiationless transitions. Spin states and their interconversion. Kashas rule and solvent effect. Spin orbit coupling. Energy transfer processes. Donoracceptor complexes, excimers, exiplexes.

Fluorescence quenching (static and dynamic). SternVolmer analysis, Timescale of molecular processes in solution.

Steadystate and timeresolved fluorescence.

Fluorescence anisotropy. Biochemical fluorophores. New fluorescence technologies: Multiphoton Excitation, Fluorescence

correlation Spectroscopy, Single molecule detection. [12]

Photoelectron spectroscopy: Experimental methods, ionisation processesses and Koopmans theorem. Photoelectron spectra and their interpretation. Applications. [5]

Mass Spectrometry: Basic concepts. Instrumentation, Fragmentation and rearrangements (including McLafferty rearrangement) of different classes of organic molecules. Isotope effects. [5]

Recommended Books:

1. Modern Spectroscopy J. M. Hollas.Wiley, 2004.

2. Physical Methods in Chemistry, R. S. Drago, 2nd Ed., Saunders, 1992.

3. Essentials of Photochemistry, A. Gilbert and J. Baggot, Blackwell Scientific Publications, 1992.

4. Fundamentals of photochemistry, K. K. RohatgiMukherjee, Wiley Eastern Ltd., 1978.

5. Molecular Fluorescence, Bernard Valeur, WileyVCH, 2002.

6. principles of Molecular photochemistry: an introduction, p. Walsh, n. J. Turro, V. Ramamurthy, J. C. Scaiano, University Science Books, 2008.

7. Principles of Fluorescence Spectroscopy. Joseph R. Lakowicz, 3rd Edition, Springer, 2006.

8. Interpretation of Mass Spectra, F. W. McLafferty, 1980.

9. Spectrometric Identification of Organic Compounds, R. M. Silverstein, G. C. Bassler and T. C.Morrill, John Wiley, New York, 5th Ed., 1991.

C601: Physical methods in Chemistry II

Nuclear magnetic Resonance Spectroscoy: Basic principles, Chemical shifts, Spin-spin interactions. Application of 1H and 13C nMR spectroscopy including nOE, COSY, nOESY, and other 2D techniques in the structure determination of bioorganic compounds. Application in conformational analysis. Multinuclear (31p, 19F, 29Si) nMR of various inorganic and organo-metallic compounds. Instrumental aspects. nMR of paramagnetic sample: Contact shifts and pseudo contact shifts, shift reagents. Pulsed nMR: modern multiple-pulsed experiments including 2D nMR. [20]

Electron Spin Resonance Spectroscopy (eSR): a brief review of theory. analysis of ESR spectra of systems in liquid phase, radicals containing single set, multiple sets of protons, triplet ground states: Transition metal ions; Fe, Cu, Mo, Cr, Mn, VO2+ containing systems: g values, symmetry. The practical interpretation of ESR spectra, in solid state and solution states. Multiple electron systems; Triplet ground state, Zerofield splitting, Kramers degeneracy, Spectral line-shapes when D « hν, D ~ hν and D » hν. EPR of photoexcited triplet states. [7]

Doubleresonance Techniques (eNDOR): EnDOR in liquid solution, EnDOR in powders and nonoriented solids. EnDOR spectra of free-radicals coupled to multiple sets of nuclei with spin. EnDOR of paramagnetic metals and complexes. Biological Applications: Substrate free radical, Flavins and metal free flavin proteins, Photosynthesis, Heme proteins, Iron- Sulfur proteins, Spin labels. [7]

mossbauer Spectroscopy: Basic physical concepts, spectral line shape, isomer shift, quadrupole splitting, magnetic hyperfine interaction. Interpretation of Moss- bauer parameters of 57Fe, 99Ru, 101Ru, 195Pt, 193Ir and 110Sn. Some special applications: Solid state reactions, thermal decomposition, ligand exchange, electron transfer, isomerism, surface studies and biological applications. [7]

Recommended Books:

1. nMR Spectroscopy: Basic principles, Concepts and applications in Chemistry, H. gunther, 2nd Ed., John Wiley & Sons, 1995.
2. Spectrometric Identification of Organic Compounds, R. M. Silverstein, G. C. Bassler and T. C. Morrill, John Wiley, New

York, 5th Ed., 1991.

3. Basic 1 H and 13 C nMR Spectroscopy, M. Balci, Elsevier Science, 2005.
4. Electron paramagnetic Resonance: Elementary Theory and practical applications, J. a. Weil, J. R. Bolton and J. E. Wertz, Wiley interscience, new York, 1994.
5. Physical Methods in Chemistry, R. S. Drago, 2nd Ed., Saunders, 1992.
6. Mossbauer Spectroscopy: an introduction for inorganic Chemists and geochemists, Mcgraw Hill, UK, 1973.
7. Mossbauer Spectroscopy, n. n. greenwood and T. C. gibb, Chapman & Hall, 1971.
8. Electron Spin Resonance : Elementary Theory and practical applications, J. E. Wertz and J. R. Bolton, Mcgraw Hill, 1984.

C604: Coordination Chemistry

1. **Theories of bonding:** CFT (including Jahn-Teller). Effects of ligand field (spectrochemical series, enthalpies of hydration, spinel structures. Shortcomings of CFT. MO theory of coordination complexes. Electronic Spectra of complexes including Orgel diagrams and Tanabe Sugano diagrams. [10]
2. **Magnetism:** introduction to Magnetism. Origin of diamagnetism. paramagnetism: Van Vleck formula and its approximated forms, Curie law. Magnetic susceptibility, orbital quenching and spin-only moment. Magnetic exchange interactions in coordination compounds: ferrimagnetism and antiferromagnetism. Bulk magnetic properties and ferromagnetism. Molecule-based magnetic materials: organic magnets and single molecule magnets. [10]
3. **Mechanisms of reactions of transition metal complexes:** Substitution (Kinetic effects: labile vs inert) and electron- transfer reactions (Outer-sphere, Self-exchange; inner-sphere). [7]
4. **Bioinorganic Chemistry:** Basic principles (why specific metal ions are present in certain proteins/enzymes): Heme proteins, types, structure and function (including

mechanism of function): Hemoglobin, myoglobin, Cytochrome C, Cytochrome p450, Catalases, peroxidases. non-Heme proteins: Hemeerythrin, Ribonucleotide reductase, Methanol monooxygenase (a) iron-Sulfur proteins: Ruberodoxin, Ferredoxin; (b) Dna / Rna : Ribozymes. [10]

5. **Transition metal based supramolecular structures:** Ligand design and applications. [5]

Recommended Books:

1. Advanced inorganic Chemistry, F. a. Cotton, C. a. Murillo, and M. Bochmann, Wiley interscience, 2001.
2. Inorganic Chemistry, D. F. Shriver and p. W. atkins, Oxford University press, 1999.
3. Supramolecular Chemistry: Concepts and perspectives, J. M. Lehn, VCH, 1995.
4. Principles of Bioinorganic Chemistry, S. J. Lippard and J. M. Berg, panima publications, new Delhi, 1997.
5. Bioinorganic Chemistry; inorganic Elements in the Chemistry of Life. Kaim, B. Schwederski Wiley, 1994
6. Biological inorganic Chemistry: Structure and Reactivity Harry B. gray, Edward i. Stiefel, Joan Selverstone Valentine, ivano Bertini University Science Book; 2006
7. Reaction Mechanism of inorganic and Organometallic Systems, R B Jordan, 2nd Edn., Oxford University press, 1991.

References:

1. Bioinorganic Chemistry, asim K. Das, allied Books, Kolkata, 2004.
2. Molecular Symmetry and group Theory: a programmed introduction to Chemical applications, a. Vincent, John Wiley, 2001.
3. Mechanism of inorganic Reactions, F. Basolo and R. g. pearson, 2nd Edn. Wiley, 1967
4. Inorganic Reaction Mechanisms, M L Tobe and J Burgess, 1st Edn., Wesley Longmans Ltd. 1999.
5. inorganic Chemistry- principles of Structure and Reactivity, J.E. Huheey, E. a. Keiter, R.L. Keiter and O. K. Medhi, pearson Education, 2007.

C605: Chemical Binding

Introduction: Review of basic principles of quantum mechanics, atomic structure, variation and perturbation methods.[3]

Electronic structure of diatomic molecules: Born-Oppenheimer approximation, H+ ion, molecular orbitals of ground state and excited states of H+ (LCAO- 22 MO), homo and heteronuclear diatomic molecules, electronic term symbols, valence bond theory of diatomic molecules, comparison of valence bond and molecular orbital theories. Term Symbols for diatomic molecules. [12]

Self-consistent Field methods: Hartree-Fock theory of atoms and molecules, post-Hartree-Fock theories, configuration interaction wave functions.[8]

Electronic structure of polyatomic molecules: SCF-MO treatment of closed shell systems and applications to molecules (H_2O, NH_3, CH_4) ; potential energy surface and equilibrium geometry, molecular vibrational frequencies. Brief introduction to density functional theory. [9]

Virial theorem and chemical bonding. The Hellman-Feynman theorem. [4]

Semi-empirical and molecular mechanics treatment of molecules, Huckel molecular orbital theory for conjugated organic molecules and its applications to ethylene, butadiene, benzene; delocalization energy and stability. [6]

Recommended Books:

1. Modern Quantum Chemistry: introduction to advanced Electronic Structure, a. Szabo and n. S. Ostlund, Dover, 1996.
2. Molecular Quantum Mechanics, p.W. atkins and R.S. Friedman, OxfordUniversity press, 3rd Edn., 1997.
3. Quantum Chemistry, i. n. Levine, 5th Edn., pearson Education, 2000.

C665: Advanced Organic Chemistry

Review of Basic Bonding Concepts; Conformational analysis; Stereochemistry; Kinetics and Thermodynamics of Organic Reactions; Reaction Mechanisms and Con- formational Effects on Reactivity; Oxidation Reactions; Reductions Reactions; Enolate Chemistry; Metalation Reactions; Key Ring Forming Reactions; Olefin Synthesis; Conjugate Additions; Synthetic analysis and Design; Total Synthesis of natural products; asymmetric Synthesis; Combinatorial Chemistry.

Recommended Books:

1. E. V. anslyn, D. a. Dougherty “Modern physical Organic Chemistry” California University Science Books, 2006.

2. E. L. Eliel, S. H. Wilen "Stereochemistry of Organic Compounds" Wiley-interscience, 1994.

3. R. Bruckner "Organic Mechanisms: Reactions, Stereochemistry and Synthesis" Springer, 2010.

4. F. a. Carey, R. J. Sundberg "advanced Organic Chemistry parts a & B: Structure and Mechanisms" 5th Edition, Spring- er, 2007.

5. M. B. Smith, J. March "Marchs advanced Organic Chemistry" 6th Edition, Wiley-VCH, 2007.

6. E. J. Corey, X.-M. Cheng "The Logic of Chemical Synthesis" Wiley-interscience, 1995.

7. T. Hudlicky, J. W. Reed "The Way of Synthesis: Evolution of Design and Methods for natural products" Wiley-VCH, 2007.

8. p. Wyatt, S. Warren "Organic Synthesis: Strategy and Control" Wiley, 2007.

9. M. Christmann, S, Br¨ase Eds "asymmetric Synthesis- The Essentials" 2nd Edition, Wiley-VCH, 2008.

10.10. K. C. nicolaou, R. Hanko, W. Hartwig Eds. "Handbook of Combinatorial Chemistry", VCH-Wiley, Weinheim 2002.

Elective Courses

C602: Chemical Rate Processes

1. Kinetic Measurements: General features of fast reactions; study of fast reactions by flow techniques, relaxation methods (T-Jump, P-Jump, ultrasonic, pulse radiolysis, NMR); flash photolysis; salt and solvent effects on reactions in solutions. [5]

2. Chain Reactions: Features of chain reactions; thermal and photochemical reactions (hydrogen-bromine reaction, decomposition of aldehydes and ketones). [5]

3. Kinetics of oscillatory reactions: introduction to oscillatory reactions; Belousov-Zhabotinsky and Field-Koros-noyes models. [4]

4. Rate Theory: Concept of potential energy surfaces, transition state theory including its statistical mechanical treatment, phenomenological theories of unimolecular reactions (Lindemann, Hinshelwood), statistical mechanical theories of unimolecular reactions (RRKM). [10]

5. Chemical Dynamics: Collision theory and Reaction Dynamics, Reaction Cross section and rate constant, Brief idea of Molecular Beam Scattering, Dynamics in condensed phase. [10]

6. Femtochemistry : Concepts and perspectives; applications to studies of dynamics and control of chemical reactions.[6]

Recommended Books:

1. Physical Chemistry, i. Levine, Tata Mcgraw Hill, 5th Edn., 2007.
2. Physical Chemistry : a Molecular approach, D. a. McQuarrie and J. D. Simon, University Science Books, 1997.
3. Chemical Kinetics and Dynamics, J. i. Steinfeld, J. S. Francisco and W. L. Hase, prentice Hall, 1999.
4. Chemical Dynamics in Condensed phases: Relaxation, Transfer and Reactions in Condensed Molecular Systems, a. nitzan, Oxford Univ. press, 2006.

References:

1. Basic Chemical Kinetics, H. Eyring, S. H. Lin and S. M. Lin, John Wiley & Sons, new York, 1980.
2. The World of physical Chemistry, K. J. Laidler, Oxford University press, 1993.

C603: Chemistry of Heterocycles and Natural products

1. **Chemistry of Heterocycles:** introduction and application of Heterocycles; nomenclature of aromatic and non-aromatic Heterocycles; Synthesis and Reactivity of 5&6-membered aromatic Heterocycles with One or Two Hetero atoms. [12]
2. **Chemistry of Natural Products:** introduction and application of Carbohydrates; Steroids, Terpenoids, Fatty Lipids, prostaglandins and alkaloid; Biogenesis and Total Synthesis of Selected natural products. [20]
3. **Chemistry of Biomolecules:** Classification and Structures of Amino Acids; Pipe- tides, Proteins and Nucleic Acids; Solid phase Synthesis; nucleic acids Synthesizer. [10]

Recommended Books:

1. J. a. Joule, K. Mills “Heterocyclic Chemistry” 5th Edition, Blackwell, 2010.
2. T. Eicher, S. Hauptmann “The Chemistry of Heterocycles” 2nd Edition, Wiley-VCH, 2003.
3. R. J. Simmonds, “Chemistry of Biomolecules: an introduction” RSC, 1992.
4. i. L. Finar, “Organic Chemistry” Vol. ii, ELBS, 1990.
5. S. V. Bhat, B. a. nagasampagi, M. Sivakumar “Chemistry of natural products” Springer, 2005.

6. E. J. Corey, X.-M. Cheng "The Logic of Chemical Synthesis" Wiley-interscience, 1995.

7. T. Hudlicky, J. W. Reed "The Way of Synthesis: Evolution of Design and Methods for natural products" Wiley-VCH, 2007.

C651: molecular modeling

Introduction: What is molecular modeling? Computable quantities. [1]

Concept of Potential energy Surface: Stationary points, Born-Oppenheimer approximation, geometry optimization, normal modes of vibration. [3]

Molecular mechanics: Basic principles, properties that can be calculated, Strengths and weaknesses. [3]

Quantum mechanics: Hartree-Fock-Self-Consistent-Field theory, post-Hartree- Fock (Electron correlation) methods, Density functional theory, Semi-empirical methods. [7]

Chemical Dynamics: Unimolecular and Bimolecular reactions, Reaction path and transition states, Classical trajectories, direct dynamics, Quantum dynamics. [6]

Simulations of molecular ensembles: properties as ensemble and time averages, Molecular dynamics simulations, Monte Carlo simulations. [10]

Modeling Lab: Hands-on experience for using different simulations methods and algorithms pertaining to the course.[10]

Recommended Books:

1. C. J. Cramer, Essentials of Computational Chemistry, Wiley, 2004.
2. i. n. Levine, Quantum Chemistry, prentice-Hall of india, 2006.
3. p. W. atkins, Molecular Quantum Mechanics, Oxford, 2008.
4. M. p. allen and D. J. Tildesley, Computer Simulation of Liquids, Oxford, 1987.
5. a. R. Leach, Molecular Modelling, prentice Hall, 2001.
6. F. Jensen, introduction to Computational Chemistry, John Wiley & Sons, 2007.

C653: Classics in molecules

1. introduction, Understanding Structural Diagrams of Organic Molecules, protein and Three-Dimensional protein Structure, nucleic acids, Synthesis, Biosynthesis. [7]

2. Urea & acetic acid, glucose, aspirin, Camphor, Terpineol, Tropinone, Haemin, Quinine, Morphine, Steroids & the pill, Strychnine, penicillin, Longifolene, prostaglandins & Leukotrienes, Vitamin B12, Erythronolide B & Erythromycin a, Monensin, Avermectin, Amphotericin B, Ginkgolide B, Cyclosporin, FK506 & Rapamycin, Calicheamicin $\gamma 1$,

Palytoxin, Taxol, Mevacor, Zaragozic acids & Cp Molecules, Brevetoxin B, Ecteinascidin 743, Epothilones, Resiniferatoxin, Vancomycin, Thiostrepton. [20]

3. Modern Drug Discovery and Developments, Designed Small Drug Molecules for Mental illness, Viral infections, gastrointestinal Disorders, Heart diseases and Sexual Dysfunction. [12]

4. Dna Technologies, Vaccines, antibodies, Diabetes, anemia, Rheumatoid arthritis, Breast Cancer, Biologics. [7]

Recommended Books:

1. K.C. nicolaou and Tamsyn Montagnon, “Molecules that Changed the World”, VCH, 2008.

2. E.J. Corey, L´aszl´o Ku¨rti and Barbara Czak´o, “Molecules and Medicine”, VCH, 2008.

3. J. Block and J. M. Beale “Wilson and gisvold’s Textbook of Organic Medicinal and pharmaceutical Chemistry”, 11th Ed., Lippincott Williams & Wilkins, 2003.

C652: Solid State Chemistry

Crystal Chemistry: a brief introduction to crystallography, Lattices, unit cells, symmetry, point groups, space groups. Packing: CCp, HCp, voids, radius ratio rules. Bonding in crystals: ionic, covalent, metallic, van der Waals, hydrogen bonds. Description of crystal structures: metallic & nonmetallic structures, aB, aB2, aB3 (ReO3), spinels, pyrochlores, perovskites, K2niF4 etc. paulings rules for ionic crystal structures and the concept of bond valence. Methods of crystallography: powder, single crystals, X-ray, neutron and electron diffraction. [7]

Defects in solids: Origin of defects in crystals; perfect and imperfect crystals; thermodynamics of defect formation; types of defects : point defects, line defects, plane defects;Schottky and Frenkel defects; thermodynamics of Schottky and Frenkel defect formation; crystal classifications; Madelung constant and lattice energy.[7]

Electronic structure of solids: atoms to molecules to crystals; orbitals to bonds to bands; Electronic structure of crystalline solids, elementary band theory: metals, insulators and semi-conductors., Solid state ionics; intrinsic and extrinsic semiconductors. Transport property measurement techniques: electrical resistivity, thermopower, Hall effect Magnetism of d vs. f metal compounds.[8]

Critical Phenomena: phase transitions (Order-disorder, Martensite-austenite, Spinoidal decompositions); liquid crystals; structure-property relations (magnetic, electrical, superconductivity, optical and thermal). Powder synthesis by conventional and modern chemical methods, reactivity of solids, decomposition mechanisms, powder processing (sintering and diffusion processes), tailoring of solids, special methods for single crystal growth and thin film depositions. [10]

Synthesis of solids: Chemistry behind synthesis; intercalations; synthesis/preparation of single crystals; hydrothermal methods. Framework Solids; Zeolites, aluminophosphates and related structures; Metal-organic framework compounds - their structures and properties.[6]

Superconductivity: Superconductivity: General aspects of superconductivity; effects of magnetic field; BCS Theory; oxide Superconductors. [4]

Recommended Books:

1. Solid State Chemistry and its applications, a. R. West, John Wiley, 1987.
2. Solid State Chemistry, L. Smart and E. Moore, Chapman and Hall, 1992.
3. Principles of the Solid State, H. V. Keer, Wiley Eastern Ltd., 1994.
4. New directions in solid state chemistry, C.n.R. Rao and J. gopalakrishnan, Cambridge University press, 2008.
5. The Electronic Structure and Chemistry of Solids, p. a. Cox, Oxford University press, 2005.
6. Ionic crystal, lattice defect and non-stoichiometry, n.n. greenwood, Chemical pub. Co., New York, 1970.
7. An introduction to crystal chemistry, R.C. Evans, Cambridge University press, 1964.

C654: Crystallography

1. Origin of X-rays, Filters, monochromators, sealed tube, rotating anode synchroton radiation, safety considerations. [5]
2. Crystals and their properties- Concepts of symmetry, direct and reciprocal lattice, planes, indices, unit cell, Bragg's law in direct and reciprocal lattices. Primitive and non-primitive lattices, point and space groups, equivalent positions, systematic absences and space group determination, occupancy factors. [15]
3. Theory of structure factors, argand diagram and its use, Lorentz and polarization corrections, absorption corrections, absolute scale of intensities; unit cell determination, data collection parameters, data reduction, phase problem and structure solution by patterson and direct methods. [15]
4. Structure refinement techniques, presentation and interpretation of structural data, examination of CIF file and critical evaluation of a structure. Errors and pitfalls, twinning and disorder, Renninger effect, extinctions, anomalous scattering and its use. [10]

Recommended Books:

1. X-ray structure determination: a practical guide, g.H. Stout and L.H. Jensen, Springer, 1992.

2. Fundamentals of crystallography, C giacavazzo, Oxford University press

3. X-ray analysis and the structure of organic molecules, Jack. D. Dunitz, Wiley, 1996.

4. Crystal Structure Determination, Werner Massa, Springer.

5. Structural inorganic Chemistry, a. F. Wells, Clarendon press, 1986.

C655: Principles of Drug action

Pharmacodynamic Phase in Drug action: introduction to pharmacodynamics, Biochemical Basis of Drug action, Drug absorption, distribution and bioavailability, passive diffusion, active transport mechanisms, Excretion and reabsorption of drugs. [7]

Pharmacokinetic Phase in Drug action: General classification of pharmacokinetic properties, Pharmacokinetic models, intravascular administration, Extravascular administration, Estimation of pharmacokinetic parameters, The use of pharmacokinetics in drug design. [7]

Novel Therapeutic agents: Synaptic Pharmacology: Cholinergic- and adrenergic systems, CnS agents: antipsychotics, antidepressants, CVS Agents: Antihypertensives, Antineoplastic agents, Analgesic and anti-inflammatory agents, Drug toxicity. [12]

Concepts in Drug metabolism: Basic principles and factors affecting drug metabolism, Secondary pharmacological implications of metabolism, phase i metabolic reactions, phase ii metabolic reactions, Drug metabolism and drug design, prodrugs, Metabolic pathways for common drugs. [7]

Stability of Drugs and medicines: Oxidation and stability of free-radicals, prevention of oxidative deterioration, autoxidation of fats and oils, Examples of drugs susceptible to ageing and hydrolysis, Other mechanisms of degradation.

[6]

Drug Development: Clinical trials (phase-i to phase-iV), Formulation development, Quality control aspects (methods of assay). [6]

Recommended Books:

1. Thomas g. (2003) Fundamentals of Medicinal Chemistry, Wiley.

2. Cairns D. (2008) Essentials of pharmaceutical Chemistry (3rd Ed.), pharmaceutical press.

3. Block J and Beale JM. (2003) Wilson and gisvold's Textbook of Organic Medicinal and pharmaceutical Chemistry (11th Ed.), Lippincott Williams & Wilkins.

4. Rang Hp, Dale MM et al. (2007) Rang & Dale's pharmacology (6th Ed.), Churchill Livingstone.

5. Hardman Jg, Limbird LE et al. (2001) goodman & gilman's The pharmacological Basis of Therapeutics, Mcgraw-Hill professional.

C656: advanced Bio-inorganic Chemistry

Principles of bioinorganic chemistry (Justification of why certain protein/enzyme contains a particular metal ion) [3]

Heme Proteins: Types, function and mechanisms, Myoglobin, Hemoglobin, Cytochrome c, Cytochrome p450, peroxidases (Horseradish peroxidase, Chloroperoxidase), Catalase, Cytochrome c Oxidase, Synthetic porphyrins of biological relevance. [5]

Iron-Sulfur Proteins: Types, function and mechanisms, Rubredoxin, Ferredoxins, aconitase [3]

Non-Heme Proteins: Types, function and mechanisms, Mononuclear Systems (Catechol-1,2-Dioxygenases, Transferrin, Ferretin, Superoxide Dismutase, isopenicillinn- Synthase) Dinuclear Systems (Hemerythrin, Ribonucleotide Reductase, Methane Monooxygenase, purple acid phosphatases) [6]

Copper Proteins (Type i, ii, and iii): Types, function and mechanisms, Blue Copper proteins; Hemocyanin, Tyrosinase, Catechol Oxidase; Superoxide Dismutase; ascorbase Oxidase, Laccase; galactose oxidase [5]

Molybdenum enzymes: Types, function and mechanisms, Oxo-Transfer Enzymes; Xanthine Oxidase; nitrogenase.

[5]

Manganese: photosynthesis (photosystem i and photosystem ii); function and mechanisms. [4]

Zinc enzymes: function and mechanisms, Hydrolytic Enzymes (Carbonic anhydrase; Carboxy peptidase a; alkaline phosphatase). [5]

DNa/RNa: Types, function and mechanisms, Dna nicking enzymes; Dna polymerase; Ribozymes. [5]

Environmental & medicinal aspects: acid-rain; green-house Effect etc. Radiopharmaceuticals; photo-Dynamic Therapy; anti-Tumor Drugs (cis-platin, Carboplatins; Bleomycins); ion-pumps. [5]

Recommended Books:

1. principles of Bioinorganic Chemistry; S. J. Lippard and J. M. Berg, panima publications, new Delhi, 1997.

2. Bioinorganic Chemistry ; inorganic Elements in the Chemistry of Life; W. Kaim, B. Schwederski Wiley, 1994

3. Biological inorganic Chemistry: Structure and Reactivity; Harry B. gray, Edward i. Stiefel, Joan Selverstone Valentine, ivano Bertini, University Science Book; 2006

4. Specific Review Articles to be collected from Internet.

C657: Nuclear magnetic Resonance

Classical NmR Spectroscopy: nuclear magnetism, Bloch equations, chemical shift, linewidth, scalar coupling [4]

Theoretical description of NmR spectroscopy: Expectation value of magnetic moment, density matrix, pulses and rotation operator, chemical shift and coupling Hamiltonians, concept of coherence, one pulse experiment. [5]

Product Operator Formalism: Operator spaces, basis operators, free precision, pulses, single and multiple quantum coherences, application of pOF to study spin echo and standard polarization transfer protocols like inEpT. [6]

Practical aspects of NmR spectroscopy: Tuning, matching, shimming, temperature calibration, spectrum referencing, sampling theorem, quadrature detection, Fourier transformation, zero filling, apodization, phasing, signal to noise ratio, spin decoupling, pulse field gradients, water suppression, one dimensional experiments. [14]

Two dimensional NmR experiments: Two dimensional spectroscopy, coherence transfer, COSY, double quantum filtered

COSY, TOCSY, nOESY, HSQC, HMQC, sensitivity enhanced HSQC. [10]

Higher dimensional NmR experiments: need for higher dimensional experiments, HnCa, Hn(CO)Ca, introduction to the new trend of fast multidimensional experiments: gFT, spatially spatial encoding. [3]

Recommended Books:

1. protein nMR Spectroscopy, 2nd Ed, John Cavanagh, W. J. Fairbrother, a. g. palmer iii, M. Rance and n. J. Skelton, Elsevier academic press, 2007

2. Spin dynamics 2nd Ed., Malcolm H. Levitt, John Wiley and sons Ltd., 2008

C658: Advanced Functional Materials

Introduction to materials in modern Technology: Materials as an enabling element of technological progress. Functions that materials perform. The properties - structure - processing connection. [2]

Semiconductor materials: intrinsic semiconductors, Band Structure of Semi- conductors, impurity Semiconductors, ii-V and ii-Vi compounds, Hall Effect, SC devices. Charge carrier dynamics in semiconductor nanomaterials. [10]

Dielectric materials: Dielectric constant and polarizibility, insulating materials, Ferroelectrics, piezoelectrics, Measurement of Dielectric properties, applications. [6]

Nanosized magnetic materials: Basic concepts of magnetism. Types of magnetic behavior, Magnetic domains, soft and hard magnets, Classification Magnetic Nanomaterials, Ferrofluids, Single-domain particles, Physical Properties of Magnetic nanostructures, nanomagnetism for Biological applications. [6]

Polymer materials and nano-composites: Classification of Polymers, Structure- Property Correlation, Molecular weights, Conduction in polymers, natural composities, incorporation of nanomaterials into polymer Media, Organic polymer nanocomposites, Metal and Ceramic composites, Clay nanocomposite Materials, polymer- Clay nanocomposites, polymer/ graphite nanocomposites, polymer Composites with Carbonnanotubes. [10]

amorphous and Porous materials: Crystalline vs. amorphous Solids, glass Formation, Structural Models of amosphous Materials, properties of Metglasses, Evolution and Development of porous Materials, Chemistry of Microporous Materials, Mesoporous Materials, Semiconductor nanoparticles in Zeolites, polymers and Carbon Materials in Zeolites. [10]

Recommended Books:

1. Fundamental of nanotechnology, gabor L. Hornyak, John J. Moore, Harry F. Tibbals, Joydeep Dutta, CRC press, Taylor & Francis group, 2009

2. Optical Properties and Spectroscopy of Nanomaterials, Jin Zhng Zhang, World Scientific Publishing Co. Pte. Ltd, 2008.

3. Science of Engineering Materials and Carbon nanotubes, C. M. Srivastava, C. Srinivasan, new age international pub- lishers.

4. Optimization of polymer nanocomposite properties, Edited by Vikas Mittal, WiLEY-VCH Verlag gmbH & Co. Kgaa, Weinheim, 2009.

5. Chemistry of Zeolites and Related porous Materials: Synthesis and Structure RUREn XU, WEn- Qin pang, JiHOng YU, QiSHEng HUO, JiESHEng CHEn, John Wiley & Sons (asia) pte Ltd, 2007.

6. polymer nanocomposites Handbook Rakesh K. gupta Elliot Kennel Kwang-Jea Kim, CRC press, Taylor & Francis group, 2008.

C659: Supramolecular Chemistry

Introduction: Understanding of Supramolecular Chemistry (Multidisciplinary nature, Complementarities in biology); Selectivity; Supramolecular interactions; Chelate and Macrocyclic Effects; Characterizing Supramolecular Systems; Structural, Kinetic and Thermodynamic. [6]

molecular Self-assembly: Non-Covalent Interactions: Electrostatic, Hydrogen Bonding, π –π Stacking, Dispersion and Induction Forces, Hydrophobic or Solvophobic Effects, π-Electron Donor-Acceptor Systems, Catenanes and Rotaxanes, Tran-sition Metal Directed assemblies; Molecular Macrocycles and Boxes: Locked and Unlocked Molecular Boxes, Ladders and grids, Cages; Hydrogen Bond Directed assemblies: Rosettes and Ribbons, peptide nanotubes; Self- Replicating Molecular Systems. [12]

Synthesis of macrocycles: High Dilution Technique; Coordination Template Effects; Cation Binding and De-Metallation; porphyrins; Corrins; Crown Ethers; Cryptands; Spherands; Sepulchrates; Siderophores; Calixarenes. [4]

molecular Sensors of ions and molecules: anions, Cations and neutral Molecules Receptor Design principles: Recognition by Electrostatic and Hydrogen Bonding, Lewis acidic Hosts interactions etc.; introduction to Fluorescence probing Techniques and applications: Fluorescent Molecular Sensors of ions and Molecules, Logic gate etc.; Expanded porphyrins, amide Functionalized Metallo Compounds, Cyclophanes, Electrostatics and Hydrophobicity, Hydrogen Bond Receptors, Chiral Recognition; Hydrophobic Effect: Recognition in Water; Solvent Effect; Cyclodextrins; Calixarenes; Metallo Receptor For nucleic acid Bases; Boronic acid Receptors for Sugars. [20]

Recommended Books:

1. D. J. Cram and J. M. Cram, Container Molecules and their guest, Monographs in Supramolecular Chemistry, Ed. J. F. Stoddart, The Royal Society of Chemistry, Cambridge, 1994.
2. J. M. Lehn, Supramolecular Chemistry: Concepts and perspectives, VCH, Weinheim, 1995.
3. Comprehensive Supramolecular Chemistry, Ed. J. L. atwood, J. E. D. Davies, D. D. Macnicol, F. Vogtle, Volumes 2 and 3, Elsevier Science, Oxford, 1996.
4. Supramolecular Chemistry of anions, Ed. a. Bianchi, K. Bowman-James, E. garcia-Espana, John Wiley and Sons, new York, 1997.
5. Supramolecular Chemistry, p. D. Beer, p. a. gale and D. K. Smith, Oxford University press, 1999.

6. a practical guide to Supramolecular Chemistry, peter J. Cragg, John Wiley & Sons Ltd, England, 2005.

C660: Chemistry of Nanomaterials

Introduction: nano and nature, Fascination and Motivation of nanoparticle Research, Bottom-up and Top-down approaches [3]

Zero and One-Dimensional Nano structures: introduction, aqueous and non- aqueous Sol-gel Chemistry, Surfactant- assisted Synthesis, Solvent-Controlled nanoparticles, assembly: introduction, Oriented attachment and Mesocrystals, Superlattices, Core-Shell nanoparticles: introduction, Types of Systems, Characterization, properties. [10]

Carbon Nanomaterials: Fullerenes and their Derivatives, Carbon nanotubes: Structure and properties, nanocrystalline Diamond [8]

Self-assembled Monolayers: introduction, Monolayers on gold, growth process, phase transitions, patterning monolyers, Mixed Monolayers Structure, Electrochemistry and applications of Self-assembled Monolayers of Thiols [4]

nano and Micro-elumsion: Surface active agents, Micellization, Mechanism of emulsion, Characterization of Microemulsion [8]

Application of nanomaterials: Solar Energy Conversion, Molecular and nano- electronics, nanocatalyis, Biological applications and other applications. [12]

Recommended Books:

1. Nanoparticles: Synthesis, Stabilization, passivation, and Functionalization, Edited by R. nagarajan, T. alan Hatton, aCS SYMpOSiUM SERiES 996.

2. Metal Oxide nanoparticles in Organic Solvents, Markus niederberger and nicola pinna, Markus niederberger and nicola pinna, Springer-Verlag London Limited 2009 .

3. Fundamental of nanotechnology, gabor L. Hornyak, John J. Moore, Harry F. Tibbals, Joydeep Dutta, CRC press, Taylor & Francis group, 2009.

4. Carbon nanomaterials, advanced Materials Series, Edited by Yury gogotsi, Taylor and Francis group, LLC, 2006.

5. Carbon Nanotubes and Related Structures, Edited by Dirk M. Guldi and Nazario Mart´ın, WILEY- VCH Verlag GmbH

& Co. Kgaa, Weinheim, 2010.

6. nano: The essential, Understanding nanoscinece and nanotechnology, T. pradeep, Tata Mcgraw- Hill publishing Company Limited.

7. Applied Surfactants, Thrwat F. Tadros, WiLEY-VCH Verlag gmbH & Co. Kgaa, Weinheim, 2006.

C661: Advanced Bio-organic Chemistry

Enzymology: Mechanistic studies of enzymatic reactions. Studies of enzyme kinetic for substrate/inhibitors (reversible/ irreversible) and their future aspects in drug design. The role of cofactors and hormones in enzymatic reactions. Enzymes as Catalysts in organic chemistry reaction (group Transfer Reactions, Reduction and Oxidation; Monooxygenation; Dioxygenation Substitutions, addition/Elimination; Carboxylations; Decarboxylation; isomerizations; aldol and Claisen Reactions; and Retroreactions; Formylations, Hydroxymethylations, and Methylations; Rearrangements. [12]

Application of enzyme Kinetics: Substrate Kinetics; Kinetics of Enzyme inhibition; Substrate inhibition; nonproductive Binding; Competing Substrates; Multi- substrate Systems; allosterism and Cooperativity. [5]

Biosynthesis of secondary metabolites: polyketide Biosynthesis; Saccharide Biosynthesis; Shikimate pathway (pDF); Shikimate pathway Flavonoids; alkaloid Biosynthesis; alkaloid Bioynthesis: Tyrosine Derivatives; Terpene Biosynthesis with example-Taxol, vancomycine, penicillin and other recent discovered natural products. Design and synthesis of modified secondary metabolites analogues. Isotope labeling (radioactive/non-radioactive) and their application in biosynthetic pathways. [12]

Non-natural bio-active molecules: Synthesis and importance of these amino acids (β, γ&δ), non-ribosomal peptides and nucleotides (pna, Lna, Tna & other stable analogues). [5]

Introduction of vital bio-macromolecule secondary structures: g-Quadruplex, i-motif, Rnai (mi-Rna & si-Rna) & Collagen and their application in therapeutics. [5]

Recommended Books:

1. Organic Chemistry of Enzyme-Catalyzed Reactions, Revised Edition by Richard Silverman published: FEB-2002. iSBn 10: 0-12-643731-9. aCaDEMiC pRESS

2. Structure and Mechanism in protein Science: aguide to Enzyme Catalysis and protein Folding by alan Fersht, publisher:

W. H. Freeman; 1st edition (September 15, 1998)

3. Evaluation of Enzyme inhibitors in Drug Discovery: a guide for Medicinal Chemists and pharmacologists (Methods of Biochemical analysis); by Robert a. Copeland, publisher: Wiley-interscience; 1 edition (March 28, 2005).

4. Dewick, paul M. Medicinal natural products: a Biosynthetic approach. 2nd ed. new York, nY: John Wiley & Sons, inc., 2001. iSBn: 9780471496410 (paperback);

5. Structural Diversity of g-Quadruplex Scaffolds; Stephen neidle and Shankar Balasubramanian, CRC press Copyright Year-2006.

6. Gene Silencing by Rna interference: Technology and application, by Muhammad Sohail (Editor), CRC press; 1 edition (July 26, 2004).

7. Modified Nucleosides: in Biochemistry, Biotechnology and Medicine (ed P. Herdewijn), Wiley-VCH Verlag GmbH &

Co. Kgaa, Weinheim, germany.

8. Natural products: The Secondary Metabolites , James R. Hanson Copyright Year:2003. iSBn: 978-1-84755-153-5

C662: Polymer Chemistry

Classification of polymers, Nomenclature of polymers, Synthesis of polymers using different methods, viz chain polymerization, step polymerization, ring-opening polymerization etc. polymerization techniques, viz Bulk polymerization, Solution polymerization, Suspension polymerization, Emulsion polymerization etc. [10]

Polymer characterization, Molecular weight-number average, weight average; significance of molecular weight; methods of characterizing molecular masses, gpC, Viscosity, Mass analysis, end-group analysis, Thermal properties - melting point, glass transition temperature (Tg), factors influencing Tg, relation between Tg and molecular weight. Crystallinity in polymers - degree of crystallinity in polymers, structural regularity and crystallinity. [15]

Kinetics of polymerization, free-radical, cationic and anionic polymerization and polycondensation. [5]

Copolymerization, free-radical and ionic copolymerization and copolycondensation [5]

Steriochemistry of polymerization, types of stereoisomerism in polymers, properties of stereoregular polymers, different methods for the synthesis of steroregular polymers. Less traditional approaches: aTRp, RaFT, ROMp, Surface functionalization of polymers [5]

Biodegradable polymers: Synthesis and challenges [3]

Recommended Books:

1. Odian, g. principles of polymerization. 4th ed. Hoboken, nJ: Wiley-interscience, 2004.

2. allcock, H. R., Lampe, F. W. in Contemporary polymer Chemistry; prentice-Hall: Engelwood Cliffs, nJ, 1990

3. Billmeyer Jr. F. W. Textbook of polymer Science Wiley - inter Science.

C663: molecular Reaction Dynamics

Introduction: The rate constant - History and current view. What is molecular reaction dynamics? [2]

Theoretical methods i: Transition State Thoery (TST), RRKM Theory. [5]

Theoretical Methods ii: Rate and cross-section, Classical scattering theory, Quantum scattering theory (reactive and non- reactive), Connection to TST and RRKM. [10]

Experimental methods: newton's diagrams, Molecular Beams, State-resolved spectroscopic techniques, imaging techniques. [8]

Applications: photoselective chemistry - photodissociation and photoisomerization dynamics, Dynamics in real time (ps, fs and attosecond regimes), Molecular energy transfer, Control of chemical reactions, Condensed phase dynamics, Dynamics of gas-surface reations. [15]

Recommended Books:

1. R. D. Levine, Molecular Reaction Dynamics Cambridge University press, nY 2005.
2. J. I. Steinfield, J. S. Fransisco and W. L. Hase, Chemical Kinetics and Dynamics, Prentice Hall Inc., NJ, 1999.
3. Journal articles.

C664: Theory of molecular Spectroscopy

Recap: introduction and review of basic quantum mechanics, molecular symmetry. [3]

Rovibronic Hamiltonian - Coordinates and momenta: Euler angles, axis systems, rotational and vibrational angular momentum, normal and internal coordinates, the g matrix, the gF matrix. [8]

Rovibronic wave functions: Classification of rotational, vibrational, rotation- vibration, and electronic wave functions, Hund's cases. [6]

Energy levels and interaction: Rotation-vibration interactions, vibronic and rovibronic interactions, Renner-Teller and Jahn-Teller effect, Rydberg states, spin effects. [8]

Transition intensities and Optical selection rules. Electric - magnetic dipole electric quadrapole transitions, multiphoton processes and Raman effect. [7]

Advanced topics Spectroscopy at high energies, intramolecular vibrational energy redistribution (iVR), and wave-packet approach to spectroscopy. [8]

Recommended Books:

1. P. R. Bunker and p. Jensen, Molecular Symmetry and Spectroscopy, nRC Research press, Ottawa.

2. J. D. graybeal, Molecular Spectroscopy, Mcgraw-Hill.
3. P. F. Bernath, Spectra of atoms and Molecules, Oxford University press, nY, 1995.
4. E. B. Wilson, J. C. Decius and p. C. Cross, Molecular Vibrations: The Theory of infrared and Raman Vibrational Spectra,Dover, nY, 1955.

C666: Catalysis: Reaction mechanisms and applications

Introduction to catalysis; fundamental concepts. [5]

Survey of ligands; Characteristics of the transition-metal in the complexes; Elementary steps. [10]

Reaction mechanisms and applications: Carbonylation, Hydroformylation, Hydrogenation, metathesis reactions, oxidation reactions, isomerization reactions, Cross-Coupling reactions, and C-H functionalization reactions.[20]

Examples of synthetic and industrial applications. [5]

Recommended Books:

1. The Organometallic Chemistry of the Transition Metals. R. H. Crabtree, John Wiley & Sons, 2005.
2. Industrial Catalysis. J. Hagen, Wiely-VCH, 2006.
3. Homogeneous Catalysis. p. W. n. M. van Leeuwen, Kluwer academic publishers, 2004.
4. Homogeneous Catalysis. S. Bhaduri, D. Mukesh, John Wiley & Sons, 2000.
5. Metal-Catalyzed Cross-Coupling Reactions a. de Meijere, F. Diederich (Eds.), 2004.
6. Catalysts for Fine Chemical Synthesis. S. M. Roberts, g. poignant, John Wiley & Sons, 2002.
7. Catalysis of Organic Reactions, S.R. Schmidt, CRC press, 2007

C667: Advanced main Group Chemistry

(a) Direct bonds between metal atoms: Mg and Ca compounds with metal-metal bonds
(b) Multiple bonded group 13, 14 and 15 elements: Synthesis, reactivity and bonding [12]

nHC stabilized low oxidation state main group metal complexes[4]

Low oxidation state main group metal hydrides: synthesis and reactivity [4]

NHCs analogues with low valent group 13 and 14 elements: Synthesis, structure and reactivity studies; (a) Boron(i), aluminum(i), gallium(i), indium(i) and Thallium(i) heterocycles (b) Silicon(ii), germanium(ii), Tin(ii), and Lead(ii) hetero cylces [8]

Role of main group compounds in catalysis, organic synthesis and medicinal chemistry [8]

Inorganic New materials: nanomaterials, polymers and chemical sensors [6]

Recommended Books:

1. Inorganic Chemistry-principles of Structure and Reactivity. 4th Edn. Huheey J. E.; Keiter, E. a.; and Keiter, R. L. Harper-Collins, nY, 1993
2. Concepts and Models of inorganic Chemsitry. 3rd Edn. Douglas, B.; McDaniel, D.; and alexander, J. John Wiley, New York. 1993
3. Chemistry of the Elements. 2nd Edn. greenwood, n. n.; and Earnshaw, a. pergamon, Oxford, 1989
4. Organometallics: a concise introduction, C. Elschenbroich and a. Salzer, 3rd Edn. 1999
5. Inorganic and Organometallic polymers. Chandrasekhar, V. Springer-Verlag, Heidelberg, 2005
6. Journal articles

C668: Advanced Fluorescence Spectroscopy

1. **Phenomena of Fluorescence and instrumentation for Fluorescence Spectroscopy:** introduction. Jablonski Diagram, Characteristics of Fluorescence Emission, Fluorescence Lifetimes and Quantum Yields. Spectro fluorometers, Light Sources, Monochromators, Optical Filters, photomultiplier Tubes, polarizers. [5]
2. **Fluorophores:** intrinsic or natural Fluorophores; Fluorescence Enzyme Cofactors, Extrinsic Fluorophores; protein- Labeling Reagents, Membrane probes, Red and near-infrared (niR) Dyes, Dna probes, Chemical Sensing probes, Viscosity probes, green Fluorescent proteins, Long-Lifetime probes. Quantum Dots. [4]
3. **Life-Time measurements:** Time-Domain and Frequency- Domain Measurements. Time-Correlated Single-photon Counting; principle and instrumentation, alternative Methods for Time-Resolved Measurements; Streak Cameras, Upconversion Methods. Data analysis. [6]
4. **Some important Photo-processes:** Dynamics of Solvent and Spectral Relaxation: Measurement of Time-Resolved Emission Spectra (TRES), Theory for Time-Dependent

Solvent Relaxation, Fluorescence Quenching: Theory, Fractional Accessibility to Quenchers, Applications of Quenching to Proteins; Fluorescence Anisotropy: Origin of the Definitions of polarization and anisotropy, Measurement of Fluorescence anisotropies, Causes of Depolarization, Biochemical applications. Energy Transfer: Theory of Energy Transfer for a Donoracceptor pair, Distance Measurements Using Resonance Energy Transfer (RET), Biochemical applications of RET. [12]

5. **Multiphoton excitation:** introduction to Multiphoton Excitation, Two-photon absorption Spectra, Cross Section for Multi-photon absorption. [3]

6. **Single-molecule Detection (SmD):** Delectability of Single Molecules, instrumentation for SMD, Single-Molecule photophysics, Biochemical applications of SMD. [3]

7. **Fluorescence Correlation Spectroscopy (FCS):** principles of Fluorescence Correlation Spectroscopy, Theory of FCS, Examples of FCS Experiments. [3]

8. **Fluorescence-Lifetime imaging microscopy (FLim):** Early Methods for Fluorescence-Lifetime imaging, Laser Scanning TCSpC FLiM, Lifetime imaging of Cellular Biomolecules. [3]

9. **Radiative Decay engineering:** introduction to Radiative Decay Engineering, Review of Metal Effects on Fluorescence,

Surface Plasmon-Coupled Emission(SPCE), Applications of Metal-Enhanced fluorescence, Application of SPCE. [3]

Recommended Books:

1. principles of Fluorescence Spectroscopy, Joseph R. Lakowicz, 3rd Edition, Springer, 2006

2. advanced Time-correlated Single photon Counting Techniques, W. Becker, Springer, 2005

3. Molecular Fluorescence principles and applications, B. Valeur, WiLEY-VCH, 2002

4. Single-Molecule Detection in Solution. Methods and applications, C. Zander, R. a. Keller, and J. Enderlein, WiLEY- VCH, 2001

C669: Biomacromolecules

1. Buffers (their use in study of biomolecules), pH, pKa of amino acids, D and L amino acid nomenclature [1]

2. Biophysical techniques to purify and study proteins: Dialysis, salting out and precipitation by organic solvents, ion exchange, gel filtration, reversed phase, affinity chromatography, ultracentrifugation, gel electrophoresis [3]

3. **Proteins:** protein sequencing by chemical and mass & nMR spectroscopic methods, Use of spectroscopic tools in studying biomolecules. primary (single letter amino acid codes), Ramachandran plot, secondary structures like helices, parallel and antiparallel -sheets, circular dichroism of secondary structures, tertiary (motifs and domains: some important motifs like Rossman fold, helix turn helix, 4 helix bundles, beta barrel), quaternary structure (Hemoglobin and Myoglobin) and Enzymes [21]

4. **Nucleic acids:** a, B and Z-Dna structures, Method of replication, sequencing of nucleic acids (Chemical, dideoxy and fluorescence), Transcription, Translation, genetic code, genomes, Genes, over expression of recombinant proteins, mutagenesis (random and site directed). polymerase chain reaction (pCR) [9]

5. Carbohydrates and glycoproteins, proteoglycans, Membranes and lipids, bacteial cell wall synthesis and mechanism of some important antibiotics like penicllin, antibiotic resistance [4]

6. **Metabolism:** photosynthesis, Calvins cycle, glycolysis, Krebs cycle, electron transport, cofactors. [4]

Recommended Books:

1. Voet, D, Voet, Jg, pratt, CW Fundamentals of biochemistry: life at the molecular level, 2nd Edition, 2006

2. Berg J.M, Tymoczko J.L. and Stryer L. Biochemistry, 6th Edition,2007

3. Creighton, TE, proteins: structure and molecular properties, 2nd edition, 1993

4. Lewin B. genes iX, 2008

5. Branden C and Tooze J., introduction to protein structure, 2nd Edition, 1999.

6. Fersht a., Structure and mechanism in protein science: a guide to enzyme catalysis and protein folding, 1999

C670: Advanced Heterocyclic Chemistry

1. Introduction: Heterocyclic Chemistry introduction to heterocycles: nomenclature, spectral characteristics, reactivity and aromaticity. [2]
2. Synthesis and reactivity of three and four membered heterocycles e.g., aziridine, azirine, azetidine, oxiranes, thiarines, oxetenes and thietanes. [4]
3. Synthesis and reactivity of five membered rings with two heteroatoms: pyrazole, imidazole, oxazole, thiazole, isothiazole and benzofused analogs; Benzofused five membered heterocycles with one heteroatom, e.g., indole, benzofuran, benzothiophene. [8]
4. Synthesis and reactivity of benzofused six membered rings with one, two and three heteroatoms: benzopyrans, quinolines, isoquinoline, quinoxazaline, acridine, phenoxazine, phenothiazine, benzotriazine, pteridines. [8]
5. Synthesis and reactivity of seven and large membered heterocycles: azepines, oxepines, thiepines; spiro heterocycles; bicyclic compounds containing one or more heteroatoms [4]
6. Recent methods of C-H functionalization/activations of heterocyclic derivatives. [16]

Recommended Books:

1. Carey, F.a. & Sundberg, R. J. advanced Organic Chemistry, parts a & B, plenum: U.S. 2004
2. Thomas. L. gilchrist, Heterocyclic chemistry, (3rd Edition) 1997
3. Joules, J. a; Mills, K.; Smith, g. F. Heterocyclic Chemistry, 3rd Ed.
4. advances in Heterocyclic Chemistry, Book series Elsevier Edited by alan Katritzky
5. Branden C and Tooze J., introduction to protein structure, 2nd Edition, 1999.Journal articles

C671: Statistical Mechanics

1. Basic assumptions, concept of microscopic and macroscopic states, ensembles and averages. Calculation of distribution functions in canonical ensemble and the canonical partition function. Relations between the canonical partition function and thermodynamic functions. Calculations in other ensembles like micronanonical and grand canonical ensembles. [12]
2. Calculations of partition functions and thermodynamic properties for ideal systems of monatomic and diatomic molecules.
3. Calculations of fluctuations and equivalence of ensembles. [7]

4. Calculation of heat capacity of solids, Einstein and Debye theories, and study of chemical equilibrium in terms of partition functions.[4]

5. **Quantum Statistics:** Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac statistics. Systems of Fermions and Bosons in weak and strong degenerate limits. [7]

6. **Classical Statistical mechanics:** partition functions as integrals over phase space coordinates, Systems of interacting particles, imperfect gases, concept of radial distribution functions of liquids and applications to ionic solutions using Debye-Huckel theory.[6]

7. **Non-equilibrium Statistical mechanics:** Onsager regression hypothesis and fluctuation-dissipation theorem, calculations of transport coefficients like diffusion, conductivity. [6]

Recommended Books:

1. Physical Chemistry : a Molecular approach, D. a. McQuarrie and J. D. Simon, Viva Books, new Delhi, 1998.

2. Statistical Mechanics, D. a. McQuarrie, University Science Books, 2nd Edn., 2000.

3. Introduction to Modern Statistical Mechanics, D. Chandler, Oxford Univ. press, 1987.

4. Statistical Thermodynamics of non-Equilibrium processes, J. Kaizer, Springer, 1st Edn., 1987.

5. Statistical physics ii: non-Equilibrium Statistical Mechanics, R. Kubo, M. Toda and n. Hashitsume, Springer, 2003.

C751: Photochemistry

1. **Introduction:** importance of photochemistry; Electromagnetic Radiation; Colour perception and the Colour Circle; Beer- Lambert Law; Electronic Configurations: Multiplicity, S0, S1, T1 etc.; Electronic Transitions and Solvent Effects: π to π^*, n to π^* etc. Molecular Orbitals (FMO Approach). [6]

2. **Unimolecular Photophysical Processes:** Jablonski Diagram; Frank-Condon principle; Fluorescence; inter-System Crossing; phosphorescence; Delayed Fluorescence; Quantum Yield. [6]

3. **Bimolecular Photophysical Processes:** Thermodynamics and Kinetics of Excited State Bimolecular interactions; Excimer and Exciplex; photosensitization and Quenching; Heavy atom Effect; photoinduced Electron and Charge Transfer; Resonance Energy Transfer: Coulombic and Exchange mechanisms. [8]

4. **Fluorescence Spectroscopy:** Characteristics of Excitation and Emission Spectra; Basic Theories involving Various Fluorescence Spectral parameters; Fluorescence anisotropy; introduction to Fluorescence probing Techniques and applications; Fluorescent Molecular Sensors of ions and Molecules. [10]

5. **Photochemistry of Organic Compounds:** photochemistry of alkenes; pericyclic Reactions; photo-oxidation and photo-reduction; photochemistry of Carbonyl Compounds. [8]

6. **Applied Photochemistry:** Chemistry of Vision; photochemistry in nature; photochemistry in atmosphere; Supramolecular photochemistry; Solar Cell; Fuel cell. [4]

Recommended Books:

1. Fundamentals of photochemistry, K. K. Rohatgi Mukherjee, Wiley Eastern Ltd., 1978.
2. Modern Molecular photochemistry, n. J. Turro, University Science Books, 1991.
3. Molecular Fluorescence, B. Valeur, Wiley-VCH, 2002.
4. principles of Molecular photochemistry: an introduction, p. Walsh, n. J. Turro, V. Ramamurthy, J. C. Scaiano, University Science Books, 2008.
5. Organic photochemistry, J. M. Coxon and B. Halton, Cambridge University press, 1974.
6. Molecular Reactions and photochemistry, C. H. Depuy and O. L. Chapman, prentice Hall of india.
7. Photochemistry and pericyclic Reactions, J. Singh and J. Singh, new age international publishers, 2003.
8. Pericyclic Reactions, ian Fleming, Oxford Science publications 1998.

C752: Pharmaceutical Chemistry

1. **Drug discovery and development:** The why and wherefore of drugs; Stereochemistry and solubility factors; principles of drug design (molecular and biochemical); 'Lead' modification approach, SAR/QSAR; Computer-aided drug design; natural products drug discovery. [15]

2. **Basic Principles of medicinal chemistry:** Drug action at enzymes; Drug action at receptors; physio-chemical aspects of drug molecules; selected examples of drugs and natural products. [15]

3. **Pharmacodynamics and Pharmacokinetics:** Drug distribution and survival; Concept of prodrug; pharmacokinetic models; Drug metabolism. [10]

Recommended Books:

1. Essentials of pharmaceutical Chemistry, D. Cairns, pharmaceutical press, 2nd Edition 2003.

2. Fundamentals of Medicinal Chemistry, g. Thomas, Wiley-Blackwell, 1st Edition, 2003.

Group Theory and Molecular Spectroscopy (6 credits)

Group Theory

Symmetry Elements, Symmetry Operations, Point Groups, Symmetry Representations, Applications of symmetry to Molecular Orbital diagrams of simple molecules (examples: H_2O, BeH_2). Definition of a group and basic theorems, molecular symmetry groups and classes, Great orthogonality theorem, Matrix representation of groups, irreducible representations and Character Tables. Symmetry properties of wave functions, orbitals as basis sets for irreducible representations, symmetry adapted linear combinations. (12)

Introduction to Spectroscopy

Interaction of light with matter, Transition moments and transition probabilities, Einstein's coefficients, Oscillator strength. (2)

Diatomic Molecules

(a) Electronic Spectra: Born-Oppenheimer approximation, Potential energy curves of diatomic molecules, Frank-Condon principle, electronic transitions in homonuclear and heteronuclear diatomics.(4)

(b) Microwave and Infrared Spectroscopy:

Simple harmonic oscillator and rigid rotor model, Rotational spectra of diatomic molecules, Stark effect, vibrational spectra of diatomic molecules, anharmonic corrections, selection rules, fundamental and overtone bands, Isotope effects, vibrational rotational coupling. (6)

Polyatomic Molecules:

(a) Electronic spectra: Electronic structure, electronic spectra of polyatomic molecules - linear conjugated molecules, aromatic molecules, transition metal compounds, fluorescence, phosphorescence, internal conversion and charge transfer. (9)

(b) Rotational, Vibrational spectra of Polyatomic Molecules

Symmetric and asymmetric top molecules, normal modes of vibration and their classification by group theory, coupling between rotational and vibrational degrees of freedom, Symmetry and normal modes of vibration. Rovibrationic spectra, Concept of anisotropic polarizability and Raman spectra. (9)

Recommended Books

1. Chemical Applications of Group Theory, F. A. Cotton, John Wiley, 3rd Ed., 2003.
2. Symmetry and Spectroscopy: An Introduction to Vibrational and Electronic Spectroscopy, D. C. Harris and M. D. Bertolucci.
3. Fundamentals of Molecular Spectroscopy, C. N. Banwell and E. M. McCash, Tata McGraw Hill, 1995.
4. Molecular Spectroscopy, G. M. Barrow, McGraw Hill, 1985.
5. Spectra of Atoms and Molecules, P. F. Bernath, Oxford Univ. Press, 2005.
6. Modern Spectroscopy, J. M. Hollas, John Wiley, 4th Edn., 2004.
7. Molecular Symmetry and Group Theory, R. L. Carter, John Wiley and Sons, 1998.

C754. Organic Chemistry Project-1:

C755. Organic Chemistry Project-II

C756. Inorganic Chemistry Project-I

C757. Inorganic Chemistry Project-II

C758. Physical Chemistry Project-I

C759, Physical Chemistry Project-II

BACK TO MAIN

GOVERNMENT OF INDIA

BHABHA ATOMIC RESEARCH CENTRE

Ph.D. IN ENGINEERING SCIENCE (PROGRAM CODE: ENGG04)

SYLLABUS

BARC Training School, Mumbai

HUMAN RESOURCE DEVELOPMENT DIVISION

MUMBAI 400085

PREFACE

The Department of Atomic Energy (DAE) has the multi pronged mandate of the utilisation of the power of the atom towards generation of power, development of advanced technologies, directed research in various scientific and engineering disciplines, production of radioisotopes for societal applications in medicine and agriculture and towards national security. In order to become self reliant and self sustaining in this high technology area, the need for generating highly skilled manpower and ensuring its continuous availability was indispensable. Thus in 1957, the BARC Training School (BARCTS) was established as a centre for in house training of professionals. These professionals today form the backbone of the Nuclear Power Programme. More than 9000 trainees have graduated from BARC TS over the last 61 years and provide the technological leadership in DAE for all its important programmes. Over the last five and a half decades, the BARCTS has grown into a model institute, recognised internationally as a school of excellence.

The academic activities of BARCTS are carried out by the Human Resource Development Division (HRDD) from its campus situated at Anushakti Nagar, well away from the hustle and bustle of Mumbai, nestling between wooded hills and sylvan surroundings, close to the BARC premises. This crucible of learning has been a focus of attraction to many a bright young talent, eager and willing to learn, guided and mentored by an academia drawn from the pool of experts available within DAE. Hailing from some of the best universities in India, they are nurtured with care and concern, by means of a holistic approach to training and personality development. A judicious mix of academics, practical training and soft skills training is imparted at the Training School and at the state of the art laboratories of BARC. A well equipped hostel with sports, recreation, and internet facilities provides the right environment needed for wholesome development. The lure of a professionally challenging career with opportunities for upgradation of skills, an objective merit recognition based career growth pattern and attractive compensation packages have attracted the best talents to BARCTS.

The BARCTS has two principle programmes, the One-Year **Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)** and the **DAE Graduate Fellowship Scheme (DGFS)**

Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)

OCES is the flagship programme of the BARC Training School and its affiliates. Under this scheme, engineering graduates from eight engineering disciplines- Mechanical, Chemical, Metallurgy, Civil, Electrical, Electronics, Instrumentation & Computer Science and Science Post-Graduates from Physics, Chemistry & Biological Sciences are selected and imparted a

rigorous one year training in the field of Nuclear Science and Technology. In addition to the above 11 disciplines, selected post graduate candidates from the Physics and Chemistry disciplines are also inducted into a course specifically designed for the purpose of providing a holistic training in all aspects of radiological safety. This course has been named as "Radiological Safety Engineering' course.

The curriculum provides multidisciplinary training in topics relevant to the nuclear industry, frontier areas of science and technology and some super specialized areas. Training is imparted by adjunct faculty comprising the scientists and engineers working in various projects of DAE. In this manner, not only the objective of training but also the greater task of seamless and effective knowledge transfer from the expert to the acolyte is carried out successfully. The scheme also ensures the retention of the trained manpower within the Department thereby maximising the benefits of the training programme to the Department.

A total of about 150 courses in the above disciplines comprising more than 4000 lectures are delivered by more than 500 adjunct faculty members from BARC and other educational institutes during this period.

OCES Training Objectives: It involves one year of academic and training programme at the BARC Training School. The training programme aims to ensure that the selected candidates are provided with the necessary facilities and opportunities to acquire knowledge and develop skills for meeting the challenging technological goals of the country in the field of nuclear S&T. The training courses are organized in a structured manner as detailed below

- Foundation courses impart multidisciplinary training in the topics relevant to the nuclear industry.
- Core courses bring all selected candidates from different universities to the same or common level of understanding in the core subjects of the respective disciplines.
- Elective courses impart training in few specialized areas in respective disciplines.

OCES graduates are also eligible for the award of Post Graduate Diploma in Nuclear Science/Engineering & Technology of HBNI. After joining the DAE, the eligible OCES graduates can undertake one year project work leading to the award of M.Tech./M.Phil. Degree of the HBNI.

DAE Graduate Fellowship Scheme (DGFS)

In order to meet the requirement of highly specialised professionals in specific areas, DAE initiated the DGFS Programme for inducting engineers at MTech level in collaboration with the six IITs viz. Bombay, Delhi, Kanpur, Kharagpur, Madras, Roorkee and BHU in addition to some other elite institutes such as NIT Rourkela and ICT, Mumbai. The scheme strengthens the research-education linkage with premier institutes of the country in the areas of interest to DAE and provides useful synergy between the nuclear sector and the academia

Under this scheme, trainees selected for the OCES programme as well as one of the above institutes pursue the M.Tech degree under the sponsorship of DAE. On completion of the MTech degree, the candidates are absorbed into DAE as a Scientific Officer with advance increments. These Fellows then undergo a 4-month Orientation Course for DGFS Fellows (OCDF) after successful completion of M.Tech.

Orientation Course for DGFS Fellows (OCDF)

Several topics of interest to the Department do not form part of the MTech curriculum. To provide an exposure to such topics, the DGFS Fellows undertake a four months orientation course in the BARC Training School **(Orientation Course for DGFS Fellows- OCDF)** after successful completion of their MTech. Programme.

This document furnishes the course structures of all disciplines and syllabi of the courses conducted by the BARC Training School under each discipline.

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SYLLABUS

ENGINEERING SCIENCES

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REVISED CREDITS
FOR
COURSES IN ENGINEERING
SCIENCES

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (MECHANICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for PVP	EN610	60	6	250
2	Computational fluid Dynamics and Heat Transfer	EN611	50	6	200
3	Finite Element Method	EN621	30	4	125
4	Fracture Mechanics	EN622	40	4	150
5	Mechanics of Solids	EN624	40	4	150
		Core Total	**220**	**24**	**875**

ELECTIVES (MECHANICAL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Machine Design	EN711	25	2	100
4	Material Science in Nuclear Engineering	EN712	25	2	100
5	Multi-scale material modelling	EN715	30	4	125
6	Nuclear Emergencies	EN716	35	4	150
7	Reliability Engineering	EN718	25	2	100
8	Vibration	EN721	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (CHEMICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25	2	100
2	Advanced Mass Transfer	EN604	25	2	100
3	Code design for PVP	EN610	30	4	125
4	Computational Fluid Dynamics and Heat Transfer	EN611	50	6	200
5	Nuclear Chemical Engineering	EN628	35	4	150
6	Process Dynamics and Control	EN634	45	6	200
7	Process Modeling, Simulation and Optimization	EN635	45	6	200
		CORE TOTAL	**225**	**30**	**950**

ELECTIVES (CHEMICAL) – Any 3 Courses - 9 CREDITS

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Material Science in Nuclear Engineering	EN712	20	2	75
4	Membrane Technology	EN714	35	4	150
	ELECTIVES TOTAL (APPROX)		**90**	**8-10**	**350**

	THEORY TOTAL	**535**	**62-64**	**2175**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 535; Total Credits: 106-108; Total Marks: 2775

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - METALLURGY

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (METALLURGY)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	2	75
2	Extractive Metallurgy	EN620	40	4	150
3	Mechanical Metallurgy	EN623	30	4	125
4	Nuclear Materials	EN628	50	6	200
5	Nuclear Metallurgy	EN629	30	4	125
6	Physical Metallurgy	EN630	40	4	150
7	Process Control & Instrumentation	EN631	25	2	100
		CORE TOTAL	**230**	**26**	**925**

ELECTIVES (METALLURGY) Any 3 Courses- 9 Credits

S.No.	Subject Title		Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Image processing and Machine Vision	EN710	30	4	125
4	Materials Characterization	EN713	20	2	75
5	Multi scale Material Modeling	EN715	30	4	125
6	Nuclear Chemical Engineering	EN628	35	4	150
7	Nuclear Emergencies	EN716	35	4	150
8	Welding Science & Technology	EN723	25	2	100
		ELECTIVES TOTAL (APPROX)	**90**	**8-12**	**350**

	THEORY TOTAL	**540**	**58-62**	**2150**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 540; Total Credits: 102-106; Total Marks: 2750

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (CIVIL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1	30	4	125
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2	30	4	125
3	Design Basis Hazards & Geotechnical Engg	EN621	40	4	150
4	Earthquake Engineeing & Structural Dyanmics	EN609	45	6	200
5	Finite Element Method	EN626	30	4	125
6	Mechanics of Solids	EN624	40	4	150
		Core Total	**215**	**26**	**875**

ELECTIVES (CIVIL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Struct Dynamics & Earthquake Engg	EN724	30	4	100
2	Construction Materials, Management & Quality	EN614	30	4	100
3	Safety & Reliability of Civil Engineering	EN722	25	2	100
4	Project Management	EN717	25	2	100
	ELECTIVES TOTAL (APPROX)		**80**	**8-10**	**300**

	THEORY TOTAL	**515**	**58-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 520; Total Credits: 102-104; Total Marks: 2600

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECRICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	20	2	75
2	Computer Based System Design I	EN612	25	2	100
3	Electrical Systems for Nuclear Power Plants	EN618	30	4	125
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**195**	**22**	**800**

ELECTIVES (ELECTRICAL) Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design II	EN702	25	2	100
2	Artificial Intelligence and its Applications	EN703	30	4	125
3	Computer Based System Design II	EN704	25	2	100
4	Digital Signal Processing & Image Processing	EN706	30	4	125
5	Image Processing & Machine Vision	EN710	30	4	125
6	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
7	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**525**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECTRONICS)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	4	125
2	Advanced Nuclear Instrumentation	EN605	40	4	150
3	Embedded & Computer Based Sys. Design	EN619	45	6	200
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**200**	**28**	**825**

ELECTIVES (ELECTRONICS) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Embedded Electronics Software	EN707	25	2	100
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**60-66**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 104-110; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
		FOUNDATION TOTAL	**240**	**26**	**950**

CORE ENGINEERING (INSTRUMENTATION)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40	4	150
2	Computer Based System Design I	EN612	25	2	100
3	Modern Control Systems Design and Simulation	EN625	35	4	150
4	Reactor C&I and Human Machine Interface	EN636	40	4	150
5	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
6	Reliability Engineering	EN639	20	2	75
		CORE TOTAL	EN639	**20**	**775**

ELECTIVES (INSTRUMENTATION) Any 3 Courses-- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	125
2	Computer Based System Design II	EN706	25	2	100
3	Digital Signal Processing & Image Processing	EN707	30	4	125
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
		ELECTIVES TOTAL (APPROX)	**90**	**8-12**	**350**

	THEORY TOTAL	**525**	**54-58**	**2075**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-102; Total Marks: 2675

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25	2	100
2	Computer Graphics & Visualisation	EN613	35	4	150
3	Distributed Computing	EN616	45	6	200
4	Networking & Information Security	EN6627	40	4	150
5	Reactor Control Engineering	EN637	15	2	75
6	Software Engineering and Formal Methods	EN640	40	4	150
	CORE TOTAL		**200**	**22**	**825**

ELECTIVES (COMP. SCIENCE AND ENGINEERING) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Data Base Management System & Web Technology	EN705	30	4	100
3	Digital Signal Processing & Image Processing	EN706	30	4	125
4	Embedded Electronics Software	EN707	25	2	100
5	Feedback Control System	EN708	25	2	100
6	Image Processing & Machine Vision	EN710	30	4	125
	3 ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

FOUNDATION COURSES

EN501: Accelerator Physics and Technology

Basic Accelerator Physics (5)

- Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons;
- Ion sources.
- General equations of motion in a combined electric and magnetic field, beam rigidity; relativistic expressions, weak and strong focusing principle; condition for strong focusing.
- Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.
- General design of a cyclic accelerator.
- Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;
- Matrix techniques in beam optics; first order transfer matrix of dipole, quadrupole, transfer matrix of a drift space; quadrupole doublet;
- Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters
- Introduction of normal (room temperature) DC and pulsed magnets, construction features. Superconducting coils, magnets and their construction features.
- Momentum compaction; Phase stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.
- Synchrotron radiation sources; spectrum of emitted radiation; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators.

RF Linacs (12)

Introduction to Linacs

- Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.
- Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac
- Transit time factor and the energy gained in a linac.
- Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.
- General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature RF structures.

Proton Linac

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.
- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
- Introduction to Space charge effects.
- Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Accelerator Driven Systems & RF electron accelerators

Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.

Accelerator Technology (13)

General

- Material selection for Accelerator components
- Mechanical Design and fabrication issues; tolerances, surface finish, etc
- Thermal management in accelerator systems
- Alignment requirements of accelerator magnets and RF structures, methods and instruments for alignment and surveying in accelerators.

Ultra High Vacuum Systems

Basic concepts in Vacuum

- The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
- Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
- Basics of low pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, Sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.

Cryogenics Systems

Introduction to Cryogenic Engineering

- General and basics, Cryogenic properties, Basic cycles
- Large Cryogenic Systems for Accelerators

Cryogenic Equipments

- Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

References

1. Principles of RF Linear Accelerators, T. P. Wangler, (John Wiley & Sons Inc., 1998)
2. Introduction to Accelerator physics – Arvind Jain
3. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer, (John Wiley & Sons Inc., 1982)
4. An Introduction to the Physics of Particle Accelerators - M. Conte, W.W. Mac Kay.
5. Handbook of Accelerator Physics and Engineering - A. Chao, M. Tigner.
6. Particle Accelerator Physics (Vol 1 and Vol 2) - Helmut Widemann.
7. Principles of Charged Particle Acceleration – Stanley Humphries.
8. Fundamentals of Beam Physics - James Rosenzweig.
9. An Introduction to Particle Accelerators - E. J. N. Wilson.
10. Accelerator Physics - S. Y. Lee.
11. The Physics of Particle Accelerators, An Introduction - Klaus Wille.
12. The Principles of Circular Accelerators and Storage Rings - Philip Byrant.
13. Introduction to Vacuum Technology-Compiled by K.G. Bhushan, BARC

EN 502:Engineering Maths-I (15) (All Engg)

- Overview of arithmetic errors in computations
- Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
- Linear systems solutions by direct methods, iterative methods and acceleration techniques.
- Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
- Linear systems: Eigen values.
- Non -Linear systems: Newton-Rapson & Successive Approximation methods
- Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
- Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
- Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and
   Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 503: Engineering Maths-II (20) (ME Group)

- Introduction to discretization methods and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations, wave equation
- Formulation of the matrix methods by equilibrium concepts (1D-heat conduction, 2D-truss and 1D-hydraulic flow examples).
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's methods, Piecewise approximations. Basis of Finite Element Method, energy principles in structural mechanics and principles of minimum potential energy, assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit methods.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.
- Finite element formulation for laminar and turbulent flows.
- Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
- Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
- Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
- Response Surface Method 2K+1, factorial design, 3k factorial design
- Monte Carlo Method
- Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Artificial Intelligence and Genetic Algorithm
- Artificial Neural Network
- Gram-Schmidtt Orthogonalization
- Transformation of matrix

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
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6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.
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14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 504:Engineering Maths-II (20) (MT)

Applications in Materials Science:

- Use of matrix in crystallography. Stereographic analysis, lattice correspondence, orientational relationship, applications to twinning and martensitic. transformations,
- Tensor analysis in phase transformation and deformation studies
- Analysis of diffusion data, Solutions of diffusion equations - error function and Eigen value analysis, Polynomial fitting of diffusion profiles.

Application in thermodynamics of metallurgical systems:

- Temperature dependence of thermodynamic quantities, graphical and analytical integration of Gibbs-Duhem equation. Introduction to database for thermodynamic tables
- Analysis and synthesis of phase diagrams, introduction to first principles calculations of phase diagrams with computer demonstration, cluster variation and Monte Carlo methods

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wilev, 1966.
2. Todd R.J. "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods.
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McCraw-Hill Book Co. 1983.
6. Rajaraman V,, "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C. "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis

1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B,, "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers. 1968.
11. Conte S.D,, "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo,McGraw Hill. 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G,, "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis". Addison Wesley, 1984.
15. Rajsekaran S,, "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987; •
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation' Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.-• •
19. Acton, "Numerical Methods That Work"
20. Forsythe et. al,, "Computer Methods for Mathematical Computations"
21. Forsythe et. al,, "Computer Solution for Linear Algebraic Systems"
22. Golub Gene H., "Matrix Computations"
23. Griffiths D. V., "Numerical Methods Engineers: A Programming Approach"
24. Williams P. W,, "Numerical Computation.
25. Strang G,, "Applied Mathematics"
26. Crank J,, "Mathematics of Diffusion"
27. Worked Examples in the Geometry of Crystals: MKDH Bhadesh
28. Materials Science & Technology, Vol.4; Rudman.

EN 505: Engineering Maths-II (20)(EE Group)

- Transforms: Laplace & solution to ODE, Bilinear & Z transforms, Discrete cosine transforms & compression, Entropy & Haufman coding for compression
- Solution of Matrix Differential Equation: Existence & uniqueness of solutions, Solution of Non-Linear continuous time state equation, Solution of Linear time varying continuous time state equation, Solution of linear time invariant continuous time state equations
- Basic Procedure for Designing Conservational Logic: Quine McCluskey method, Iterative consensus method, Design example
- Design of Sequential Circuit Using Sequential Machine Flow Chart: Sequential machine flow chart, Reading reduced dimension maps, Output function synthesis, Next state function synthesis, State assignment & design examples
- Counting Statistics and Error Prediction: Statistical models -Binomial, Poisson and Gaussian distributions, Application of statistical models: Error propagation, Optimization of counting experiments, Limits of detectability, Distribution of time intervals

References:

1. F R Grantmacher, "The Theory of Matrices", New York: Chelsea Publishing Co., 1960.
2. R Bellman, "Introduction to Matrix Analysis", II ed., New York, McGraw Hill, 1970.
3. E Kreyszig, "Advanced Engineering Mathematics, 5th ed., Wiley Eastern Ltd., 1985.
4. Paul R Halmos, "Finite Dimensional Vector Spaces", and New York: D Van Nostrand Co. Inc., 1965
5. Bajpei et.al, "Numerical Methods for Engineers and Scientists"
6. Dahlquist et.al, "Numerical Methods"
7. G Strang, "Applied Mathematics"
8. Golub Gene H, "Matrix Computations"
9. Numerical Methods for Scientists and Engineers, By H.M.Antia, Hindustan Book Agency,New Delhi.
10. Numerical Methods for Mathematics, Science and Engineering, Mathews(IInd Ed), Prentice Hall of India.

EN 506:Health Physics and Radiological & Industrial Safety (20)

Health Physics

Introduction

- Radiation sources, its interaction with matter and units**:** Natural and Induced radioactive sources,
- Units of radioactivity, half-life and decay constant, specific activity.
- Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter.
- Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given).
- Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given),
- Exposure-dose relationship, Bragg-Gray principle.

Biological effects, Radiation Protection and Regulation:

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Importance of radiation protection programme in DAE.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.

- Radiation protection philosophy,
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Principles of radiation detection and monitoring

- Basic operating principles ofa) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type ofRadiation monitors/Radioactivity measurement methods adopted for radiation protection should be taught.

Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management.
- Personal monitoring, area-monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures:

- Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper),
- Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation, Protective equipments

Nuclear Accidents, Emergency Preparedness and Management:

- Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

INDUSTRIAL SAFETY ASPECTS

Introduction:

- Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques

Hazards due to physical agents:

- UV and IR radiation, Lasers, Microwave radiation; noise, heat

Chemicals hazards:

- Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals

Evaluation:

- Instrumental methods, air sampling methods, liquid effluent monitoring

Occupational exposure limits:

- Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50

Handling, storage and control:

- Engineering control measures and safety features,
- Safety management techniques such as safety audit, Personal/ administrative control, and Medical control

Fire and explosion hazards:

- Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits,
- USNFPA Classification of Flammable/combustible liquids: flammable gases;
- Engineering safety for prevention of fire and explosion,
- Hazard area classification, selection of equipment, detection and extinguishing systems.

Hazard identification, assessment and control:

- Hazard identification: Concept of risk and Risk management
- Formal methods of hazard identification and assessment:
- Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies
- Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation.

Management of major hazard Installations:

- Plant Layout and Engineering Design Consideration
- Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic Releases,
- Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment,
- Emergency Planning Guidelines, Development of Emergency Plan

Health and safety regulatory aspects:

- Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate.
- EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

References:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute Of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment And Control; Vol-1, 1996 2 Edition, Frank P Lees.

EN 507:Material Science in Nuclear Engineering (EE) (20)

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction methods --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices.
- Material characterization techniques --- XRD, RBS, SEM, TEM, EDAX, XPS, IR and Raman Spectroscopy.
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials, mechanical properties and measurement techniques, strength and ductility, creep, fatigue and wear testing
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Reactor core materials, Zircalloys, Zr-Nb alloys --- fabrication, properties and applications in reactors
- Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels) --- fabrication, properties and applications.
- Chemistry of fuel materials: Production of Uranium, Plutonium and Thorium.
- Heavy water: Production process, purification, properties and applications.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)

2\. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)
3\. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)
4\. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)

EN 508: Nuclear Fuel Cycle Technology(35)

An overview (1)

FRONT END

Mining, Milling and Associated Processing of Indian Uranium Resources(1)

- General Introduction
- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.

Case Studies (1)

- Jaduguda and Turamdih Uranium Ore Processing
- Tummalapalle Uranium

Metal Purification using Hydro-Metallurgical Processes (1)

- Process, Equipment, Quality control

Metal Production by Metallothermic Reduction Processes (1)

- Process, Equipment, Quality control

WasteManagement and Safety (1)

- Associated wastes, characterisation and management

BACK END

Reprocessing (4)

- Nuclear fuels and generation of Pu239 & U233
- Spent fuel management options.
- Characteristics of spent fuel (RR, PHWR, AHWR ,FBR&LWR).
- Reprocessing by PUREX -Head end operations, solvent extraction cycles including the conversion of nitrates to oxides.
- Reprocessing of AHWR and FBR spent fuels.
- Prevention of criticality in reprocessing plants.

Waste Management (3)

- Waste sources.
- Radioactive waste classification.
- Management of low and intermediate level wastes.
- Vitrification of high level liquid waste.
- Schemes for partitioning of high level waste including recovery of valuable fission products.
- Storage and disposal of radioactive wastes.
- Various decontamination techniques to address alpha bearing materials.

Instrumentation & Control (3)

- Measurement techniques for level, pressure, temperature, interface density and flow Instrumentation and control associated with transfer devices—steam jets, pumps and air lift pots
- Interlocks related to major equipments like pulse column, dissolver, evaporator, joule melter and ion exchange column
- Computerised data acquisition and control system

Radiation Monitoring System (2)

- Area monitoring instruments, stack monitors, criticality alarm systems, effluent monitors,PCW & steam condensate monitors
- Single line diagram for Class-4, Class-3 and UPS
- Earthing, cabling, lightening protection system, VF drives

Civil (1)

Design aspects of back end technology facilities- Design classification and seismic categorization, considerations for external events, Standards/codes for design

Metallurgy (2)

- Corrosion aspects and material of construction for reprocessing and waste management plants.
- Degradation modes of SS 304L in nitric acid.
- Welding techniques, quality assurance and special requirement for in cell equipment.

Mechanical (7)

- Spent fuel transportation- shipping cask design and regulatory requirement.
- Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
- Remote handling system in reprocessing.
- Automation in plutonium powder handling.
- Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
- Sampling system. Transfer devices and valves for radiochemical plants.

Features of Radiochemical Plant (7)

- Layout considerations and design philosophy for back end operation.
- Control of radiation exposure including shielding and barriers.
- Ventilation aspects and Off gas handling and treatment.
- Utilities requirement for back end.
- Mechanical design aspects of metallic and joule melter.
- Radiation shielding windows.
- Remotisation and remote handling in vitrification plants

EN 509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40)

Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulas gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

1. Wakil M.EI, "Nuclear Power Engineering", McGraw- Hill.
2. Strosal and Vapet, "Power Plant Engineering & Economics".
3. Lewis E.E., "Nuclear Power Reactor Safety", Wiley Inter Science.
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von-Nostrand, 1981.

Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time.Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
  - Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio, blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly
  - Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
  - Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination

References:

1. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors", Pergamon Press
2. Yevick J.G., "Fast Reactor Technology", Plant Design, M.I.T, Press.

Module 3:Advanced Reactor Concepts (6)

Introduction(1)

- Need for Advanced Reactors and in what way these are different from conventional reactor
- International initiatives – INPRO, GIF etc.
- Definition of sustainability and INPRO areas of sustainability
- Brief Description of the INPRO Guidelines and Methodology to Evaluate INES
- Basic principles, User requirements, Key Indicators, Allowable parameters etc.

Directions of Development in the World(1)

- GIF and other advanced reactor concepts

Indian Programme on Advanced Reactors and Associated Challenges (2)

- AHWR
- AHWR-LEU
- CHTR, IHTR, MSBR etc.

Reactor Physics Design Challenges(1) ADS and applications(1)

EN 510:Reactor Physics & Engineering (55)

Module 1 :Nuclear Reactor Physics (33)

Properties of Nuclei

Binding energy-formula and interpretation, nuclear forces, nuclear structure.

Fission Process

- Fission rate and reactor power
- Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
- Fissile, fertile and fissionable materials
- Fission product activity after shut down –decay heat.

Interaction of Neutrons with Matter

- Production of neutrons

Concept of microscopic cross section:

- Inelastic and elastic scattering

Variation of cross-section with energy

- Fast, resonance and thermal ranges
- 1/v law of neuron cross-section
- Resonance absorption, Doppler effect.
- Eta vs E curve conversion & breeding concept
- Thorium utilization

Diffusion of Neutrons
- Fick's law and its validity
- Steady state neutron diffusion equation
- Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.

Chain Reaction
- Four Factor formula
- Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
- Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,

Slowing Down Process
- Neutron slowing down
- Slowing down power/ moderating ratio of moderators
- Slowing down with spatial migration
- Fermi age concepts, migration length
- Multi zone reactors
- Ideas of reflectors/blankets, reflector savings, form factor.

Heterogeneous Reactors
- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

Reactor Kinetics
- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

Core Burn Up
- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

Neutron Poisons
- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

Reactivity Coefficients
- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Module 2: Reactor Engineering & Radiation Shielding (22)

Reactor Engineering (14)
- Introduction to reactor system & Indian Nuclear power programme
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems
- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR),
- Fast reactors;
- Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
- Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.

Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.

- Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
- Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.

Nuclear Fuel Cycle (2)
- Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
- Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
- Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
- Advanced fuel cycles

Radiation Shielding (6)
- Source of various neutron & Gamma radiation within the reactor system
- Attenuation of neutrons & gamma rays

- Dose rates for gamma rays for various source geometries
- Buildup factors for homogeneous & multiple layer shields
- Removal diffusion theory for neutron attenuation
- Coolant activation, heat generation
- Streaming of radiation through gaps & void in the shield

CORE COURSES

E601: Advanced Chemical Reaction Engineering (25)

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
- Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
- Reactor design: counter-current moving bed reactors, fluidized bed reactors.
- Advanced topics in reaction engineering- three phase reactors, photochemical reactors, integral reactor-separators, complex systems.
- Examples from nuclear chemical engineering.

References:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

EN602: Advanced Electrical Engineering Design-I (20)

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Methods, Finite Element Methods, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Methods: MFL Technique, Eddy current Technique, Remote Field eddy current Methods. (5)

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronics Circuit Design Techniques (30)

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Programmable Logic Devices: PLD, CPLD and FPGA, Technology architecture (4)
- Hardware Description Languages: VHDL – language details (6)
- Digital Circuit Design using VHDL: Design methodology and optimization, Design of a multiplexer, counter, finite state machine etc., test bench (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. Actel HDL Coding Style Guide, 2009 edition, Published by Actel Corporation, Mountain View, CA 94043. Free softcopy available on Actel website (www.actel.com).
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles

10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25)

- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Rate based approaches for design.
- Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors.
- Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors.
- Adsorption and ion exchange equipment.
- Membrane separation and other advanced mass transfer processes.
- Process intensification approaches.

References:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)

EN605: Advanced Nuclear Instrumentation (40)

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and methods of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems ,Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.

Reactor Instrumentation:

- Fundamental Considerations / Philosophies, requirements, and scope.
- Measurement ranges of reactor neutron flux and considerations
- Types of neutron detectors FC,10B, BF3, CIC and SPND for in-core and out-of-core use.
- Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR,LR, Lin, LinR and ρ)
- Noise reduction techniques, considerations and practice: EMI Interference, Grounding and shielding.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma Monitors, Neutron Monitors, Contamination Monitors, including networking and RADAS.

References

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

EN606: Advanced Operating Systems (25)

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Processs Subsystem : Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem : Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Interprocess Communication : Message Queues, Shared Memory, Semaphores, Mailboxes, Sockets, Fundamentals of Socket Programming, Remote Procedure Calls [1][6]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing, Features of distributed Unix, Logical time, Concurrency Control [1][5]
- Unix Shells: Unix Shell Commands & Fundamentals of Shell Programming [1][2]

- Linux: Packaging and Distribution, Loaders, Virtual Terminals, Internal and External Drivers, Threads, Interfaces, X Window System, Hard Disk Partitions, File System Enhancements, Extended File Systems, Virtual File System, System Tuning. [3, 9, 10]

References:

1. The Design of Unix Operating Systems : Maurice J. Bach, Prentice Hall
2. Unix Programming Environment : Kerninghan & Pike, Prentice Hall
3. Linux Internals : Rubini, O'Reilly & Associates
4. Operating Systems Concepts: Silberschatz, Galvin, John Wiley
5. Distributed Operating Systems : Tanenbaum, Prentice Hall
6. Unix Network Programming : W. Richard Stevens, Prentice Hall
7. Xlib Programming : Adrian Nye, O'Reilly & Associates
8. Inside Windows NT , David A. Solomon, Microsoft Press
9. Demblon & Spitzner, http://learnlinux.tsf.org.za/courses/build/internals/internals-all.html
10. Tigran Aivazian, http://www.faqs.org/docs/kernel_2_4/lki.html or http://students.mimuw.edu.pl/SO/Linux-doc/LinuxKernel-2.4.pdf

EN607: Applied Process Instrumentation (40)

- Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables:
- **Flow**: Differential pressure flow elements: Orifices , venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters. Applications and limitations of various flowmeters. Two phase flow measurements.
- **Pressure**: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.
- **Level**: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
- **Temperature**: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
- **Temperature transmitters**- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
- **Analytical Instrumentation**: Conductivity, pH, ORP and Turbidity measurement.
- **Other Measurements**: Relative humidity; viscosity and density measurement
- **Control valves:** Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
- **Instrument Impulse lines and instrument fittings**: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
- **P & I Diagrams, loop and hook up diagrams:** P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

EN 608 Civil Engineering Design of Concrete and Steel Structures

EN 608.1Civil Engineering Design of Concrete and Steel Structures-I (30)

Introduction to various structures of nuclear facilities Classification of structure and design basis

Radiation protection objectives, defense in depth, safety functions, safety classification, seismicclassification, quality classification, design classification, design for natural and man induced events.

Design Loads:
- Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
- Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
- Severe Environmental Loads: operating basis earthquake,severe windincluding gust effect and aerodynamic instability, design basis flood load,tsunami.
- Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind- induced missile

Design of RC structures:
- DesignofRC structures as per IS456,AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 ,designloadcombinations,design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies

Design for shrinkage, creep & heat of hydration:

Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies..

Foundation design
- Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
- Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
- Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

EN 608.2 Civil Engineering Design of Concrete and Steel Structures-II (30)

Introduction to Prestressed Concrete structures

Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.

Design of lined and unlined containment structures

Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.

Design of steel structures of nuclear facility

Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections,design of embedded parts and anchor boltsas per AERB and ACI standards, case studies.

Design of water-retaining structures

Design of overhead and underground tanksusingun-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.

Design of cooling towers

Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

References

1. IS 456 (2000) "Plain and Reinforced Concrete – Code of Practice ".
2. ACI 318 (2014) "Building code requirements for structural concrete".
3. ACI 349 (2013) "Code requirements for Nuclear Safety related concrete structures".
4. RCC-G "Code of Practice for Design of Prestressed Nuclear Containment Structures". 5. ISO 14000
6. Raju, N. K. (2006), "Prestressed concrete", Tata McGraw-Hill Education.
7. ACI 207 (1995) "Effect of restraint, volume change and reinforcement on cracking of massive structures".
8. Bowles, J. E. (2001) "Foundation analysis and design", Tata McGraw-Hill Education.
9. Rao, N.S.V.K. (1988),"Vibration analysis & foundations dynamics", Wheeler publishing.
10. IS 2974-1, 1984,"Code of practice for design and construction of machine foundations".
11. Arya, S.C., Oneill, M.W. and Pincus, G. (1979), "Design of structures and foundations for vibrating machines", Gulf Publishing Co.
12. Manohar, S. N. (1984) "Tall Chimneys design and construction", Mcgraw-Hill Book Comp.
13. ANSI/AISC N690 (1984), American and National Standard – Nuclear facilities, "Steel safety related structures for design fabrication and erection".

EN 609 Earthquake Engineering and Structural Dynamics(45)

Introduction to Seismology
- Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA),Design Basis Earthquake,Concept of

Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra
- Seismic instrumentation for micro-earthquake and strong motions.

Structural Dynamics
- Introduction to dynamic loading, different types of dynamic loadings, concept of damping,derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
- Single degree of freedom of system (SDOF)–undamped& damped system, free & forced vibration; Response to harmonic and impulse loading,concept of transmissibility and vibration isolation,estimation of damping of structural system using free & forced vibration approach;response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
- Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
- Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies)& eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
- Introduction to dynamics of continuous system

Seismic Response Analysis of Structures
- Seismic response analysis using response spectrum and time history approach
- Modal superposition method, Modal combinations and spatial combinations, missing mass correction
- Time history analysis using direct time integration,
- Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction

Random vibrations
- Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.

Special Seismic Design Considerations

Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain, curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures;Seismic Design Optimization, Principles of performance based design, dynamic response control techniques such as base isolation, dampers etc.

Seismic Requalification of Existing Installations

Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection, review basis ground motion, evaluation of seismic margin capacity, retrofitting.

Case Studies

Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear installments.

References

1. Chopra, A.K. (2007), “Dynamics of structures: Theory and application to earthquake engineering”, Prentice Hall.
2. Clough, R. W. and Penzien, J. (1993). “Dynamics of structures”, McGraw Hill, Inc.
3. Mario Paz and William Leigh (2006), "Structural Dynamics-Theory and Computation", Springer.
4. Thompson, W. T. (1972),“Theory of Vibrations with Applications” Prentice-Hall, Englewood Cliffs.
5. ASCE 4-98 (1998), “Seismic Analysis of Safety related Nuclear Structures and Commentary on standard for seismic analysis of safety related nuclear structures”.
6. AERB/SG/S-11, “Seismic Studies and Design Basis Ground Motion for NPP Sites”.
7. IAEA SAFETY STANDARDS SERIES No. NS-G-3.3 (2002), “Evaluation of Seismic Hazards For Nuclear Power Plants”.
8. IS 1893-1 (2002), “Criteria for Earthquake Resistant Design of Structures”.
9. IS 13920 (1993),“Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces”.
10. Dowrick D.J., “Earthquake Resistant Design”
11. Park and Pauley, “Reinforced Concrete Structures”
12. Pankaj Agrawal, Manish Shrikhande, (2006), Earthquake Resistant Design Of Structures
13. AERB monograph, (2008), SEISMIC SAFETY OF NUCLEAR POWER PLANTS

EN 610: Code Design for PVP (60)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
- Thick cylinder and sphere and derivation of Lame’s equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin- walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
- Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material

and allowable stresses. Design of saddle supports.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 and Div.2.
- Difference between metallic pressure vessel and FRP pressure vessels

Nuclear Pressure Vessels and Piping (30)
- Monotonic and Cyclic Stress-Strain Curve, Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Failure modes of pressure vessels, Ratchetting and shakedown.
- Organization of Boiler and Pressure vessel Sec. Ill code. Safety classification and Criterion for selection of ASME sec. Ill classes. Design loadings and service loadings as per NCA 2140.
- Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Definition of B, C and K stress indices.
- Design of Nuclear piping as per Sec. Ill div.1. Design rules for standard support as per NF 3400, Design rule for piping support - NF 3600.
- ASME code rule for component support
- Design rule for Plate and shell- Type support as per NF 3200, Design rule for Linear-type support - NF 3300.
- Design rule for component support - NF 3500, Core support structure Design - NG 3300.
- Fracture Toughness requirements for materials for pressure vessels, pipings and boltings.
- Failure Analysis Diagram.
- Protection against Nonductile Failure - Appendix G, Basis of Low Cycle fatigue Design. Fatigue evaluation of vessels.
- Strain concentration factor ' Ke', Local strain approach: Neubar and Zarka rule, Elastic and elastic-plastic fatigue analysis of nuclear pipings, Leak-Before-Break Design Concept.
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec. Ill.
- NDE requirements, Examination of welds, Acceptance standard.

References:

1. Harvey J.F., “Pressure Vessel Design”, CBS Publication
2. Brownell L.E., and Young E.D., “Process Equipment Design” Wiley Eastern Ltd., India
3. ASME” Pressure Vessel and BoilerCode”, Sec. VIII, Div. I and Div. II, 1985
4. American StandardCode for Pressure Piping”, - B31.1, 1972
5. American Standard Code for Pressure Piping”, - Petroleum, Refinery Piping, B31.3, 1972
6. “Standard of Tubular Exchanger Manufactures Association”, 7th Edition, 1988.

EN 611: Computational Fluid Dynamics & Heat Transfer (50)

Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):
- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme
- Laminar Boundary Layer and Forced Convective Heat (5):
- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
- Convective heat transfer for internal and external flows
- Low and high Prandtl number limits and different thermal boundary conditions
- Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer (5):
- Reynolds decomposition for turbulence
- Prandtl's mixing length theory, Mixing length models
- Structure of turbulent boundary layer over flat plate and through circular cylinder
- Calculation of friction factor and drag coefficient
- Analytical and semi-analytical correlations for calculating heat transfer coefficients
- Analogy between heat and momentum transfer

- Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
- Turbulence Modeling:
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
- Reynolds stress models: algebraic and differential models
- Low Reynolds number models
- Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
- **Natural Convection (3):**
- Basic Equations of natural convection
- Boussinesq approximation
- Derivation of Dimensionless groups from basic equations
- Analytical approximations
- Numerical solution of approximate equations

Numerical Solution of Complete Fluid Flow and Energy Equation (10):

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation
- Streamfunction-vorticity-temperature formulation
- Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
- Primitive-Variable (P-V-T) formulation
- Pressure velocity coupling for incompressible flow:
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
- Simple grid generation techniques for structured grid:
- Elliptic, parabolic and hyperbolic equation method
- Grid adaptation
- Domain decompositions in CFD and heat transfer
- SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer (12):

- Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
- Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.
- Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
- low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
- Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
- Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.
- **Heat Transfer With Phase Change (10):**
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
- Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model)
- Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)
- Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
- Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
- Critical Flow: Models for single – phase and two-phase critical flow.

References for CFD:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.

14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor &Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

EN 612: Computer Based System Design- I (25)

Hardware Design

- Overview of microprocessors and peripherals: 8086, 68000, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications
- Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL)
- Case Study: Design of a single board computer with shared memory interface, I/O board design using ADC, DAC etc with emphasis on signal conditioning and isolation
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues

EN 613: Computer Graphics and Visualization (35)

- Introduction overview, Graphics software/hardware and types of graphics applications (1)
- 2D/3D Geometric Transformations, Affined transformations-Translation, Rotation, Scaling, Shear and reflection. (3)
- Homogeneous coordinates, composite transformations, rotation with qutenion, current transformations and matrix stacks. (3)
- Two dimensional viewing 2D viewing – window, viewport, viewport transformations, clipping operations, line clipping algorithms – Cohen-Sutherland, Liang-Barsky, polygon clippimg algorithm – Sutherland-Hodgman. (4)
- Three dimensional graphics – Planer geometric projections – parallel and perspective, Mathematics for projections, classical three-dimensional viewing, specifying views, viewing transformations, 3D clipping operations. (4)
- Hidden surface removal, object space and image space approach, back face culling, z-buffer algorithm, LOD.(2)
- Illumination and shading – Basic illumination models, light sources, material properties, polygon shading methods – flat, gouraud and phong shading, ray tracing methods. (2)
- Color - Color perception, color models – RGB,CMY,HSV (1)
- Visual Realism – Depth cuing, texture mapping, transparency, shadow, steropsis. (2)
- Curves and surfaces – Representation of curves and surfaces, Algebric and geometric form, Blending functions, interpolation, Hermite, Bezier, B-spline curves and surfaces, Rational polynomials, NURBS (5)
- Modern Graphics Architecture – Graphics Pipeline, GPU, PCI Express (2)
- Case Study – Using OpenGL (3)
- Scientific Visualization – Introduction, Geometry (Structured & Unstructured Grids), Data Representation (Scalar, Vectors), Volume Rendering (Marching Cubes, Ray Casting) (3)

EN 614 Construction Materials, Management and Quality Assurance (30)

Construction Materials

- Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
- Reinforcement: Passive and active (Prestressing)
- Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
- Paints
- Water-proofing materials & membranes

Shuttering/Formwork

Design philosophy, different design requirements, climbing shutter design, slip form work.

Prestressing system

Cable ducts, anchorage and grouting, qualification of Prestressing system

Quality Assurance (QA)

- QA in Civil Engineering design
- QA in materials
- QA in construction
- QA in operation & maintenance
- Inspection during construction, Regulatory inspection

Construction Procedure & Construction Safety

- Dewatering, rock excavation, consolidation grouting

- Construction safety, Job Hazard Analysis.

Contract Management

Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication

References:

1. Singh, K. A. N."ISO 9000-Quality Systems", Dolphin books, New Delhi.
2. Quality systems requirements (QS 9000) – Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 3rd edition
3. Quality system assessment (QSA) Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 2nd edition
4. CPWD Works Manual (2012), Central Public Works Department, Government of India, Published by DIRECTOR GENERAL, CPWD, NIRMAN BHAWAN, NEW DELHI-110 011.
5. Manual of Internal Inspection/DAE Works Procedure (2010), Department of Atomic Energy, Government of India.
6. ATOMIC ENERGY (FACTORIES) RULES (1996), Atomic Energy Regulatory Board, Government of India.

EN 615: Corrosion (15)

- Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables, composition and heat treatment. (3 Lectures)
- Forms of corrosion: uniform attack; corrosion rate measurements, Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion, low temperature sensitization, corrosion of weldments; stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen embrittlement, hydrogen attack, corrosion fatigue; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, failure analysis, specification tests, advanced methods for on-line corrosion monitoring. (7 Lectures)
- General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification. (1 Lecture)
- Corrosion in the nuclear industry – Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. corrosion in fluoride and ammonia containing environments; liquid metal corrosion. low alloy steels, stainless steels and Ni and Cu base alloys, protective magnetite formation on carbon steel, stress corrosion cracking of stainless steels and nickel base alloys. high temperature oxidation and hydriding of zirconium alloys, materials for fast breeder reactor system. Effects of radiation on corrosion (4 Lectures).

References:

1. Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. Corrosion – L.L. Shrier (Ed.) Vol.I & II, 1963.
5. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
6. Modern Electrochemistry, Vol. 1 & 2 – J. O.M. Bockris and A.K. Reddy
7. Corrosion of Stainless Steels – A.J. Sedricks.
8. Stress Corrosion Cracking – Materials Performance and Evaluation – Ed. Russel H. Jones, ASM Int., 1993
9. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN 616: Distributed Computing (45)

Advanced Computer Architecture

- Advances in CPU Architecture
  a. Advancements in CPU architecture – Dynamic Instruction level parallelism, Branch prediction, register renaming
  b. Static instruction level parallelism - EPIC, VLIW
  c. Hyperthreading
- Multi core architectureAdvances in Memory
  a. SDRAM, DDR, DDR-2
  b. Registered ECC, FB-DIMM
  c. CPU – Memory Interfacing techniques - FSB, Hypertransport, Quickpath
- Advances in I/O interfaces
  a. Shared I/O bus
  b. Switched I/O fabric
  c. Serial and parallel I/O bus
  d. Case studies - PCI, PCI-X, PCI-Express, PCI-Express Gen2
- Advances in Interconnect techniques
  a. Shared and switched networks
  b. Interconnect fabrics

  c. Approaches for improving interconnect performance
  d. Case studies – Ethernet, Infiniband, SCI
- Cache
  a. Associative, Direct mapped
  b. Write through, Write back
  c. MESI
  d. Shared caches
- Advances in storage systems
  a. Direct attached storage, Network attached storage, Storage Area Networks
  b. File level and block level accesses
  c. Storage protocols
  d. Case studies - ATA, SATA, SCSI, SAS, Fiber channel
  e. Case studies - FC, iSCSI, iSER, SRP

Parallel Computing

- Introduction to High Performance Computing
  a. Need for HPC
  b. Applications of HPC
  c. HPC Overview – Conventional Supercomputers, Parallel Computers, Classification (SISD, SIMD, MIMD)
- Pipelining, Vector processing, SIMD
  a. Pipeline, Speedup and Efficiency of pipeline
  b. Pipeline stalls, out of order execution
  c. Techniques to improve pipeline efficiency
  d. Superscalar, Superpipelined, VLIW, EPIC architecture
  e. Vector processors, vector instruction sets, registers
- MIMD Architecture
  a. Classification of MIMD machines
  b. UMA, NUMA, CC-NUMA, COMA, NORMA
- Interconnection networks and topologies
  a. Interconnection Concepts – Bandwidth, Latency, Network Diameter, Bisection Width, Node degree, Static and Dynamic Networks
  b. Various topologies – Ring, Hypercube, Torus, Mesh, CLOS, Fat tree etc.
- Current Parallel Architectures
  a. Parallel Vector processor
  b. Symmetric Multiprocessors
  c. CC-NUMA
  d. Massively Parallel Computers
  e. Clusters of workstations
- Clusters
  a. Classification of clusters
  b. Cluster software
  c. File systems for clusters
- Software concepts of High Performance Computing
  a. Parallelism – Algorithmic, Geometric, Event, Data
  b. Granularity – Coarse and Fine grains
  c. Speedup, Efficiency, Amdahl's and Gustaffson's Laws
- Parallel Programming Models
  a. Shared Variable Model
  b. Message Passing Model
  c. Threads Model
  d. Data parallel Model
- Design of parallel algorithms
  a. Data dependencies
  b. Data partitioning
  c. Communication patterns
  d. Synchronization
  e. Load balancing
- Parallel Programming Environments
  a. Parallel Languages
  b. Parallel Extensions to Sequential Languages
  c. Parallel APIs – MPI, OpenMP
- Parallelization of example programs – Dot product, Matrix Multiply, etc. at the pseudo code level
- Message Passing Interface (MPI)
  a. Introduction to MPI
  b. MPI constructs
  c. Example programs in MPI
- Benchmarking
- Case studies – ANUPAM series of parallel computers

Grid Computing

- Introduction to Grid Computing
  a. Evolution of Grid Technology comparison with contemporary technologies,
  b. Issues of virtualization, events that have lead to grid computing, client-server, peer-peer, operating system perspective,
  c. Overview of Grids: Formal definition of Grids - how do they work?
  d. How are they different from clusters? Computational Grids, Data Grids, Production Grids worldwide - Applications of Grid.
- Components of Grid
  a. Grid Security- concepts of single sign on, How the security requirements are met?
  b. Concept of Digital certificate- How RSA works? - Working of Kerberos
  c. Concepts of Myproxy services
- Grid Resource management
  a. Issues in Grid Resource management
  b. Abstract model for Grid Resource Management
- Grid Scheduling
  a. Issues in Grid Scheduling
  b. Taxonomy Of Grid Schedulers
  c. Resource Discovery issues
- Visualization and interactivity in Grids, High Performance Computing in Grids- Grid enabled MPI – MPI-G2
- Grids Services
  a. How are they different from Web services?
  b. Concepts and their implementation
- Data Management in Grids
- Information services- Building information services in Grids
- Grid Portals, Their Purpose, Issues in Portal design, discussion on portlets
- Grid Workflow
  a. Concepts
  b. Taxonomy of Grid Workflow
- Semantic Grids
- Virtualization
  a. Concept
  b. Its utility in Grid Computing
- Grid Enabling Applications
  a. Issues
  b. Implementations
- Discussion about GRID standards
  a. OGSA
  b. OGSA-DAI
- Comparative study of different Grid Middlewares
  a. Lacuna in current Grid Architectures
  b. Grid as operating system of operating systems
- Case study of Middlewares:
  a. GT4,
  b. Glite
  c. DAE Grid
- Future of Grids - Concepts of Cloud Computing

References

1. Advanced Computer Architecture, Kai Hwang
2. Scalable Parallel Computing, Kai Hwang, Zhiwei Xu
3. Introduction to Parallel Computing, Ananth Grama, George Karypis, Vipin Kumar and Anshul Gupta
4. High Performance Computing – Paradigm and Infrastructure, Laurence T.Yang, Minyi Guo
5. Storage Networks Explained, Ulf Troppens, Rainer Erkens, Wolfgang Muller
6. Computer Organization and Architecture: Designing for Performance, William Stallings
7. Grid Computing – Making the Global Infrastructure a Reality, Fran Berman, Geoffery Fox, Anthony J. Hey
8. The Grid2 Blueprint for a new Computing Infrastructure, Ian Foster, Carl Kesselman
9. Grid Computing for developers, Silva
10. Current Journal Articles in the area of Parallel Computing, Computer Architecture and Grid Computing

~~EN 617~~

EN 618: Electrical Systems for Nuclear Power Plants (30)

- Interaction of Nuclear Power Station With The Grid Number of evacuation lines; Optimum size of NPP in grid; Brief introduction to Power System Analysis - Short circuit, load-flow and stability studies, Tariff and Capacity factor.
- Ehv Switchyard Design Switching schemes; Clearances; Com parison between types of svvitchyards; Brief introduction to equipments in switchyard and their functions; Lightning arresters and insulation co-ordination; Lightning protection.

- Protection Line protection; Generator protection; Transformer protection; Motor protection.
- Selection of Transformers Accessories; Types; Specifications and testing; Voltage regulation calculations.
- Selection of MV & LV Switchgear Types; specifications and testing, MCCS; Distribution boards; Generator circuit breaker; ELCB.
- Motors In NPP Types of motors; Radiation withstand requirements; Performance requirements.
- Station Auxiliary Systems of NPP Class 1, 11, Ill and IV systems classifications; Nature of electrical loads and supply voltages; Effect of voltage variation on Electrical equipments and remedial measures; Emergency transfer system; Load shedding scheme; Auto transfer schemes; synchronizing schemes.
- Class 1 e requirements Cabling, lighting & grounding Specific requirements for safety related electrical equipments & systems in NPR Cabling, Lighting, Grounding systems in NPP; Bus ducts. Introduction to seismic qualification of electrical equipments., Electrical system control from Control Room. Introduction to []G sets, UPS & Batteries.
- Billing and metering scheme for a typical NPP. Introduction to brushiess and static excitation systems for Generators. Introduction to SCADA systems.

References:

1. Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity :.CBProblems and Remedial Measures. IAEA Report - Technical Reports Series No. 271.
2. Elements of Power System Analysis - W.D. Stevenson
3. Electrical Transmission & Distribution Hand Book - Westinghouse Electrical Co., USA
4. Protective Relays - Application Guide, GEC Measurements.
5. Manual on Layout of Substations - CBIP, New Delhi
6. The J & P - Transformer Book
7. The J & P - Switchgear Book
8. Utilization of Electrical Energy - E. Openshaw Taylor
9. Cabling - Siemens Hand Book
10. Illumination Engineering Society - IES Lighting Hand Book
11. Modern Power Station Practice - Volume D - Electrical System & Equipment, British Electrical International.
12. Standard Hand Book for Electrical Engineers - Donald G. Fink and H. Wayne Beaty
13. IEEE-80 - IEEE Guide for Safety in AC Substation Grounding
14. IEEE-308 - Criteria for class 1E Equipments for Nuclear Power Generating Stations
15. IEEE-323 - Qualifying class 1E Equipments for Nuclear Power Generating Stations
16. Indian Nuclear Power Programme with PHWR - Published by Directorate of E & P A, NPCIL, Bombay
17. IS-3716 - Application Guide for Insulation Coordination
18. IS-2309 - Code of Practice for the Protection of Buildings and Allied Structures Against Lightning
19. Handbook of Batteries and Fuel Cells - McGraw Hill Book Company

EN 619: Embedded & Computer Based System Design (45)

Module I [22]

Part A - Microprocessor based Design [10]

- 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
- Introduction to Microcontrollers and comparison with Microprocessors
- Introduction to DSP Processors

Part B [12]

- ARM processor: architecture details and introduction to programming
- Board level buses: I2C and SPI
- Introduction to USB

Module II [23]

Part A – Computer based hardware design [8]

- Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
- Industry standard bus systems: ISA, PCI, VME: Mechanical, electrical, functional and procedural specifications
- Multi processing, bus arbitration and Plug and Play
- System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
- Design Case Study:
- I/O Board design, bus interface (ISA, PCI) FIFO and shared memory interfaces.

Part B - Computer Communication and Networks [7]

- Overview of asynchronous and synchronous communication standards
- Encoding (NRZ, Manchester),
- Ethernet, Industrial networks, Field Bus, CAN bus
- Networking hardware: Cables, Hubs, switch and routers.

Part C - Software development for embedded and PC based systems (8)

- Basic RTOS concepts
- C programming for ARM based applications
- Programming for PC based systems:
  - Interface between applications & device drivers
  - Windows: Programming of I/O, ISR, DMA

References:

1. Computer Networks. By: A.Tanenbaum

2. Principles of Communication. By: Taub and Schilling.
3. Microprocessors and Interfacing. By: D.V.Hall
4. CAN Application Note: Robert Bosch GmBH
5. Microcomputer System 8086/8088 family- Architecture, Programming and Design.

Yi -Cheng Liu & Glenn.A.Gibson.

6. The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486 and Pentium series: Architecture, Programming and Interfacing. By: Barry.B.Brey.
7. The Scientist and Engineer's guide to DSP. By: Steven.W.Smith
8. High speed digital design: A handbook of black magic. By: Howard Johnson & Martin Graham
9. Interference control in computer and microprocessor based equipment. By: Michel Mardiguian
10. Interfacing to the IBM Personal Computer. By: Lewis C. Eggebrecht
11. PCI bus system architecture – Mindshare publication
12. VME bus standard document
13. USB complete. By: Jan Axelson
14. ARM System Developer's Guide. By: Andrew Sloss, Dominic Symes, Chris Wright
15. Designing Embedded Hardware. By: John Catsoulis

EN 620: Extractive Metallurgy (40)

Principles of Metallurgical Thermodynamics (15)

- Thermodynamic Functions: Enthalpy, Entropy, Free Energy, Chemical Equilibria
- Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Phase Diagrams
- Solution Thermodynamics, Integral and Partial Molar Thermodynamic Properties
- Experimental Methods- Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.
- Computation of predominance area diagram and Phase diagrams

Kinetics(5)

- Principles of Chemical Kinetics, Homogeneous Reactions, Effect of Concentration, Effect of Temperature
- Theory of Reaction Rates, Heterogeneous Reactions, Reaction Models, Mass Transport Phenomena, Heat Transport Phenomena.

Process Metallurgy (25)

- Methods of attaining High Temperatures,Measurement of Temperature,
- Vacuum Metallurgy Principles and Equipments,
- Process Metallurgy of Rare and Refractory Metals,
- Resources of Special Metals, Beneficiation Methods, Physical, Chemical, Separation Methods, Halide Metallurgy, Vacuum Metallurgy, Electro Metallurgy, Reduction Processes, Refining Processes, Ultrapurification Processes,
- Preparative aspects of Special Materials and Alloys,
- Advanced Materials Processing Techniques,
- Reprocessing of irradiated nuclear fuels, Process Metallurgy of - Uranium, Thorium, Plutonium, Beryllium, Zirconium, Hafnium, Niobium, Tantalum, Rare Earths.

EN 621: Finite Element Techniques (35)

- **Introduction to FEM:** Weighted residual method, Galerkin's methods, Weak form formulation, Piecewise approximations. Basis of Finite Element Method, Variational principles, energy principles in structural mechanics, Element libraries 5
- **Element shape functions**: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements. 15
- **Bar element:** Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss
- **Beam element:** Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- **2D plane elements** – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- **2D isoparametric formulation** – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature.
- **Incompatible displacement model**: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements.
- **Introduction and Application to 3D elements:** Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Plate bending elements: Thin and Thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration

- **Shell element**: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking.
- **Introduction to Nonlinear problems:** Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method
- **Finite element applications for design**:Finite element modelling and discretization criterion, h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

References:

1. **Bathe K.J., Finite elemen**t procedures in engineering Analysis, Prentice Hall of India, 1990
2. Cook R.D., D.S. Malkus and M.E. Plesha, Concepts and Applications of finite element analysis, John Wiley, 2000.
3. Reddy J.N., An Introductions to Finite Element Method, 4th Edition, McGraw Hill, 1993.
4. Seshu P., Finite Element Method, Prentice Hall of India, New Delhi, Fourth printing, 2006.
5. Zeinkiewicz, O.C., and K. Morgan, Finite elements and approximation, John Wiley, 1983.
6. Zeinkiewicz, O.C., and R.L. Taylor, The Finite Element Method, Vol. 1 & 2, Tata McGraw Hill.
7. M. Asghar Bhatti, Advanced Topics in Finite Element analysis of Structures, John Wiley, 2006.

EN 622: Fracture Mechanics (40)

Linear Elastic Fracture Mechanics (5)

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks and concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture
- Superposition of K
- Plastic zone correction - Irwin's approach
- Basic design principles in LEFM
- **Plane stress vs. plane strain - Variation of toughness (KIc and Kc)**

Elastic-plastic Fracture Mechanics (5)

- J-integral as energy release rate
- J-integral as amplitude of HRR singularity
- J-integral as contour integral
- Laboratory measurement of J-integral - η factor approach
- Fracture resistance of materials – J-R curve and JIc and possible explanation for shape of J-R curve
- Stable and unstable crack growth – Tearing Modulus approach
- J-controlled fracture
- Basic design principles in EPFM
- **J-estimation schemes**

Laboratory measurements of material fracture properties (2)

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- KIc testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of JIc from J-R curve – blunting line equation and SZW

Limit load (2)

- Definitions of limit load
- Global and local limit load
- Basic expressions of limit load of some common geometries

R6 method (2)

- Basic principles of R6 method
- Sensitivity analysis

Fatigue (7)

- Conventional high and low cycle fatigue – S-N diagram, Coffin-mansion relation
- Fatigue crack growth under constant and variable amplitude loading
- Rainflow algorithm
- Environmental effects on fatigue crack growth
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- **Experimental determination of Paris law constants as per ASTM procedure Fracture assessments of welds (2)**
- Basic aspects of fracture assessment of welds – residual stress effect
- Special considerations in fracture toughness determination of welds

PTS and ASME reference/Master curve (6)

- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Warm pre-stress effect

- Reference ASME curve in assessment of PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Computational Fracture Mechanics(4)

- Barsoum's crack tip element and showing the singularity from shape function
- Evaluation of SIF by displacement correlation technique from FEM
- Evaluation of 2-D J-integral by contour integral technique
- Evaluation of 3-D J-integral by domain integral technique

Fracture Mechanism (4)

- Basic mechanism of ductile fracture – Void nucleation, void growth and coalescence
- Cleavage fracture- Mechanism of cleavage initiation
- Mathematical model of cleavage fracture toughness, explanation for scatter in cleavage fracture toughness, RKR model

Application of Fracture Mechanics Principles to Leak-Before-Break (1)

- History of LBB
- Basic concepts of LBB – three levels
- Application to Indian reactors

EN 623: Mechanical Metallurgy (30)

Elasticity and Plasticity

- Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
- Equations of equilibrium.
- Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria

Dislocations:

- Elastic stress field of edge and screw dislocation.
- Self energy of dislocations.
- Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP

Deformation Behaviour

- Single crystal deformation, critical resolved shear stress, Schmidt's factor, Thermally activated deformation, Strengthening mechanisms.

Creep of Metals and alloys

- Various stages of creep and creep laws
- Types of creep tests, evaluation of parameters of a creep test and its use
- Factors influencing creep resistance
- Deformation mechanism map and identification of creep mechanisms, Irradiation creep

Fracture Mechanics

- Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
- Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
- Concepts of R-curves, Evaluation of various fracture parameters, fracture control

Fatigue of Metals:

- High cycle and low cycle fatigue
- Factors contributing to fatigue failure and its mitigation
- Various stages of fatigue damage and Fatigue life improvement
- Fracture mechanics approach to characterize crack growth behavior

References:

1. Engineering Fracture Mechanics - S. A. Meguid.
2. Mechanical Metallurgy - G. E. Dieter
3. Mechanical Behaviour of Materials - T. H. Courtney
4. Elementary Dislocation Theory - J. Weertman & J. R. Weertman
5. Introduction to Dislocations - D. Hull
6. Mechanical Metallurgy : Principles and Applications - M. A. Meyers & K. K. Chawla
7. Deformation and Fracture Mechanics of Engineering Materials - R. W. Hertzberg

EN 624: Mechanics of Solids (40)

Introduction to Theory of Elasticity Mathematical Frame Work (2)

- Illustration of concepts of elasticity, Stress-strain curve, Isotropy, Homogeneity
- Illustration of equilibrium equation, Cauchy equation and stress strain relation in 1-D
- Solution of 1-D boundary value problems using theory of elasticity equations: (a) Natural frequency determination. (b) Solution under external excitation force to show resonance condition, stress wave etc.
- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Kronecker Delta, Permutation symbol ; Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of Stress (3)

- Description / Notations of Forces
- Description / Notations of Stress
- Component of stress
- Reciprocity of shear stress in 3D

- Stresses Transformation using direction cosines
- Stress Traction Vectors or Traction Vectors
- Stress component on an arbitrary plane
- Principal stresses
- Stress Invariants
- Mohr's Diagram for 3D state of stress
- Hydrostatic and Deviator components of stress
- Principle planes and their orthogonally
- Octahedral plane, Octahedral stresses
- State of pure shear

Analysis of Strain (2)

- Description / Notation of Strain in 3D
- Components of strain
- Strain Transformation using direction cosines
- Principle Strains, Strain Invariants
- Cubical Dilation
- Strain Deviator Tensor
- Maximum and Octahedral Shear Strains

Principles and Fundamental Equations of Elasticity (8)

- Strain and displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Stress and strain relationship
- Equations of equilibrium (Navier's Equations , Lame's equations)
- Strain Energy
- Uniqueness theorem
- Bounds on elastic constants
- Superposition Principles
- Saint-Venant's Principle
- General Solution Procedures for a elasticity problem

Two and Three Dimensional Formulation (8)

- Elasticity equation for Plane strain
- Elasticity equation for Plane stress
- Biharmonic equations
- Airy's Stress Functions
- Solution for beam bending problems
  a) Special cases by use of polynomials
  b) General solutions using fourier series method
- Solution in polar co-ordinates
  a) Tube subjected to internal and external pressure (Lame's problem) ; shrink fit
  b) Stress Concentration due to a circular hole in stressed plate (Kirsch's problem)
- Stress in spherical shell under internal and external pressure

Thermal Stresses (4)

- Thermal stress definition and their significance
- Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
- 2D thermal stress analysis
  a) The problem of circular disk
  b) The problem of circular cylinder
- 3D thermal stress analysis : The problem of sphere
- Transient thermal stress

Introduction to Plasticity (4)

- Stress-strain curve, Examples of Multiracial stress
- Different Yielding Criteria and their significance
- Yield Surface , Tresca and von-Mises
- Path dependence of Plastic Strains
- Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
- Prandtl-Reuss Equations
- Incremental or flow theory
- Deformation theory of plasticity, Hencky equations
- Plasticity Relations (plastic strain and total strain)

Theory of Plates

- Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
- Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.

- Introduction to analysis of Thick Plates

Theory of Shells

- Introduction to shell theory.
- Classification of shells, Membrane theory of shells of revolution and translation.
- Application to spherical, conical and cylindrical shells.
- Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
- Application to cylindrical shells, spherical and conical shells.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Piblications, Inc.
6. Plasticity Theory and Application, Alexander Mendalson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K .Chandrasekhara, University Press
9. Stresses in shell- W.Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN 625: Modern Control Systems Design and Simulation (35)

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analyti- cal methods of modeling.
- State Space Characterization State 5PaCe representation, solution of state equation, state Transition matrix, properties of STM, computation methods, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kaiman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Control- lability and observability of Discrete data systems.
- Stability liapunov,s stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design Guillemin-Truxal design Procedure, pole placement by state feedback. H,' meth- od, Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kaiman filter as OPtimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency re- sponse methods, Recurise Least square Identification technique.
- Introduction to Adaptive and Robust control.

References:

(Reference materials will be provided during the course)

EN 626 Design Basis Hazards and Geotechnical Engineering (40)

Design Basis Hazards (Natural)

Role of civil engineering in achieving overall nuclear safety: Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.

Introduction to hazard evaluation:

Hazard due to internal and external events, case studies.

Seismic Hazard

Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum

Flood hazard

- Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
- Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
- Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding

Wind hazard

Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India,Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.),

Solar radiation

Temperature map(Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)

Snow hazard

Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides

Design Basis Hazards (Human-Induced)

Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)

Geotechnical Engineering

Soil Mechanics

- Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
- Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
- Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability; Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.
- Bearing capacity – Determination of bearing capacity for soils and Rock.

Geotechnical and Geophysical investigations:

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

Soil Dynamics and Liquefaction

Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

References:

1. Kramer . S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. **I**S 875(Part 3) (1987) " Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. **I**S 875(Part 4) (1987) " Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance"
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – "Basic and applied soil mechanics".
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities'
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN 627: Networking and Information Security (40)

Networking

General Issues in the transport of data traffic over networks of digital transmission media.

- V.24, V.35, Modems, xDSL, Multiplexing

Circuit switching & Packet switching

- ISDN (BRI), PRI.

Datalink Layer

- Data link layer protocols, Medium access method, Flow control, Error Control
- Ethernet technologies, Bridge, Switching, Analysis of collision domain, Layer 2-based network attacks

Introduction to Satellite communication

- Satellite orbits, VSATs, VSAT network Topologies

Network Layer

- IP, IP Fragmentation, ARP, DHCP, Classes of IP address, CIDR, Layer 3 based network attacks, ICMP
- IP Routing algorithms, RIP, OSPF, BGP.

Transport Layer

- TCP & UDP, TCP Call establishment & Call termination, Sockets, TCP state machine, TCP timers
- RTP, Layer 4 based network attacks

Firewall
- Layer 3 firewall, Layer 4 firewall, Application based firewall

Network Applications
- FTP, DNS, Mail, application based attacks

Network Security
- Data security, type of possible attacks on data etc?
- Ecurity services for secure data communication?
- Like Identification, Authentication, Authorization, Data Integrity, Confidentiality, Non-repudiation, Replay, Availability etc.
- Cryptography and its services Cryptology, cryptanalysis.
- Components of cryptology like algorithms, Keys, Message Digest, Digital signature, Digital Certificates etc. with block diagram.

Types of Algorithms
- Symmetric and Asymmetric.

Symmetric Algorithm
- stream cipher algorithms
- Type of stream ciphers, Unconditional security with stream ciphers, one time pad, LFSRs, Linear complexity in LFSRs, Shanon's concept of perfect secrecy
- Type of possible attacks, Conversion of block ciphers onto stream ciphers etc.

Asymmetric Algorithms
- Diffie-Hellman, RSA with detail mathematics and applications.
- Key management methods for symmetric and asymmetric keys.
- PKI infrastructure, Digital certificates, digital signatures for asymmetric key managements. CRL (certification revocation list)
- Symmetric key certificates. Difference between symmetric and asymmetric key certificates etc.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN 628: Nuclear Chemical Engineering (35)

Intoduction

Role of chemical engineering in the nuclear industry

Recovery & processing of nuclear materials from ores / intermediates (5)
- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources , New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths : Occurrence, importance and separation.

Uranium Conversion / reconversion (6)
- Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF6: choice and problems, Fluorination of UF4, Purification and collection process for UF6, Conversion to UO2.

Isotope Separation (9)
- Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical- exchange: H2S-H20, NH3-H2, monothermal and bithermal process, salient features of equipment like contacting towers, tower internals. Heavy water plants in India. Final enrichment and upgradation plants. Distillation and electrolysis, Tritium removal.
- Laser based separation and new processes (2)
- A brief description of laser based isotopic separation processes.
- Fuel Reprocessing (6)
- Fuel Reprocessing: Introduction to Radiochemistry; Differences between a conventional chemical plant and radio chemical plant- Process and equipment limitations, criticality, safety and other hazards, numerical examples, ventilation, shielding, Typical compositions and burn-up of irradiated nuclear fuels.
- Thermal Reactor Fuel Reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements. Evolution of solvent extraction process fore reprocessing, 'PUREX' and 'THOREX' processes in detail; Head-end process, flow sheet, co-decontamination and partitioning cycles.
- Fast Reactor Fuel Reprocessing and Introduction to reprocessing of Thorium based fuels.

Nuclear Waste Management (7)

- Sources, characteristics and classification of radioactive wastes; general philosophies of management.
- Method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Discussion of the various chemical engineering operations involved. Use of desalination and membrane separation techniques in waste management.
- Conditioning of radioactive waste- cementation, bituminisation, use of polymers and vitrification methods.
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical Engineering in Decommissioning of nuclear facilities.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series,IAEA,Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)

EN 629: Nuclear Materials (50)

Melting & Casting (10)

- Introduction to vacuum measurement units and types of vacuum pumpsincluding diffusion pump & turbo- molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and methods to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits

Mechanical working of Metals (10)

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Methods of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Powder Metallurgy & Advanced Ceramics (30)

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production methods, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.
- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. "Introduction to Ceramics" by Kingery et al.
11. "Ceramics Through Chemistry" by Brinker et al.
12. "Electroceramics" by Buchanan
13. "Ceramics Fabrication Processes" by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman

16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
19. 'Ceramics Fabrication Processes" by Wang.

EN 630: Nuclear Metallurgy (30)

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post- Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradition effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels,definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister fomation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Bengamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brain R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN 631: Physical Metallurgy (40)

- Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor Stereographic projection, X-ray, Electron and Neutron diffraction Common Crystal structures and quasi crystals, Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics
- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation. Ordered omega and Hydride formation.
- Recovery, Recrystalization and Grain Growth

References:

1. Physical Metallurgy Principles - R. E. Reed-Hill
2. Modern Physical Metallurgy - R. E. Smallman
3. Introduction to Metallurgy - A. H. Cottrell
4. Physical Metallurgy - P. Haasen
5. Introduction to Physical Metallurgy - S. H. Avner
6. Structure of Metals - C. S. Barrett & T. B. Massalski
7. Crystallography and Crystal Defects - A. Kelley and G. W. Groves
8. Principles of Phase Diagrams in Materials Systems - P. Gordon
9. Thermodynamics of Alloys - C. Wagner
10. Introduction to Metallurgical Thermodynamics D. R. Gaskel
11. Physical Chemistry of Metals - L. W. Darken and R. W. Gurry
12. Metallurgical Thermochemistry- O.Kubuschewski

13. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering - K. Denbigh
14. Modern Chemical Kinetics - H. Eyring
15. Kinetics of Phase Transformations in Metals - J. Burke
16. Transformation in Metals - P. G. Shewmon
17. Phase Transformations in Metals and Alloys - D. A. Porter and K. E. Easterling
18. Diffusion in Solids - P. G. Shewmon
19. Modern Metallography - R.E. Smallman and K.H.G. Ashbee
20. Electron Optical Applications in Materials Science - L. E. Murr
21. Electron Microscopy and Analysis - P. J. Goodhew and F. J. Humphreys
22. Defect Analysis in Electron Microscopy - M. H. Loretto and R. E. Smallman
23. Thermoanalytical Method of Investigation - P. D. Garn
24. Thermal Analysis - T. Daniels
25. Methods of Surface Analysis - A. W. Czanderna (Ed.)

EN 632: Process Control and Instrumentation (MT)(25)

Principles of Measurement (2)

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.

Sensors, Transducers and Transmission methods for parameters (10)

- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical& Radiation Pyrometers.
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli's Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

Principles of Automatic Control Systems (8)

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doeblin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN 633: Process Control & Instrumentation (EE)(30)

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysterisis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of following process variables
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter, Different types of standard pressure taps for orifices. Variable Area Flowmeters- Glass tube rotameters, armoured rotameters, bypass rotameters,
- Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs- Wire wound and thin film RTDs, self heating error, differential temperature measurement by using RTDs. Thermistors - Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer, two colour pyrometer.
- Pressure and Differential Pressure: Manometers-U tube, well and inclined manometers, mechanical pressure gauges- Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressureTransducers and transmitters, Smart pressure transmitters, Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauges, Mcleod gauge.
- Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass,

Purge system, capacitance probes, displacer type, ultrasonic type, nucleonic type and conductivity type level gauge.
- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- Distributed Control System: Programmable Logic Controllers, Smart Transmitters Control room concepts.
- P & I Diagrams: P &ID symbols, Typical P &ID.
- Class 1E Instruments in nuclear power plant: Definition of Class 1E equipment, various tests for Class 1E equipment qualification.

References:

1. 'Fundamentals of Temperature, Pressure and Flow Measurements" – Bendict
2. "Instrument Technology", Vols. 1 to 5, - E.B. Jones, Butterworth and London
3. "Mechanical and Industrial Measurements" - R.K.Jain, Khanna Publishers, New Delhi
4. "Measurement System, Application and Design", Ernest D. Deophhlin.
5. "Fluid Meters" - ASME Publication
6. "Principles and Practice of Flow meter Engineering" - L.K. Spink, Published by the Foxboro Company
7. "Process Instruments and Control Handbook" - Edited by D.M. Considine, McGraw Hill
8. "Handbook on Applied Instrumentation": Edited by D.M. Considine and S.D. Ross, McGraw Hill
9. "Instrument Engineer's Handbook", Part I & II: Edited by Bela G. Liptak, Chilton Book Company
10. "Instrumentation for Process Measurement and Control", Norman A. Anderson, Hilton Co.
11. "Manual on the use of Thermocouples in Temperature Measurements" (ASME Publication by subcommittee 4).
12. "Process Control Systems: Application Design and Tuning". F.G. Shinskey, Mcgraw Hill.
13. "Fluid Meters - Their theory and Application" Edited by H.S. Bean. ASME Publication

EN 634: Process Dynamics & Control (45)

Instrumentation , Controls & Computers(20)

- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real- time control applications.

Advanced Process Control (25) Background theory

- Introduction to state-space controls, state & measurement equations, general solution **o**f the state equation, state- transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.

Introduction to Advanced Process Controls

- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

EN 635: Process Modelling, Simulation & Optimization (45)

Simulation

- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Methods of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent methods.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution methods for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization:

- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies.Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals,evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.

- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

References:

1. Bisio, A and R.L.Kabel, 'Scale-up of Chemical processes', Wiley-Interscience,NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W.Hoffman, A.I.Johnson, D.R.Woods and P.T.Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Methods and Modelling for Chemical Engineers, Winley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain,A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)
6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs,E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Rekliatis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Methods & applications, John Wiley,N.Y (1983)

EN 636: Reactor Control and Instrumentation and Human Machine Interface (40)

Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
- Practical

EN 637: Reactor Control Engineering & Instrumentation -1(15)

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic methods (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant Tav program, constant pressure program, Boiler level and

pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., " Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN 638: Reactor Control Engineering & Instrumentation-2 (20)

- Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.
- Reactor Instrumentation
  - Measurement ranges of reactor neutron flux and considerations
  - Principles of detection and types of neutron detectors: in-core and out – of –core
  - Modes of signal processing: Pulse, Campbell, DC
  - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- Health Physics Instrumentation
  - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
  - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
  - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Contamination Monitors

References:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerl

EN 639: Reliability Engineering (EE)(20)

Introduction: Reliability Engg Applied to C&I Systems

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

Reliability Maths/Statistics

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

Fault Tolerance and Systems Reliability:

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

QA/QC Concepts in Brief:

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.

Environmental Qualification and Reliability Testing:

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

PSA/PRA Concepts in NPPs:

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

Additional safety concepts:

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
- Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc.

References:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
6. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
7. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
8. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
9. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
10. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), ('Formal Methods' has been explained).
11. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
12. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
13. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN 640: Software Engineering and Formal Methods (40)

Software Engineering (20)

- Importance of Software Engineering (1)
- Life cycle, Phases and Work-Products of different Phases, traditional models, agile models, Extreme programming (1)
- Project Management: Relationship to lifecycle, planning, control, Risk Management, Cost Models.(1)
- Requirements: Gathering, Categorization, Analysis, and Specification.(1)
- Software Architecture and Design: Architectural Styles, Design Notation, Design principles. (5)
- Object oriented Design: OOAD, Design Patterns (7)
- Testing: Principles of program Testing, Test Coverage, Static Analysis, and Tools for testing. (2)
- Support Activities: Configuration Management, Verification and Validation, Software Engineering Standards, Documentation formats, Tools and environments for Software Engineering (2)

Formal Methods (20)

- Introduction to Formal Methods, Role of Formal Methods in Software Life Cycle – development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, Statecharts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing - Assertions and their verification (dynamic and Static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)

- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic,, Case study from hardware and software, model cheking tools (SPIN, NuSMV etc.) (4)

References:

1. Software Engineering: Roger S. Pressman McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Adison-Wesley
3. Unified Modeling Language *User Guide*: G. Booch, J. Rumbugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I & II , Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K. McMilan, Kluwer, 1993

ELECTIVE COURSES

EN 701: Advanced Computational Techniques (30)

Programming Language C++

- C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.
- C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initialisers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogona Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions,parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

EN 702: Advanced Electrical Engineering Design-I I (25)

Special Electrical Machines

- Special Electrical Machines and their applications :Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

Pulse Power Technology

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

EN 703: Artificial Intelligence Methods & Applications (30)

- **AI Basics**Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert

Systems.

- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence **theorem,** Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification methods, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig
2. Genetic Algorithms in Search, Optimization, and Machine Learning, by David E. Goldberg
3. Neural Networks: A Comprehensive Foundation, by Simon Haykin
4. Reinforcement Learning: An Introduction, by Richard S. Sutton and Andrew G. Barto

EN 704: Computer Based System Design- II (25)

Communication, Networking, Realtime systems, RTOS and Software

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- USB
- Encoding schemes
- Local Area Networks
- OSI 7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Networking hardware – cables, hub, switch, router, etc
- Role of fibre optics in communication
- Fieldbus standards
- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking
- Realtime Systems, their characteristics and applications
- Realtime Operating Systems:
- Concepts of
- Process and threads
- Concurrency
- Latency, context switching
- Scheduling policies
- Inter process communication
- Semaphores
- Priority inversion
- Shared memory
- Common systems calls, Communication features in RTOS
- Comparative study of various RTOSs
- Integrated S/W development environment

EN 705: Data Base Management System and Web Technology(30)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

EN 706: Digital Signal Processing and Image Processing (30)

Digital Signal Processing

- **Introduction**

Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**

  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
- Fast Fourier Transform

Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- Digital filters

FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- DSP Applications

  Applications of digital signal processing in nuclear and other fields.

Image Processing

- **Introduction**

  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- **Image Enhancement**

  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- **Image Segmentation andAnalysis**

  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation; Boundary extraction and representation;
- **Morphological operations**

  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy- based methods;

  Image Compression Models, Error free compression, Lossy compression, Standards;

References:

1 Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
1. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles,
2. Algorithms and Applications, Prentice- Hall of India,1995.
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.
4. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine
6. Vision,Vikas Publishing House,2003.
7. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004

EN 707: Embedded Electronics Software(25)

Programmable Digital System Design, Representation & Synthesis [8]

- Introduction to HDLs, Introduction to PLD, FPGA, ASIC. Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Handel-C, VHDL. Introduction to Design Flows and EDA Design Tools.

Real-time Software [11]

- Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion,

Priority Inheritance
- Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development

Introduction to Microprocessors / Microcontroller and Interfaces [6]
- Introduction to Microprocessor and microcontroller, Synchronous and Asynchronous Standards, RS232C, RS485, FieldBus (Profibus, Foundation FieldBus, CAN, Ethernet , MIL-STD-1553B), TTP

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P.Singh & Renu Singh
3. Fieldbus Technology: by N.P.Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN 708: Feedback Control Systems (25)
- Introduction: The control systems, Basic elements of FIB control systems, Types of FIB control systems.
- Transfer Function: Transfer function of linear systems, Impulse response, Block diagrams, Signal flow graphs, Mason's gain formula, Polar plots, Bode plot.
- State Variable Characterization: State concept, State equation, Standard representation, State transition matrix and solution of state equations, relationship between state equations and transfer functions, Characteristic equation, Illus- trative examples of some electrical, mechanical, electromechanical systems.
- Time Domain Analysis: Test input signals, Time domain perform- ance characteristics, Transient response of a typical second order system, PID controllers
- Stability: Definition, Routh-Hurwitz criterion, Nyquist criterion. Relative stability, Gain and Phase margins.

EN 709:Fluid Power Technology (25)
Basic Fluid Power & Components

Basic principles of Hydraulics and pneumatics
- Fluid power introduction and fundamentals of fluid mechanics
- principle of pneumatics, basic definitions
- pressure – gauge, vacuum, absolute; flow
- Pressure loss, Power, torque, energy – mechanical, hydraulic etc. , power, force, speed, viscosity, hydraulic terms in fluid power, resistances, bulk modulus, Pascal’s Law, law of conservation of energy
- Transmission and multiplication of force, Momentum theorem, Angular momentum theorem, continuity equation, Euler's equation of motion, Bernoulli’s theorem, laws of compression, forces developed by jets on plates (curved plate, moving plate, etc.) orifice flow formula, flow measurement, pressure measurement, comparison of Pneumatics with Hydraulic power transmissions.

Hydraulic Fluids and pneumatic air
- Basic properties of hydraulic fluids and pneumatic air, compressibility, pour point, flash point, fire point,
- Desirable properties of fluid, undesirable properties of fluids,
- Types of fluid, composition of fluids, effects of additives to hydraulic fluids,
- Advantages of various types of oil.
- Advantages of oil vs. air as working fluid.

Fluid power pumps and compressors
- Function and purposes of pumps and compressors
- Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump. (ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps (iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
- Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
- Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.

Hydraulic and Pneumatic pressure control

Pressure Control Valves, construction and working principles of relief valves- direct acting and pilot operated relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Hydraulic fuse, pressure switch, Pneumatic Pressure regulating valves.

Flow control valves

Basic two way valves, non-compensated flow control valves, throttle valves, restrictor valve, needle valve, ball tip valve, check valves, control valve circuits, pressure compensated flow control valve, demand-compensated flow control, pressure, temperature-compensated, flow control valve, methods of speed regulation in pneumatics.

Directional control valves

Application of directional control valve (DCVs),, designs, construction and operation of check valves, pilot operated check valves, rotary and spool type valves, two way valves, shuttle valves, three way valves, diversion valves, four way valves, solenoid operated, control valves, operation of directional control valves, mounting interfaces, designation, type of actuation of DCVs, pneumatic direction control valves – two way, three way, four way valves, etc., solenoid operated, push button operated, lever operated pneumatic DCVs.

Actuators

Definitions, linear actuators – Hydraulic cylinders, Plunger type, , piston type, Single acting, double acting cylinders, spring return type, tandem and telescopic cylinder, construction of hydraulic cylinders, cylinder seals – piston seal, rod seal, wipes, wear pads, etc. mounting style of cylinders, Pneumatic reciprocating actuators.

Rotary actuators –motors and limited rotation rotary actuators, their types, construction, advantages, vane type single and double vane rotary actuators, rack and pinion type rotary actuators, gear motors – external and internal, gerotor motors, vane motors, Radial piston motors, non-rotating barrel type axial piston motors, advantages of hydraulic motors. Pneumatic rotary actuator, radial piston, vane, and axial piston type air motors etc.

Seals

Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

Pipes, Tubes and Hoses, fittings

Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.

Accessories

Hydraulic and pneumatic filters, their applications, working principles and designs, beta ratio, absolute filtration, nominal filtration, selection of filters, heat exchangers – types, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, types of pneumatic filters, regulators, lubricators, mufflers, dryers, reservoirs etc.

Hydraulic Circuit Design

- Introduction to fluid Power Symbols, Overview of IS 7513,
- Classification of hydraulic circuits, Criteria for designing open loop hydraulic circuits, Analyzing resistive loads, overrunning loads and inertial loads, Heat generation and control.
- Flow control circuits, Pressure control circuits, Direction control & check valve circuits, Cylinder circuits, Pump circuits, Hydraulic motor circuits, Accumulator circuits, Intensifier circuits, Regeneration circuits.
- Sizing of Hydraulic circuit components :
- Reservoir.
- Heat Exchanger: Oil to air heat exchanger, Oil to water heat exchanger.
- Filters: Sizing of suction filter, return line filter, pressure line filter, Beta ratio, Necessary sizing information for filters.
- Fluid Conductors: Flow v/s Pressure drop, Pressure losses, tube/ hose sizing, Pressure rating, Hose/ Tube designation, Calculation of pressure drop in straight lines, bends, fittings etc.
- Pumps: Fixed displacement, variable displacement pumps, Design of suction side and pressure side of pump
- Hydraulic cylinders and motors.
- Accumulator: Isothermal &Adiabatic charging / discharging of accumulator. Sizing of accumulator for various applications i.e. energy storage, shock absorber etc.
- Valves sizing: Direction, pressure & flow control valves.

- Hydraulic Circuit Dynamics considerations: Bulk modulus, Spring rates, natural frequencies, Transmission line dynamics, Pulses in transmissions, Energy controls, Load energy output interaction, system stability, damping, time constant, system response, hydraulic system parameters i.e. resistance, capacitance, impedance.

Advanced Hydraulic Control Circuits

- Various pilot operated valves, construction features, operation, and advantages.
- Modular valves, Stacked type direction control valves, flow control valves, pressure control valves and

combinations.
- Electrically modulated pressure control valves, flow control valves. Pulse width modulation,
- Proportional controls, Servo controls, construction, Uses, differences, operation, advantages and disadvantages.
- Cartridge Valves: Design and construction features of cartridge valves, Types and Operation of cartridge valves, Advantages of cartridge design.
- Advanced pump controls, load sensing, pressure compensation.
- Integrated Hydraulic Circuit:Construction , Advantages of integrated hydraulic circuit, Case study of PVG32 valve, Various modules of PVG 32 valve block, Features of integrated hydraulic circuit of PVG 32, Electronic control capabilities.
- Pneumatic control circuits, proportional and servo valve, proportional and servo actuators

Water Hydraulics and Component Design
- Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals.
- Case Study-1: Differential Pressure Reducing Valve: Conceptual design and sizing
- Case Study-2: Auto Differential Pressure Control Valve - Conceptual design and sizing.
- Case Study-3: Pressure Compensated Flow Control Valve - Conceptual design and sizing.
- Case Study-4: Pilot Operated Pressure Control Valve - Conceptual design and sizing

Electronics and Instrumentation for Hydraulics:
- Current/ Voltage Sources and its measurements, Electronic components –resistance, capacitor, transistors, Opamps etc. Basic circuits for Addition multiplication, division using Opamps. Digital electronics, Logic gates.
- Analog to Digital converters (ADC) and Digital to analog controllers (DAC), Signal conditioning circuits, filters.
- Sensors-Pressure measurement, pressure switches, Position measurement, limit switches-proximity switches, Velocity measurements, Temperature measurement, temperature switches, Viscosity, density measurement, Force, torque, strain measurements.
- Controllers, Closed loop and open loop controllers, Proportional, Integral, derivative controllers and its uses and characteristics. Analog and digital controllers, comparison between digital and analog controllers. Programmable logic controllers, different I/O modules, wiring sensors to PLC. Introduction to microcontrollers, Applications, programming.
- Data Acquisition, Communication buses RS232,RS485, CAN bus, MODBUS, CANOpen bus uses and applications.

Fluid Logic & Control:
- Need for Fluid Control.
- Building Basic Elements for Control Logic (AND, OR, NOT, NAND, NOR).
- Function Implementations using Control Logic.

Experiments :
1. Tuning of PID controller in rotary actuator test facility.
2. Speed control of hydraulic motor using PLC.
3. Measurement of cleanliness level of hydraulic oil samples using particle counter.
4. Qualitative analysis of oil samples using Ferrograph.
5. Establishing position control using frictionless hydraulic linear actuator.
6. Finding characteristics of Differential Pressure Reducing Valve.
7. Finding characteristics of Auto Differential pressure control valve.
8. Finding characteristics of Pressure Compensated Flow Control Valve.
9. Finding characteristics of Pilot Operated Pressure Control Valve.
10. Study of Rexroth/Bemco oil hydraulic power pack and carrying out pressure setting, flow setting etc. in the same.
11. Experiments on ROHYTAM
12. Testing of oil hydraulic filter using filter test set-up.
13. Dismantling & assembling of various valves and actuators.

EN 710: Image Processing & Machine Vision (30)

Image Processing
- Introduction: Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;
- Boundary extraction and representation;
- Morphological operations;
- Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy-based

methods;
- Image Compression: Models, Error free compression, Lossy compression, Standards;

Machine Vision
- Imaging model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflectance, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, Boundary representation,Mathematical Morphology;
- Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, The Generalized Hough Transform;
- High Level Vision: Scene interpretation;
- Texture – Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, Classification and recognition, Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

References:

1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine , Vision,Vikas Publishing House,2003.
6. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004.
7. Davies E.R., Machine Vision Theory Algorithms Practicalities, Academic Press.
8. D.A. Forsyth & J. Ponce, Computer Vision A Modern Approach, Prentice Hall,2003.
9. Horn B.K.P., Robot Vision, The MIT press, 1987.
10. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
11. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

EN 711: Machine Design (25)

Principles of Machine Design:
- Objectives of machine design, general design rules, design methods
- Lightening of' parts and rational design schemes,
- Rigidity of structures, Cyclical/ Contact/ Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs.
- Introduction to inventive problem solving.

Design and Drawing Practices
- Drawing standards, selection of tolerances, fits, and positional tolerances.
- Introduction to Drawing Practices: (matter from various drafting standards),
- Introduction to CAD (including introduction to various drafting and solid modeling softwares)

Sealing Methods
- Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric 'O' rings, mechanical seals, labyrinth, valve packings.
- Methods of sealing for high and ultra high vacuum.

Special Dimensional Inspection Techniques
- Description of special dimensional inspection techniques, gaging techniques including composite and paper gauging, Advanced inspection tools including co-ordinate measuring machines and form measuring machines.

Advanced Manufacturing Techniques:
- Precision machining, super finishing, advanced manufacturing
- Micro machining.

References:

1. "Mechanical Engineering Design" by Joseph E. Shigley.
2. "Machinery's Hand Book" (24th edition)
3. "ISO Standards Hand Book" 18.
4. "SKF Bearing Catalogue."
5. "Relevant IS standards."
6. "Friction, Wear, Lubrication, Tribology Hand Book" edited by Prof. I.V.Kragelsky & V.V Alisim.

7. "Gear Hand Book by" Dudley.
8. "AGMA Standards 218.01" Dec. 1982.
9. "Industrial Sealing Technology" by H.HUGO BUCHTER

EN 712: Material Science in Nuclear Engineering (ME) (20)

- Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.
- Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X- ray Radiography, etc. for welds.

Corrosion

- Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards

Metallurgy of steels

- Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
- Selection and application of advanced alloys.

Nuclear Materials

- Fabrication, properties and application of Zircaloy, Zr-Nb alloys
- Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications.

Advanced Polymeric materials and Composites

- Physical and Chemical Properties, corrosion, mechanicalproperties
- Equipment design with polymeric materials
- Fabrication principles; standards for design, fabrication and testing.

References:

1. "Introduction to Materials Science for Engineers" - James Shackelford
2. "Physical Metallurgy Principles & Practice" - V.Raghavan
3. "Introduction to Solids" - L.V.Azaroff
4. "Structure and Properties of Materials" - Wulff Series, Wiley Eastern, New Delhi
5. "Materials in Nuclear Application" - C.K.Gupta
6. "Nuclear Chemical Engineering" - Benedict and Pigford

EN 713: Materials Characterisation (20)

Microscopy Techniques

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
  - Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
  - Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High reolution electron microscopy
  - Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, Other modes of operation, Applications in failure analysis, fracture surfaces etc.
  - Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

X-Ray Diffraction and Applications

  - Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production and detection of x-rays.
  - Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
  - Experimental methods in x-ray analysis; Laue methods, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates,

crystal size crystal perfection, crystal orientations:

Chemical Analysis (with applications in materials science).

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

Basics of Analytical Transmission Electron Microscopy,

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, Illlcorrections
- Cliff Lorimer factor, thin film correction

Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
- Fundamentals of energy filtering and its uses in life sciences
- Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
- Case studies for metallic bulk samples, life science samples, nano-materials

Physical and Thermal Characterization Techniques

- **Thermal expansion**: Methods and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
- **Thermal Conductivity**: Methods and their principle, advantages and limitations of each method, data of nuclear Fuels
- **TGA/DTA/DSC**: Methods and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
- **Elastic Properties**: Methods and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
- **Hardness**: Different methods and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

EN 714: Membrane Technology (35)

Fundamentals and Overview of Membrane Processes: (5)

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Growth Potential, Classification and description of membrane processes
- Pressure driven membrane processes (MF, UF, NF and RO)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

Novel Membranes

- Features, transport mechanism and application areas
- Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Membrane Bio-reactor, Fuel cell membranes, Membrane sensors, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

Membrane Materials, Preparation and Characterization: (10)

- Material selection
- Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity Molecular weight and molecular architecture
- Membrane preparation techniques- Phase-Inversion, In-situ polymerization, Track-etching, Slip-casting, Sintering
- Membrane Casting Aspects for continuous casting
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of charged membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
- Surface characterization -pore size, roughness, in-homogeneities, and hydrophilicity
- Bulk characterization -porosity, permeation study through flux and solute rejection.

Engineering and Design Aspects of Membrane Technology (10)

- Transport through membranes-Preferential sorption-capillary model,Solution Diffusion model, Irreversible thermodynamics model
- Derivation of basic transport equation for RO membranes

- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants
- Pretreatment considerations, Water chemistry- turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control,Scaling assessment parameters (SDI, MFI)
- Materials of construction
- Process design and system design for water desalination-Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices -pelton wheel, turbo-charger and pressure exchanger
- Effect of operating parameters on membrane performance
- Membrane cleaning and protocols
- Trouble-shooting analysis of operating plants
- Post-treatment techniques
- Membrane autopsy, Reject disposal techniques and brine management.

Membrane Technology Applications (10)

- Techno-economics of membranedesalination plant - seawater / brackish water
- Design aspects of water recovery & recycle from spent streams including sewage Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle
- Hybrid membrane systems, Combo systems -membrane + conventional- for separation application
- Nuclear Desalination
- Membrane based water purification systems-RO/UF application in food processing, pharmaceuticals and Bio-technology
- Fractionation & Value Recovery.
- Zero Liquid Discharge (ZLD)

References

1. Membrane Technology & Applications by Richard W Baker (2008)
2. Membrane Handbook by Ho and Sircar (1992)
3. Transport Phenomena in Membrane by K. Lakshminarayanaiah (1970)

EN 715: Multi-Scale Material Modeling (20)

Introduction

- Spatial and temporal hierarchy of microstructure and dynamics in materials
- Types of models: quantum mechanical, atomistic, mesoscopic, continuum
- Multiscale approaches

Short review and elements of differential equations (numerical solution)

- Differential equations in discrete and continuum simulation methods
- Ordinary differential equations for particle dynamics
- Partial differential equations, conduction/diffusion equation

Atomistic models: Molecular dynamics

- The basics of classical molecular dynamics
- Initial conditions, creating lattice structures, introducing defects
- Defining and maintaining temperature and pressure
- Boundary conditions (periodic, stochastic, conducting, non-reflecting)
- Methods for constant temperature or/and pressure simulations
- Tricks of the trade (neighbor lists, force/energy tables, potential cutoffs, etc.)

Monte Carlo methods

- The basics of Monte Carlo
- Monte Carlo integration, thermodynamic averages
- Importance sampling, Metropolis scheme
- Lattice Monte Carlo, Ising model
- Multi-state Potts models (grain coarsening, recrystallization)
- Kinetic Monte Carlo (surface processes, thin film growth)

Interatomic potentials

- Introduction, Born-Oppenheimer approximation
- Pair potentials and their limitations
- Calculation of elastic constants from potential function

- Potentials for ionic systems, ceramics
- Many-body potentials for metals
- Many-body potentials for covalently bounded systems
- Forces from "first principles"

Analysis of the simulation results

- Equilibrium properties (energy, temperature, pressure, velocity distributions)
- Structural properties (geometrical tessellation, pair correlation functions, atomic level stresses)
- Dynamic properties (diffusion, time correlation functions)

Mesoscopic methods

- Discrete dislocation dynamics
- Strain and stress fields for edge and screw dislocations in an isotropic medium
- The equation of motion in Newtonian Dislocation Dynamics
- Examples from 2D and 3D simulations
- Current problems
- Coarse-grained models

Bridging the scale gaps between different simulation levels

- Simultaneous integration of the models
- Sequential integration of the models (hierarchical approach)
- Examples of combined methods (MD-FEM, MD-MC, etc.)

Modeling at microscale

- Mechanism of ductile fracture and cleavage fracture
- Gurson constitutive law for modeling ductile damage
- Roussiler constitutive law for modeling ductile damage
- Beremin's model for cleavage fracture
- Modeling of material under transition temperature
- Case studies

EN 716: Preparedness & Response to Nuclear Emergencies (35)

- Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
- Radiation Shielding & Study of Criticality parameters and control
- Nuclear Waste Management
- Nuclear Accidents/emergencies
- Transport of Radioactive material
- Radiological accidents/emergencies
- Effects of Hiroshima & Nagasaki bombing
- Detection of Nuclear detonation
- Nuclear weapons: effect (Blast, heat, Radiation and EMP)
- Medical decontamination with demonstration
- Nuclear weapon tests (atmospheric)
- Nuclear & Radiological terrorism (Method to contain and control)
- Chemical warfare & Biological warfare (Method to contain and control it)
- Emergency Response methodology/ Philosophy
- Systems and methodology for Radiological impact assessment
- Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities
- Emergency Monitoring & Shelters
- Civil defence WEB plan for Nuclear attack on major cities
- Monitoring of High radiation field area
- Lab Visits

EN 717: Project Management (25)

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
  - Resources of project.
  - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an

activity, earliest start time EST, latest completion time LCT.
 o Scheduling in a project by critical path method, CPM
 o Scheduling in a project by Precedence Diagram Method.
 o Use of Project Management Software for project planning, scheduling & monitoring.
 o Preparation of master control management milestone network, Level-1,2, 3 & 4 network.

- Preparation of Target Plan, updating of progress, monitoring variance & reporting
 o Constraints of project and its effective management o
 Development of Six Monthly Plan and its review process o Resource
 based planning
 o Physical & Financial Monitoring of project, Use of S-curve
 o Capital Budgeting & expenditure control in a project
 o Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis methods, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN 718: Reliability Engineering (ME) (25)

- Reliability Mathematics – Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations,

Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem

- Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
- Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
- Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
- System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.

- Application of Reliability - PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

References:

1. Mishra, K.B., “ Reliability Analysis and Prediction”, Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M.,Reliability& Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., “Reliability in Engineering Design”, John Wiley & Sons, 1977.
5. Balaguruswamy, E., “Reliability Engineering” Tata Mcgraw-Hill, 1984.

14. Provan, J.W., “Probabilistic Fracture Mechanics & Reliability”, Martinus Nijhoff, 1987.
15. Nowak, A. S. and Collins, K. R., “Reliability of Structures” McGraw Hill, 2000.
16. Ayyub, B. M. and McCuen, R. H., “Probability, Statistics and Reliability for Engineers”, CRC Press, 1997.
17. Haldar, A. and Mahadevan, S., “Probability, Reliability and Statistical Methods in Engineering Design”,
18. John Wiley and Sons, Inc. 2000.

EN 719: Signal Conditioning, Recovery & EMI Aspects (25)

Review of Analog Signal Conditioning & Recovery Techniques

- Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types ofA/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

Theory of Quantization

- Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti- aliasing filters, fast algorithms for implementation.

Theory of Signal Analysis and Reconstruction

- Function space, orthogonal basis functions, Limitation of Shanon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

Review of EMI Aspects

- Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

EMI Modeling

- Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EN 720: Software Engineering (25)

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools.(3)
- Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods Testing principles, unit testing, integration testing, acceptance testing Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

EN 721: Vibrations (25)

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
- Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor;

Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinary.

- Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, aperiodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN 722: Safety and Reliability of Civil Engineering Structures (25)

Introduction to Probability Theory

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, ProbabilityDistributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

Structural Reliability

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment Method, Hasofer Lind Reliability Index, Rackwitz Fiesseler Method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

Probabilistic Safety Assessment

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

Industrial Safety

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

Safety assessment of existing structures:

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

Introduction to decommissioning of structures

References:

1. Hahn, G. J.and Shapiro, S. S. (1994), “Statistical Model in Engineering” Wiley-Interscience.
2. Ranganathan, R. (2000), “Reliability analysis and design of structures”,Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), “A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”, The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety Standard No. AERB/SS/CSE.
6. AERB (1996),“Atomic Energy (Factories) Rules”.

7. AERB (1991), “Safety Guide for Works contract”, Safety Guide No. AERB/SG/IS-1
8. AERB (1996), “The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex”, Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”.
10. Regulatory Guide 1.165 (1997), “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion”, U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (25)

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- BeamWelding Processes
- Arc-Beam Hybrid WeldingProcesses
- Study of welding arc characteristics
- Metal transferduringarcwelding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on themacro-andmicro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high coolingrates
- Phenomena of hot-crackingand coldcracking
- Residualstresses anddistortion duringand afterwelding
- Residual stressmeasurements
- Application ofaboveprinciplesto welding ofcarbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

EN724: Advanced Structural Dynamics and Earthquake Engineering(CE) (30)

I. Introduction to Structural Dynamics and Earthquake Engineering

II. Performance Based Design of structures, systems and components subjected to earthquake loading

Concepts of performance bases, Seismic demand, Capacity of structures, systems and components, performance levels, energy dissipation and damping.

II. Seismic and Vibration Control

Concepts of seismic and vibration control, Passive control using Yielding dampers, friction dampers, tuned mass dampers, Tuned liquid damper, etc., Semi active and active control strategies.

III. Base Isolation Techniques

Concepts of vibration and seismic isolation, laminated rubber bearings, Lead plug bearings, Friction Isolation System etc.

V. Testing and Modal analysis

Need of testing, Methods of testing, qualification of systems by testing, data processing using FFT and Wavelets, modal analysis for frequency, mode shapes and damping. Causes and types of experimental error, statistical analysis of data.

VI. Seismic and Vibration Instrumentation

Measurement Methods and Applications: Measurement of displacement, velocity, acceleration, pressure, forces, strain and optical methods of measurements; Data Acquisition and Processing.

Types of inputs: analog and digital signals, calibration and uncertainty, Measurement System: Performance characteristics, linearity, dynamic range, sensitivity, stability, accuracy, bandwidth, noise, repeatability, hysteresis- threshold- resolution, readability and span.

VII. Fluid-structure interaction techniques

Coupling of fluid with structure, Dimensionless numbers in fluid-structure interactions, Added mass and added stiffness, Fluid sloshing, Flow induced vibration, Flow over bluffed bodies, Vortex shedding.

VIII. Multibody Dynamics

Rigid-Body Kinematics, Kinematics for General Multibody Systems, Modelling of forces in multibody systems, contact forces, friction effect, Equations of Motion of Multibody Systems.

Numerical integration methods for free standing objects, spring-mass system with friction, Runge Kutta methods, error estimation, Computer programs.

Text / Reference Books

1. A. K. Chopra, “Dynamics of structures”, Prentice Hall, 4th edition, 2007.
2. S. S. Rao, “Mechanical vibration”, Prentice Hall, 5th edition, 2014.
3. Holman, “Experimental Methods for Engineers”, 6e, McGraw-Hill, 1994.
4. Doeblin, Engineering Experimentation, McGraw-Hill, 1995.
5. Hans-Joachim Bungartz Michael Schäfer, “Fluid-Structure Interaction Modelling, Simulation, Optimization”, Springer-Verlag Berlin Heidelberg 2006.
6. Soong, T.T. and G.F. Dargush, “Passive Energy Dissipation Systems in Structural Engineering”, Wiley & Sons, New York, 1997
7. Farid Amirouche, “Fundamentals of Multi Body Dynamics, Theory and Applications”, Springer Science, 2006

NON-SUBJECT ASSIGNMENTS

EN 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

EN 592.1: Process Control Trainer (15)

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

Expt 1

Introduction to typical process under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.

Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

Expt 2

Optimisation of process control - using ultimate sensitivity method.

Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.

Optimum gain and integral / differential time constants are calculated using empirical formulae.

Expt 3

Feed forward control configuration - study of process response in comparison with normal feedback control.

Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

Expt 4

Smart Differential Pressure transmitter.

Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.

Re range transmitter using HART communicator.

Re configure transmitter for linear and square root characteristics.

Expt 5

Final control element - Linear pneumatic control valve.

Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.

Virtual instrumentation and wireless data communication between controller and PC.

EN 592.2: Nuclear Detectors (15)

A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.

NaI(Tl) γ- Ray Scintillation Detector

This experiments imparts training on the use of NaI(Tl) detector using known γ- Ray sources (Co^{60} & Cs^{137}) , plotting of calibration curves and identification of unknown sources.

α-Particle spectroscopy using a Solid State Detector

This experiment imparts training on the use of the Solid State Detector using known α-Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup. **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter , testing counting statistics of the counter and studying absorption behaviour of β-rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN 593: Mini-Project Work (300)

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.). Project runs on a part time basis for 11 weeks from mid May to Mid July.

BACK TO MAIN

IGCAR

Ph.D. in ENGINEERING SCIENCES
(PROGRAM CODE: ENGG04)

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
ME1	Code Design for Pressure Vessels and Piping	30	4
ME4	High Temperature Design and Inelastic Analysis	25	2
ME6	Computational Fluid Dynamics	30	4
ME8	Finite Element Method	30	4
ME10	Advanced Heat and Mass Transfer	30	4
ME13	Reliability Engineering	20	2
ME14	Manufacturing Technology	40	4
Total		**205**	**24**

SPECIALISED/ELECTIVE COURSES

(Any three of the seven listed courses)

Course Code	Course Name	Hours	credits
ME3	Machine Design	25	2
	Structural Integrity Assessment Methods and NDE	30	4
	Vibration Engineering and condition Monitoring	20	2
ME5	Seismic Design of Nuclear Reactors and Facilities	20	2
	Plant Dynamics	20	2
	Experimental Mechanics	20	2
ME15	Process Control and Instrumentation	20	2

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-001-P	Project	Duration : 9 Weeks	
2.	02ENGG04-001-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

1. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
2. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
3. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
4. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
5. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
6. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
7. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity

2 **Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor

3 **Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors

4 **Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation

5 **Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions

6 **Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization

B BASIC REACTOR PHYSICS-STATIC

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety
Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down
Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
7. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology (NRST)

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flowmeter: Electromagnetic pumps and flowmeter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6.	Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7.	Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Code Design for Pressure Vessel & Piping (ME1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11.	Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , ‘Pressure vessel design’ CBS publication
2. Brownell. L. E & Young. E. D , ‘Process equipment design’, Wiley Eastern Ltd., India

3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Finite Element Method (ME8) (30 hours)

S.No.	Course content
1.	Introduction to FEM as applied to solid mechanics. Energy principles in structural mechanics and principles of minimum potential energy
2.	Element Shape and Shape Functions: Generalised co-ordinates. General requirements of shape functions; Lagrangian and Hermitian interpolation functions – CO, C1 continuity; Natural coordinate system; Derivation of shape functions for Bar, Beam, Plane, Brick and Plate elements.
3.	Bar Element: Derivation of elemental stiffness matrix and load vector; Transformation from element to global coordinate system; Assembly of Global stiffness matrix and load vector; Solution of typical 2D-plane Truss problems to evaluate Displacements and Member forces/stress; Thermal stress evaluation in Bars/Truss.
4.	Beam Element: Derivation of elemental stiffness matrix and load vector; Solution of simple Beam problems to evaluate Deflections/rotations; BM/SF distribution and determination of stresses, Shear deformation in beams. Curved Beam Element: Derivation of elemental stiffness matrix and load vector; Derivation of stiffness matrix for elbow.
5.	Axisymmetric Thin Shell Element: Strain-displacement and stress-strain relationship; Derivation of stiffness matrix and load vector for 2 noded axisymmetric thin shell element. 2D Plane Elements – 3 Noded Triangular Element: Derivation of elemental stiffness matrix and load vector, Plane Stress/Plane Strain & Axisymmetric elements: Evaluation of Strain/Stress.
6.	2D Isoparametric Element – 4, 8 and 12 noded quadrilateral Element: mapping of parent element to global space; Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of stiffness matrix for plane & axisymmetric elements; Evaluation of strain/stress at Gauss points.
7.	Introduction and Application of 3D Elements: Strain displacement and stress-strain relationship; Tetrahedron, Triangular prism and Hexahedron elements.
8.	Plane Bending Elements: Thin and Thick plate theory; Elements based on Kirchoff's Theory; Elements based on Mindlin Theory; Shear locking and Reduced Integration.
9.	Shell Element: Strain-displacement and stress-strain relationship; Flat plate and curved shell elements; 4 and 8 noded degenerated thick shell Elements, basic assumptions, degree of freedom, shape functions and shear locking.
10.	Incompatible Displacement Model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral element.
11.	Introduction to Nonlinear Problems. Meshing and Errors: Finite Element Modeling and Discritization Criterion, Adaptive meshing, classification of FEM stresses per ASME code, sources of potential error in the finite element solution

Books Suggested:

1.Finite Element Procedures-K.J.Bathe, Prentice Hall, 1996.
2.Concepts and Applications of Finite Element Analysis, R.D.Cook,D.S.Malkus & M.E.Plesha, 4th Ed., Prentice-Hall India, 2003.
3.An introduction to the Finite Element Method-J.N.Reddy, 2nd Ed., McGraw Hill Education (ISE editions)-1993.
4.Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.1, Butterworths-Heinemann,2000.
5. Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.2, Butterworths-Heinemann,2000.

6.The Finite Element Methods: its basics and fundamentals- O.C.Zienkiewicz ,R.L.Taylor &J.Z.Hu, Elsevier,2005.
7.The Finite Element Method: Linear,Static and Dynamic Finite Element analysis-T.J.R.Hughes, Dover Publication,2000.
8.Fundamentals Finite Element Analysis and Applications-M.Ashghar Bhatti, John-Wiley & Sons, NJ,2005.

3. Advanced Heat and Mass Transfer (ME10) (30 hours)

S.No.	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes & Bemoulli equations.
2.	**Laminar Boundary Layer and Forced Convective Heat:** Formulation of differential equation for hydrodynamic and thermal boundary layer. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory. Convective heat transfer for intemal and extemal flows. Low and high Prandtl number limits and different thermal boundary conditions Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method.
3.	**Turbulent Flow and Heat Transfer:** Reynolds decomposition for turbulence**.** Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical. correlations for calculating heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
4.	**Turbulence Modeling:** Eddy diffusivity models: k-£ and k-w) models, RNG based k- £ model. Reynolds stress models: algebraic & differential models. Low Reynolds number models Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
5.	**Natural Convection:** Basic Equations of natural convection. Boussinesq approximation. Derivation of Dimensionless groups from basic equations. Analytical approximations
6.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Moment, porosity, permeability etc.., homogenization method, continuity equation & energy equation, introduction to 2 phase flows & heat transfer in fluid flows.
7.	**Heat Transfer With Phase Change** : Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post dryout heat transfer. Various models available for calculation of heat transfer coefficient.. Critical Flow. Models for single - phase and two-phase critical flow.
8.	**Radiation heat transfer:** Radiation heat transfer. Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Books suggested:

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.

3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

4. Computational Fluid Dynamics (ME6) (30 hours)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme
B.	**Numerical Solution of Complete Fluid Flow and Energy Equation:**
1.	Formulations of governing equations used in numerical simulation:
2.	Stream function-temperature formulation
3.	Stream function-vorticity-temperature formulation
4.	Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5.	Primitive-Variable (P-V-T) formulation
6.	Pressure velocity coupling for incompressible flow.
7.	Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8.	Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9.	Simple grid generation techniques for structured grid:
10.	Elliptic. parabolic and hyperbolic equation method
11.	Grid adaptation
12.	Domain decompositions in CFD and heat transfer
13.	SIP and preconditioned conjugate gradient methods for solution

14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.

15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.

16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Books suggested:

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

5. Reliability Engineering (ME13) (20 hours)

S.No.	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.\
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY.

6. Manufacturing Technology (ME14) (40 hours)

S.No. **Course content**

Curriculum for Metal Forming

1. **Uniaxial tensile test**:
   a. Engineering stress, engineering stain, true stress, true strain;
   b. Extraction of plastic stress-plastic strain data from load – elongation data of uniaxial tensile tests; Hollomon type and Voce type constitutive relations;
   c. Tensile instability and significance of strain harkening exponent;
   d. Determination of strain rate sensitivity index and the significance of strain rate sensitivity;
2. Stress matrix and the derivation of the Cauchy relation from the law of conservation of linear momentum; concept of principal stress;
3. Small strain matrix and rotation matrix obtained from the displacement functions;
4. **Elements of the theory of plasticity**:
   a. Decomposition of stress matrix to hydrostatic and deviatoric matrices;
   b. Yield surfaces as a function of the second and third invariants of the deviatoric matrix with von Mises and Tresca criteria being examples; concept of equivalent stess;
   c. Normality flow rule and convexity of the yield surface; concept of equivalent strain

Curriculum for Materials Joining

1. **Welding Processes**
   a. Fusion Welding Processes: Arc Welding Processes like SMAW, GTAW, GMSE, GVSE etc. and Beam welding process like EB welding and Laser Welding
   b. Solid state Welding Process like Friction Welding, Friction Stir Welding, Diffusion bonding, Explosive welding
   c. Resistance Welding Processes
2. **Thermal Cycle during welding**
   a. Weld Thermal Cycle, Dependence of bead shape with welding speed, prediction of weld thermal cycle
3. **Residual Stress and Distortion**
   a. Generation of residual stress, Effect of residual stress on performance, removal of residual stresses, measurement of residual stresses
   b. Origin of Distortion, Control of distortion

7. High Temperature Design & Inelastic Analysis ME4: (25 hours)

S.No. **Course content**

1. Introduction: Modes of failure, material selection, criteria to assess creep effect, creep law, creep-fatigue interaction, thermal striping
2. Design Practice: Loading category, primary, secondary and peak stress intensity, allowable stress intensity (S_m), assessment of basic wall thickness, strain limits

3. Analysis: strain range under multi axial state of stress, Nuber's rule, triaxiality, elastic followup, fatigue damage, allowable numbers of cycle, creep damage, creep life prediction, creep rupture strength, creep fatigue interaction, ratcheting, efficiency diagrams and creep buckling
4. Fracture mechanics, creep crack growth, introduction to RCC-MR A16
5. In elastic Analysis: General principles for constitutive models, non unified model (plastic + creep), flow rule, creep strain hardening, classified models, viscoplastic material model, non-linear kinematic hardening, isotropic hardening, plastic strain memory, finite element Implementation, automatic time integration

Books Suggested:

1.Creep Analysis – H.Krauss
2.Mechanical Metallurgy-G.E. Dieter
3.Creep in Structures-A.R.S.Ponder and Drkhayhurst
4.Advances in Creep Design-Ed.A.I.Smith and A.M.Nickelson
5.ASME Section3 Subsection NH-1
6.French Design Code-RCCMR-Subsection RB

SPECIALISED/ELECTIVE COURSES

1. Machine Design (25 hours)

S.No.	Course content
1.	Principles of Machine Design: Objectives of machine design, general design rules, design methods, variable loads, Lightening of parts and rational design schemes, Rigidity of structures, Cyclical/Contact/Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs. Introduction to inventive problem solving.
2.	Design and Drawing Practices: Drawing standards, selection of tolerances, fits, and positional tolerances. Introduction to Drawing Practices: (matter from various drafting standards), Introduction to CAD (including introduction to various drafting and solid modelling softwares)
3.	Sealing Methods: Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric `O' rings, mechanical seals, labyrinth, valve packings. Methods of sealing for high and ultra high vacuum.
4.	Special Dimensional Inspection Techniques: Description of special dimensional inspection techniques, gauging techniques including composite and paper gauging, advanced inspection tools including co-ordinate measuring machines and form measuring machines.
5.	Advanced Manufacturing Techniques: Precision machining, super finishing, advanced manufacturing, Micro machining.

Books suggested:

1) Mechanical engineering design (In SI Units) - Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2) Design Of Machine Elements Edition 7 - Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3) Machine Elements in Mechanical Design - Mott (R L), Columbus, Charles E Merril, 1985.
4) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.

5) Mechanical Engineering Design (In SI Units) – Joseph E Shigley & Charles R. Mischke, New Delhi, Tata Mcgraw Hill, 2001.
6) Design of Machine Elements - Ed. 7 – Spoots M F, Shoup T E, New Jersey, Prentice Hall 1998
7) Machine Elements in Mechanical Desgin – Moot R L, Columbus, Charles E Merril, 1985.
8) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.
9) Fundamentals of machine design – Oriov, Mir Publishers, Moscow.
10) Fluid power applications – Anthony Esposito, Pearson education
11) Precision engineering manufacturing – Murthy R.L., New Age International
12) MEMS and Microsystems design and manufacture – Tai-Ram Hsu, Tata McGraw Hill.

2. Structural Integrity Assessment Methods and NDE (ME3) (30 hours)

S.No.	Course content
1.	Fracture Mechanism in Metals
2.	Linear Elastic Fracture Mechanics
3.	Elastic Plastic Fracture Mechanics
4.	Low Cycle Fatigue
5.	Assessment of Creep damage and creep-fatigue interaction
6.	Creep crack growth models
7.	Experimental determination of fatigue and creep curve CTOD, KIC, KIa, J-R curve and C*
8.	Basis of ASME Sec. XI Reference Curve and its use in Pressurised Thermal Shock
9.	CTOD design method
10.	J-Estimation Schemes and J-based failure assessment diagram
11.	Net Section Collapse Criteria and Reference Stress approach
12.	R-6 method and its application
13.	Thermal background of international assessment procedure
14.	RCCMR code/A-16 method and its application
15.	CEGB codes
16.	Application of R-5/R-6 for design of high temperature components
17.	Failure Assessment Diagram of PD-6493 and BS-7910
18.	J-Estimation Schemes and J-based failure assessment diagram
19.	Leak-Before-Break design method
20.	Analysis of numerical techniques/Computational fatigue, Fracture and creep
21.	Probabilistic Fatigue, Fracture and creep
22.	Bench Mark solutions
23.	Manufacturing and process-induced defects that influence structural integrity -
24.	Principles, capabilities and applications of surface examination NDE techniques
25.	Principles, capabilities and applications of volumetric examination NDE techniques
26.	Quality assurance of nuclear components with relevant codes and standards and quality concepts
27.	Structural integrity, in-service inspection and life assessment of nuclear components using NDE
28.	NDE Lab visit and Practicals

Books Suggested:

1. Practical Non-destructive testing- Baldev Raj, Jayakumar.T. and Thavasimuthu. M., Narosa publishing house, New Delhi, 1997
2. Advances in NDE for structural integrity, - Nichols. R.W., Applied Science Publishers, London, 1982.
3. Non destructive Evaluation: A tool in Design, Manufacturing and Service and Francis – Don E.Bray and Roderick K. Stanley, Taylor, CRC Press, New york, 1996.
4. Non-destructive testing, R. Halmshaw, Edward Arnold, 1991.
5. Electrical and Magnetic Methods for Non-destructive testing, - J. Bllitz, Adam Hilger, Bristol, 1997.
6. Ultrasonic testing of materials, - Josef Krautkramer, Herbert Krautkramer, Springer-Verlag. January 1983.

3. Vibration Engineering and Condition Monitoring (20 hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
7.	Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum,

coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

4. Seismic Design of Nuclear Reactors and Facilities (ME5) (20 hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
7.	**Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.

Books Suggested:

1. Chopra, A.K., "Dynamics of Structures, Theory and applications to Earthquake Engineering", Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures", New York, McGraw-Hill Book Company.
3. Mariopaz, "Structural Dynamic (Theory and Computation)", CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., "Numerical Methods in Finite Element Analysis", Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, "Engineering Seismology", IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, "Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites". AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design", BIS, New Delhi.

5. Plant Dynamics (20 hours)

S.No.	Course content
1.	**Pressure drop** in fuel Subassembly, friction, local acceleration and elevation pressure drop in wire-wrap. Flow zoning
2.	**Hot spot factors**: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors. Subchannel analysis of fuel subassemblies, mixing parameters, introduction to computer codes.

3. **Event analysis**: General safety features, General Considerations on Design Basis Events, Thermal and Hydraulic Modeling for Analysis, Safety Criteria, Design Criteria for Selection of SCRAM Parameters, Sympathetic Safety Actions, Primary Sodium Flow Halving Time, Maximum Permissible Absorber Rod Speed.

4. **Results of Analysis of Major DBE:** One Primary Sodium Pump Acceleration, Both Primary Sodium Pumps Acceleration, One Secondary Sodium Pump Acceleration, Both Secondary Sodium Pumps Acceleration, Feed water Flow Increase Events, Continuous Withdrawal of One CSR, One Primary Sodium Pump Trip, One Primary Sodium Pump Seizure, Off-Site Power Failure with Emergency Backup for PSP, Primary Pipe Rupture, One Secondary Sodium Pump Trip, One Secondary Sodium Pump Seizure, One Boiler Feed Pump Trip, Loss of Feed Water Flow to Steam Generator, Intermediate Heat Exchanger Sleeve Valve Closure, Loss of Heating in High Pressure Feed water Heaters, Spurious SCRAM. Reactor start-up, BFP Trip and over speeding at full power, Turbine Generator -Trip and subsequent plant operating actions, power setback.

5. **Decay Heat Removal:** Decay Heat Removal through OGDHRS, Decay Heat Removal through SGDHRS, Need for Forced Convection Core Flow, Decay Heat Removal during Station Blackout Situation, Adequacy of SGDHRS Capacity.

6. **Energy Release In Beyond Design Basis Events:** Local Events: Subassembly Accident, Whole Core Events: Pre – disassembly Phase, Disassembly Phase, Mechanical Energy Release / System Response Phase, Analysis of Transient Over Power Accident, Computer Codes, Analysis of Loss of Flow Accident (LOFA), Sodium Void Worth, Consequences of Fuel - Coolant Interaction

Books Suggested:
Material will be provided during the course

6. Experimental Mechanics (20 hours)

S.No.	Course content
1.	Stress & Strain: State of stress, strain, plane stress, plane strain, Thermal stress, Hydrostatic & Deviatoric Component of stress, Elastic stress-strain relationship, Elastic-Plastic strain relations, Von-mises plasticity criteria, plastic flow rule, strain hardening law, perfectly plastic material, Isotropic strain hardening material, kinematic strain hardening, combined strain hardening stress concentration, cyclic stress, Fatigue, Endurance limit, Creep, Larson Miller parameter.
2.	Photo elasticity: Polarisation, polariscope, diffused light and lense polariscope, stress optics law, plane polariscope, circular polariscope, criteria for model material selection, Isochromatic fringe pattern, Iso fringe pattern, scaling model to prototype stress.
3.	3D photo elasticity: locking of model deformations, scaling model and interpretation of the resulting fringe pattern, effective stresses, Birefringent coating, scattered light and its relation to photo elasticity, scattered light polariscope.
4.	Strain measurement methods: strain gage, basic characteristics, types of strain gages, factors in gage selection, electrical resistance strain gage, potentiometer for strain measurement, strain gage circuit, wheat stone bridge

5. Recording Instrument: galvanometer with oscillograph, transient response galvanometer, frequency response of the wheatstone bridge and galvanometer, cathode ray oscilloscope and potentiometer recorder.

Books Suggested:

1.Mechanical engineering design (In SI Units)', Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2.Design Of Machine Elements Edition 7, Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3.Machine Elements In Mechanical Design, Mott (R L), Columbus, Charles E Merril, 1985.
4.Experimental methods for engineers- J.P.Holman, McGraw Hill.
5.Theories of engineering experimentation-Hilbert Schenck, McGraw Hill.

7. Process Control & Instrumentation (Co-ordinator: A. Venkatesan) (20 hours)

S.No.	Course content
1.	Basic Concepts
2.	Units of measurements, Definitions (accuracy, precision, repeatability, span, range, hysterisis, drift, sensitivity, resolution, lag etc.) -- Sensors, transducers, Transmitters, PI diagrams, Symbols., Digital and analog devices.
3.	Sensing, Transmission, Receiving of the following Process Variables
4.	Temperature: classification, thermocouples, RTD, Thermistors, Pyrometers.
5.	Flow: Direct type, inferential type, constant area sensors, differential pressure meters, variable area meters, magnetic, ultrasonic, vortex type flow meters, and mass flow meters.
6.	Level: Direct type (Float, gauge glass, torque tube, piston tube, reflex etc) indirect type (Pressure gauge, purge, d/p with open/closed tanks, Ultrasonic, nucleonic, capacitance & conductivity).
7.	Pressure: Manometers, Bourdon, bellows, diaphragms, D/P Tx, (electronic & pneumatic), strain gauges, load cells.
8.	Analytical: pH, viscosity, conductivity, humidity, isotopic purity, and turbidity.
9.	Control System: Feedback Control theory, Modes of control, generation of control modes, Controllers, feedback & feed forward control, final control elements and valve positioners.
10.	Safety principles: Trip logic, annunciators, simple logic circuits, and smoke/fire detectors.
11.	Current Trends In Instrumentation: Smart transmitters, Instrumentation for a process loop, Paperless recorders, DAS, PLC, DRS, etc.

Books Suggested:

1. Instrument Technology Vol. I to V E.B. Jones.
2. Mechanical & Industrial Measurements, R.K. Jain
3. Automotive Process Control, Donald P. Eckman
4. Measurement Systems Application & Design, Ernest Doebelin.
5. Process Instrument & Control Handbook, Douglas Considine.
6. Instrument Engineers Handbook, Vol. I&II, Dela G. Liptak
7. Instrumentation for Process Measurement & Control, N.A. Anderson

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
ELECTRONICS AND INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
EL2	Reactor Control Engineering	20	2
EL3	Nuclear Instrumentation	20	2
EL4	Reliability Engineering	20	2
EL5	Software Engineering	20	2
EL8	Human Machine Interface for Reactor Control Instrumentation	45	6
EL10	Modern Control of Dynamic Systems	30	4
Total		**155**	**18**

SPECIALISED COURSES

Course Code	Course Name	Hours	Credits
EL6	Artificial Intelligence and Digital Signal Processing	40	4
EL7	Process Instrumentation	35	4
EL9	Embedded and Computer based systems Design	45	6
EL11	Analytical Instrumentation	25	2
Total		**145**	**16**

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-002-P	Project	Duration : 9 Weeks	
2.	02ENGG04-002-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

8. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
9. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
10. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
11. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
12. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).

13. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
14. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

Sl.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

13. Introduction to Materials Science for Engineers - James Shackelford
14. Physical Metallurgy Principles & Practice - V.Raghavan
15. Introduction to Solids - L.V.Azaroff
16. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
17. Materials in Nuclear Application - C.K.Gupta
18. Nuclear Chemical Engineering - Benedict and Pigford
19. Physical Metallurgy, Reed - Hill
20. Heat treatment of steel - Avener
21. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
22. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
23. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
24. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Fast Reactor Physics and Shielding (RP) (35 hours)

S.No.	Course content
A	NUCLEAR THEORY BASICS :
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units
2	**Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

8. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
9. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
10. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
11. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
12. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
13. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
14. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics and Radiological Safety (HP) (25 hours)

S.No. **Course content**

1.

Introduction: Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.

Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**

Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**

Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.

Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.

Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.

Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.

4. **Radiation protection and measurement (External and Internal):**

Control of external exposures (with problems in each case).

Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.
Routes of intake of radioactive material

Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

13. Introduction to Health Physics – Herman Cember
14. Introduction to Radiation Protection – Alan Martin
15. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
16. Nuclear Radiation Detection - W.J. Price
17. Radiation Detection and Measurement - G.F. Knoll
18. Biological Effects of Radiation – J.E. Coggle
19. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
20. Atoms, Radiation and Radiation Protection by James E. Turner 1986
21. Problems and solutions in Radiation Protection by James E. Turner, 1988
22. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
23. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
24. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) – (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :**
	Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology (NRST)**

1 **Properties of Sodium:** Physical and chemical properties, (hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

11. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
12. Steam Power Station, G.A. Gassort.
13. Power Plant Engineering & Economics, Strosal & Vapet.
14. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
15. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
16. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
17. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
18. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
19. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
20. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Reactor Control Engineering (EL2) (20 hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (EL3) (20 hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (EL4) (20 hours)

S.No.	Course content
12.	**Introduction: Reliability Engg. Applied to C&I Systems** Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors. Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems. Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
13.	**Reliability Maths/Statistics:** • Mathematical and statistical expressions required for reliability study. • Types of failures in electrical, electronic and computer components • Failure probability concept, statistical distribution models_ • Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions • Chi-square distribution and its use in confidence and risk factors • Baye’s theorem • Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software. • Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions. • Derivation of exponential reliability expression_ • R(t)=[exp-(lt)] for electronic components and systems. • Examples to solve

14. **Fault Tolerance and Systems Reliability:**

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model

Example from C&I system in the NPPs

15. **QA/QC Concepts in Brief:**

- QA/QC Concepts in the components, systems procurement, manufacture and
- Site installation for C&I systems in the NPPs.

16. **Environmental Qualification and Reliability Testing:**

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

17. **PSA/PRA Concepts in NPPs:**

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

18. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Software Engineering (EL5) (20 hours)

S.No.	Course content
1.	Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work- products of different phases
2.	Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics, CASE tools.
3.	Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalization, composition, polymorphism. Modeling structure and behavior, Use case diagrams, class diagrams, state diagrams, sequence diagrams, architectural and detailed design., Modeling real-time software. Introduction to Object Oriented Languages. CASE tools.
4.	Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities.
5.	Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods. Testing principles, unit testing, Integration testing, acceptance testing., Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing.
6.	Software Configuration Management: Configuration items (with examples), baselines, libraries, version control
7.	Software Engineering Standards

Books suggested:
1. Software Engineering by Roger S. Pressman, McGraw Hill International Students Edition
2. Software Engineering by Ian Sommerville, 5th Edition, Addison Wesley
3. An Integrated Approach to Software Engg. by P. Jalote, Springer/Narosa Publishers
4. Unified Modeling Language User Guide by G. Booch, J. Rumbaugh, I. Jacobson, Addison Wesley
5. Real-time UML, second edition, Bruce P. Douglass, Addison Wesley

5. Human Machine Interface for Reactor Control Instrumentation (EL8) (45hours)

S.No.	Course content
A .	**Reactor Instrumentation:**
1.	Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification
2.	RPS & RRS for FBRs : Core Temperature Monitoring System, Diversified Safety Logics, Control Logics for CSRDM & DSRDM
3.	Supervision Systems : Startup systems, Discordance supervision systems for SCRAM signals & CSRs, Alarm Generation system, ESR & PDA
4.	Component Handling Systems: I & C for Rotatable plugs, Transfer Arm, IFTM, CTM, Under Water Trolley and Storage Bays, HMI in HCR for Component handling and fuel movement monitoring.
5.	Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, low selector, high selector, median selector, voting logics, Interfaces with electrical Control gear.
6.	C & I Cables : Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
7.	Incident monitoring & mitigation systems : RCB Isolation, I&C for SGDHR, Seismic Instrumentation, Post Accident monitoring system, Video monitoring system
8.	Special systems: Fire Alarm System, Physical protection systems, Biometric Sensors, etc.
9.	Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station, DDCS for PFBR. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards, PLCs for package systems.
10.	PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

11. Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

B. Human Machine Interface (HMI)

1. Overview of plant automation.
2. Design of HMI, Soft Console versus Conventional control panels.
3. Guidelines for design of HMI displays.
4. Case study of a commercially available Professional HMI package.
5. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package
6. Practical.

Books suggested:

1. Intellution Ifix documentation
2. NPC Guidelines for development of soft consoles.

6. Modern Control of Dynamic Systems (EL10) (30 hours)

S.No.	Course content
1.	**1.** State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	**.** Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	**.** Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2^{nd} Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart
and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2^{nd}., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

SPECIALISED COURSES

1. Artificial Intelligence & DSP (EL6) (40 hours)

S.No.	Course content
	A. Introduction to Artificial Intelligence
1.	Introduction – Nature of AI problems
2.	Search – State space search
3.	Robotics – Kinematics and dynamics
4.	Knowledge Representation – Predicate logic
5.	Neural Networks – Feed forward vs Feedback
6.	Fuzzy Logic – membership functions
7.	Reinforcement Learning – Intelligent agents
8.	Genetic Algorithm – Solution representation
9.	Engineering applications including in Robotics
	B. Digital Signal Processing
1.	Introduction: Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, convolution, correlation, sampling theory, aliasing, anti-aliasing filter, quantization noise, signal reconstruction.
2.	Discrete Fourier Transform: Interpretation of DFT, properties of DFT, DFT of real signals, periodic & linear convolution and correlation using DFT.
3.	Fast Fourier Transform: Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, computation of Inverse DFT using FFT algorithm, efficient computation of the DFT of two real sequences and a 2N-point real sequence,

spectrum analysis using the FFT, windows in spectrum analysis, use of FFT algorithm in linear filtering and correlation.

4.	Digital filters: FIR and IIR filters, design techniques for FIR and IIR filters, realization of FIR and IIR systems, overview of DSP processors.
5.	DSP Applications: Applications of digital signal processing in nuclear and other fields.

Books suggested:

1.Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
2.John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice- Hall of India,1995.
3.Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.

2. Embedded & Computer based systems Design (EL9) (45 hours)

S.No.	Course content
A.	**Microprocessor Based Hardware Design:**
1.	Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Micro-controllers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
2.	Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3.	Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
4.	Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
5.	IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, testability.
6.	Embedded computer system design example.
B.	**Computer Communication and Networks**
	Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.)

C. **Fault Tolerant and Distributed Architectures**

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. **Real-Time System Design**

1. Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.
2. Overview of LINUX and Embedded NT.

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.

3. Process Instrumentation (EL7) (35 hours)

S.No.	Course content
7.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors,

flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.

8. Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.

   Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

9. Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

10. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

11. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

12. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type-Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

    Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

13. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.

14. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.
Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.

15. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrment Engineer’s Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Fieldbus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

4. Analytical Instrumentation (EL11) (25 hours)

S.No.	Course content
	Measurement related issues
1.	Sensitivity, detection limit, signal-to-noise ratio enhancement
2.	Absorption and Emission Spectroscopy
3.	UV-VIS-IR Spectrophotometry
4.	Atomic Absorption Spectrophotometry
	IR absorption methods for detection of Carbon, Sulphur, Oxygen, Nitrogen
5.	**Fluorescence Spectrometry**
6.	Generation of X-Rays
7.	X-Ray Fluorescence Spectrometry
8.	X-Ray Diffraction Spectrometry
9.	Laser florescence
10.	**Mass Spectrometry**
	Applications and importance of mass spectrometry
	Various types of ion sources
	Various types of mass analysers
	Various methods of detection
	Computer based automation and measurements
11.	**Thermo analytical methods**
	Thermal analysers-DTA and TG
	Differential Scanning Calorimeters
12.	**Electro analytical instruments**
	Voltametry, amperometry and Coulometry
	Conductivity and pH

Books Suggested:

1. Instrumental methods of analysis, - Willard & Others, Pub: CBS, New Delhi, 7th Ed.
2. Principles of instrumental analysis, - Douglas A.Skoog and James J. Leary, Saunders College Publishing, Harcourt Brace College Publishers. (IGCAR Acc. No. 063944)

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
CHEMICAL ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
	Total	**230**	**25**

CORE ENGINEERING (CHEMICAL)
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE1	Nuclear Chemical Engineering	35	4
CE2	Chemical Engineering Thermodynamics	40	4
CE3	Transport Phenomena	40	4
CE4	Multi Phase Flow Systems	40	4
CE5	Code Design for Pressure Vessels and Piping	25	2
CE6	Computational Fluid Dynamics and Heat Transfer	40	4
CE7	Advanced Chemical Reaction Engineering	25	2
	Total	**245**	**24**

SPECIALISED COURSE
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE8	Process Analysis and Control	25	2
CE9	Advanced Mass Transfer	25	2
	Total	**50**	**4**

ELECTIVE COURSES
(One course amongst the three to be chosen)

Course Code	Course Name	Hours	credits
CEEL	Preparedness &Response to Nuclear Emergencies	30	4
	Artificial Intelligence Methods &Applications	30	4
	Membrane/ Separation Process and Technology	30	4

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-003-P	Project	Duration : 9 Weeks	
2.	02ENGG04-003-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers. B-splines,Bezier curves, Response surface method, different levels of factorial design.

Book suggested

15. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
16. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
17. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
18. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
19. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
20. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
21. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
9.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
10.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
11.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
12.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
13.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
14.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
15.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
16.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

25. Introduction to Materials Science for Engineers - James Shackelford
26. Physical Metallurgy Principles & Practice - V.Raghavan
27. Introduction to Solids - L.V.Azaroff
28. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
29. Materials in Nuclear Application - C.K.Gupta
30. Nuclear Chemical Engineering - Benedict and Pigford
31. Physical Metallurgy, Reed - Hill
32. Heat treatment of steel - Avener
33. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
34. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
35. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
36. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

15. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
16. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
17. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
18. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
19. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
20. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
21. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.

Course content

1. **Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.

   Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**

   Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**

   Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.

   Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.

   Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.

   Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.

4. **Radiation protection and measurement (External and Internal):**

   Control of external exposures (with problems in each case).

   Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.

   Routes of intake of radioactive material,

   Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

25. Introduction to Health Physics – Herman Cember
26. Introduction to Radiation Protection – Alan Martin
27. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
28. Nuclear Radiation Detection - W.J. Price
29. Radiation Detection and Measurement - G.F. Knoll
30. Biological Effects of Radiation – J.E. Coggle
31. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
32. Atoms, Radiation and Radiation Protection by James E. Turner 1986
33. Problems and solutions in Radiation Protection by James E. Turner, 1988
34. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
35. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
36. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

21. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
22. Steam Power Station, G.A. Gassort.
23. Power Plant Engineering & Economics, Strosal & Vapet.
24. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
25. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
26. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
27. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
28. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
29. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
30. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.

9. Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.

10. Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.

11. Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.

12. Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements

2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.

3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types

4. Design criteria, Loadings to be considered, Analysis method and validation methodology

5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features

7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Nuclear Chemical Engineering (CE1) (30 Hours)

S.No.	Course content
1.	**An Introduction to Nuclear Chemical Engineering** General Introduction and course schematics
2.	**Production of Nuclear Materials** Production of nuclear fuels (i.e.)uranium, thorium and zirconium form ores. Alternate sources for uranium Isotope separation technologies for uranium and water Fuel fabrication technologies for various types of reactors Less common nuclear materials like Zr, Hf, Th, Be,V, Nb and Ta
3.	**Solvent Extraction of Nuclear Materials** Introduction to archival extractants and flowsheets Science and technology of primary extractant (TBP) Alternate extractants for fuel reprocessing applications Extractants for nuclear waste management applications Classical and novel nuclear solvent extraction equipment Criticality and its prevention. Other safety aspects
4.	**Nuclear Fuel Reprocessing** PUREX, Advanced PUREX, SuperPUREX processes Reprocessing of thermal reactor (PHWR and AHWR) Fuels Reprocessing of fast reactor (FBTR & PFBR) Fuels UREX process and its variants Supercritical Fluid Extraction based Superdirex Process Pyrochemical and other non-aqueous processes for reprocessing
5.	**Nuclear Waste Management** Characterization of nuclear wastes Conditioning and remediation. Post-PUREX and Post-UREX processes for isolation of important radionuclides (TRUEX, UNEX, ARTIST, SETFICS, SESAME etc.) Decontamination and decommissioning
6.	**Modeling and Simulation in Nuclear Chemical Engineering** Generation of SX data by conventional & **AKUFVE** techniques Modeling of solvent extraction data Computer codes for simulation of nuclear SX Simulation of solvent extraction process flowsheets Experimental design based variation analysis of flowsheets

Books Suggested:

1. Benedict M., Pigford T.H. and Lewi H. Nuclear Chemical Engineering, McGraw Hill. 2nd ed. (1981)
2. Long, J.T. , Engineering for Nuclear Fuel Reprocessing, American Nuclear Society, IL (1978)

3. Schulz. W.W, Navratil, J.D. and Talbot A.E., Science and Technology of Tributyl Phosphate, Vol.1, CRC Press Inc., Boca Raton, FL (1984)
4. Schulz. W.W, Burger, L.L.,Navratil, J.D. and Bender K.P., Science and Technology of Tributyl Phosphate, Vol.3, CRC Press Inc., Boca Raton, FL (1984)
5. Knief, R.A. Nuclear Energy Technology, Hemisphere Publishing corporation, NY, (1981)
6. Vilani, J., Isotope Separation, (IGCAR library)
7. Selected IGCAR Reports Concurrent literature on AFCI, UREX and allied processes

2. Chemical Engineering Thermodynamics (CE2) (30 Hours)

S.No.	Course content
1.	Classical thermodynamics - the scope of classical thermodynamics, basic concepts and definitions. Laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures.
3.	Multicomponent systems: the chemical potential, fugacity, activities, and activity coefficients.
4.	Solubilities of gases in liquids, solids in gases and in liquids.
5.	Vapour liquid equilibria at low and high pressure. (Van Laar, Peng-Robinson equations). Thermodynamics of super critical fluid
6.	Liquid-Liquid equilibria.
7.	Models for Non ideal, Non-electrolyte solutions and ionic liquids.
8.	Solution thermodynamics
9.	Phase Equilibrium: Phase rule, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations, Equilibrium in systems with supercritical components, phase stability applications.
10.	Chemical Reaction Equilibria: Equilibrium constants for Homogeneous and heterogeneous reactions.
11.	Statistical Thermodynamics

Books Suggested:

1.Denbigh, K. G., The Principles of Chemical Equilibrium, Cambridge, 1971.

2.Tester, J. W. and Modell, M., Thermodynamics and its Applications, 3rd ed., Prentice-Hall, 1997.

3.Bejan, A., Advanced Engineering Thermodynamics, Wiley, 1988.

3. Transport Phenomena (CE3) (40 Hours)

S.No.	Course content
1.	Phenomenological description of continuum approach. Reynolds transport theorem. Basic laws of conservation of mass, momentum and Energy and Multicomponent systems.

2.	Transport properties. Modeling of Engg systems and the specification of boundary conditions. Shell balances, Navier-Stokes equations; Momentum, Heat and Mass transfer in steady and unsteady viscous flows; turbulent flows; shell and differential thermal energy balances; steady and unsteady conduction; laminar, forced and natural convection; shell and energy balances of mass of species; diffusion under various driving forces, diffusion with chemical reaction; convective diffusion in dilute solutions; integral balances. Transport coefficient and the macroscopic treatment of momentum, Energy and mass transport in complex system.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Multi-phase flow systems (CE4) (30 Hours)

S.No.	Course content
1.	Multiphase flows and Classification of Multiphase, Flow Patterns (gas-liquid, liquid-liquid and gas-solid and gas-liquid-solid) - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum and energy transfer for different models: Multi-dimensional and flow regime specific models.
2.	Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. (Gas-liquid mixture transport in horizontal and vertical pipe.), vapour-liquid flow, flow boiling, sub-cooled boiling, critical heat flux.
3.	Applications of two-phase flow in the design of steam generators, thermo-syphon evaporators, condensers with non condensibles and air lift pumps. Hydrodynamic of liquid-liquid flow design variables such as holdup, characteristic velocity and pressure drop.
4.	Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. (Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile and pressure drop for turbulent slurry flow.)
5.	The phenomena of fluidization and its industrial application. Characteristics of particles. Principle of fluidization and mapping of various regimes. Two phase theory of fluidization. Bubbles in fluidized bed. Entrainment and Elutriation. Fast fluidized bed. Mixing, segregation and gas dispersion. Heat and mass transfer in fluidized bed. Solid-liquid fluidized bed and three phase fluidized bed. Design of fluidized bed reactors

Books suggested:

1. Wallis, G.B. - " One Dimensional Two phase flow", McGraw Hill Book Co., New York, 1969.
2. Govier, G.W. and K.Aziz., - " The flow of Complex Mixtures in Pipes ", Van Nostrand Reinhold Co., New York, 1972.
3. Brodkey, R.S. - " The Phenomena of Fluid Motions ", Addison - Wesley Publishing Co., New York, 1967.
4. Gad Hestsroni, (Ed.in Chief) - " Handbook of Multi Phase Systems ", Hemisphere Publishing Corporation, Washington and McGraw-Hill Book Company London, 1982.
5. Two-phase flow in pipe lines and heat exchangers – D.Chisholm, Longman Inc, NewYork.
6. Fluidization Engineering- Author: Daizo Kunni and Octave Levenspiel, Butterworth-Heinemann
7. Fluidized bed technology in Materials Processing**, -**Author: C. K. Gupta and D. Sathiyamoorthy, CRC Press.
8. Chemical Reaction Engineering, - Octave Levenspiel,Wiley Eastern Limited.
9. Handbook of separation techniques for Chemical Engineers, - Philip A. Schweitzer,: McGraw- Hill

5. Code Design for Pressure Vessels & Piping (CE5) (25 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.

6. Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.

7. Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.

8. Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.

9. Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.

10. Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

6. Computational Fluid Dynamics & Heat Transfer (CE6 & CE610) (40 Hours)

Syllabus for CE6 : Computational Fluid Dynamics (30 hrs.)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme

B. Numerical Solution of Complete Fluid Flow and Energy Equation:

1. Formulations of governing equations used in numerical simulation:
2. Streamfunction-temperature formulation
3. Stream function-vorticity-temperature formulation
4. Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5. Primitive-Variable (P-V-T) formulation
6. Pressure velocity coupling for incompressible flow.
7. Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8. Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9. Simple grid generation techniques for structured grid:
10. Elliptic. parabolic and hyperbolic equation method
11. Grid adaptation
12. Domain decompositions in CFD and heat transfer
13. SIP and preconditioned conjugate gradient methods for solution
14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

<u>Syllabus for CE610 : Heat Transfer (10 hrs.)</u>

C. Laminar Boundary Layer and Forced Convective Heat:

1. Formulation of differential equation for hydrodynamic and thermal boundary layer
2. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
3. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
4. Convective heat transfer for internal and external flows
5. Low and high Prandtl number limits and different thermal boundary conditions
Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

D. Turbulent Flow and Heat Transfer:
Reynolds decomposition for turbulence
Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder
Calculation of friction factor and drag coefficient
Analytical and semi-analytical correlations for calculating heat transfer coefficients
Analogy between heat and momentum transfer
Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models
Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

E. Natural Convection:

Basic Equations of natural convection
Boussinesq approximation
Derivation of Dimensionless groups from basic equations
Analytical approximations
Numerical solution of approximate equations

F. Reactor Heat Transfer:

Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.

Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.

Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.

low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.

Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.

Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies

G. Heat Transfer With Phase Change :

Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.

Basic equations of two phase flow; Homogenous & separated flow models for two hase flow; void fraction & phase velocity ratio (Zivi's model)

Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)

Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.

Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept.
Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
Critical Flow: Models for single – phase and two-phase critical flow.

Books suggested:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.

4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

7. Advanced Chemical Reaction Engineering (CE7) (30 Hours)

S.No.	Course content
1.	Stoichiometry rates and thermodynamics of chemical reactions. Influence of concentration and temperature. Reaction mechanism. Generalized balance equation for reactive systems.

2. Collection and analysis of rate data: differential method, Integral method, Graphical method, polynomial fit method, Methods of initial rates, Methods of excess, Methods of half life. Kinetics of homogeneous and heterogeneous reactions.

3. Conservation equations for chemically reacting mixtures; heterogeneous catalytic reactions.

4. Chemical reactions and processes of transport: external diffusion effects on heterogeneous reactions, diffusion and reaction in porous catalysts.

5. Design and analysis of chemical reactors: Isothermal and non-isothermal reacting systems, catalytic and non-catalytic reactions systems.

6. Uniqueness and multiplicity of steady states, stability analysis.
Non-ideal reactors: distributions of residence time for chemical reactors, models for non-ideal reactors.

7. Modeling of multiphase reactors: fixed, fluidized, trickle bed, slurry etc.

Books Suggested:

1. Aris R., Elementary Chemical Reactor Analysis, Prentice-Hall 1969.
2. Foggler, H. S., Elements of Chemical Reaction Engineering, Prentice Hall of India, 1994.
3. Fromment G.F. and Bischoff K.B., Chemical Reactor Analysis and Design, John Wiley, 1994.
4. Smith J.M. - " Chemical Engineering Kinetics ", McGraw-Hill, 1981.

SPECIALISED COURSES

1. Process Analysis and Control (CE8) (25 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.
2.	Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3.	Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.

4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

2. Advanced Mass Transfer (CE9) (25 Hours)

S.No.	Course content
1.	Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Film, Penetration & Surface Renewal models, Solvent extraction theory
2.	Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors. Adsorption and ion exchange equipment.
3.	Membrane separation and other advanced mass transfer processes. Process intensification approaches. (few hours for seminar by TSO’s).

Books suggested:

1. Transport phenomena in liquid extraction – G.S. Laddha and T.E. Degaleesan. McGraw Hill, 1978.
2. Separation process principles – J.d. Seader, Ernest J.Henley. John Wiley & Sons. 2nd Ed. 2005.
3. Mass transfer – Thomas K.Sher wood, Robert L.Pigford, Charles R. Wilkey. McGraw hill.
4. Mass transfer operations - Robert E. Treybal. Mcgraw-hill (1980)
5. Handbook of solvent extraction – The. C. Lo. Malcolm, H.I. Baird, Carl Hanson (editor), Krieger Pub. Co. Reprint edition (Feb 1991).

ELECTIVE COURSES

1. Preparedness & Response to Nuclear Emergencies (CE-EL) (30 Hours)

S.No.	Course content
1.	Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
2.	Radiation Shielding & Study of Criticality parameters and control
3.	Nuclear Waste Management
4.	Nuclear Accidents/emergencies
5.	Transport of Radioactive material
6.	Radiological accidents/emergencies
7.	Effects of Hiroshima & Nagasaki bombing
8.	Detection of Nuclear detonation

9. Nuclear weapons: effect (Blast, heat, Radiation and EMP)

10. Medical decontamination with demonstration

11. Nuclear weapon tests (atmospheric)

12. Nuclear & Radiological terrorism (Method to contain and control)

13. Chemical warfare & Biological warfare (Method to contain and control it)

14. Emergency Response methodology/ Philosophy

15. Systems and methodology for Radiological impact assessment

16. Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities

17. Emergency Monitoring & Shelters

18. Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment

19. Civil defence WEB plan for Nuclear attack on major cities

20. Monitoring of High radiation field area

21. Lab Visits

Books suggested:

Material will be provided during the course.

2. Artificial Intelligence Methods & Applications (30 hours)

S.No.	Course content
1.	**Robotics** Forward and Inverse kinematics, Jacobians, Manipulator Dynamics, Trajectory generation, Sensors, Manipulator Control, Force control, Path planning, Mapping & Localisation of Mobile robots, Behavior based control, Robot learning.
2.	**Genetic Algorithm** Introduction to GA and its terminology, GA operators and working principle of GAs. Different selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling and elitism. Constraint handling. Multimodal function optimization. Application of GAs, real-coded GAs. Multiobjective optimization, difference with single objective optimization, concept of Dominance and Pareto-optimality. Multiobjective GAs.
3.	**Fuzzy Logic** Introduction;Need, Historical Development and Perspective of applications. Crisp and Fuzzy Sets, Operations on fuzzy Sets. Fuzzy Arithmetic, Fuzzy relations, Fuzzy logic. Possibility Theory and Uncertainty Based information. Construction of Fuzzy Sets (with examples), Approximate Reasoning.

Applications; Pattern Recognition and Process Control (with examples).

Books Suggested:
Material will be provided during the course.

3. Membrane/Separation Processes and Technology (30 hours)

S.No.	Course content
1.	Type of membranes and membrane processes
2.	Membrane transport theory – solution, diffusion model
3.	Membrane and modules
4.	Concentration polarization – boundary layer film model – concentration polarization in liquid separation processes
5.	Reverse osmosis – membranes and materials, RO membrane categories, membrane modules, fouling control and cleaning
6.	Ultra-filtration – characterization of UF, membrane fouling and cleaning – modules and system design
7.	Other membrane processes – microfiltration, nanofiltration, pervaporation and electrodialysis
8.	Application of membranes in water and wastewater treatment
9.	Application of membranes in radioactive waste management

Book suggested:

1. Membrane Technology and Applications (2nd edition) by Richards W. Baker
2. Membrane Filtration Handbook – Practical Tips and Hints (2nd edition) by Jorgen Wagner
3. Application of Membrane Technologies for Liquid Radioactive Waste Processing – IAEA Technical Report Series No. 431.

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
Materials Science

Course Code	Course Name	Hours	Credits
MS1	Engineering Mathematics	35	4
MS2	Computational Methods	30	4
MS3	Materials and Metallurgy	25	3
MS4	Reactor Physics and Fuel Design	30	4
MS5	Health Physics	25	2
MS6	Metallurgical Thermodynamics	30	4
MS7	Experimental Methods for Materials Research	45	6
MS8	Structural Materials for Nuclear Reactors	45	6
MS9	NDE Science and Technology	30	4
MS10	Physical Metallurgy	45	6
MS11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
MS12	Introduction to Materials Science and Engineering	45	6
MS13	Corrosion Science and Engineering	30	4
MS14	Mechanical Behavior of Engineering Materials	30	4
MS15	Manufacturing Technology	30	4
Total		**505**	**65**

1. Computational Methods (MS2 -45 hours)

S.No	Course content
1.	**Programming:** Introduction to programming with C# as the reference language (C# software will be provided for practice), Getting familiarized with Matlab
2.	**Numerical Techniques:** Overview of standard numerical techniques with wpecial emphasis on statistics and solving ordinary and partial differential equations
3.	**Optimization:** Overview of techniques with special emphasis on non-linear optimi9zation using gradient descent, conjugate gradient and genetic algorithm
4.	**Neural network for predictive applications:** Overview of various neural network architectures, Multilayer perceptron model for prediction, need for neuro-fuzzy models
5.	**Atomistic modeling:** Introduction to Monte-Carlo Simulation, Basics of molecular dynamics, prediction of thermo-physical properties by molecular dynamics, computational challenges
6.	**Introduction to application of FEM:**Introduction to FEM and its application, demonstration of few simple application using Abaqus (FEM software)
7.	**Current status in modeling and simulation:** With respect to mechanical metallurgy

Books Suggested:

1. Sams Teach Yourself C# in 21 Days, B.L. Jones, SAMS publications
2. Numarical Recipes in C++: The art of scientific computing, *W.H. Press et al*, Cambridge University Press
3. Numerical Mathematical Analysis *J.B. Scarborough, MacMillan Publishers*
4. Genetic algorithms in search, optimization and machine learning, *D.E. Goldberg, Addison Wesley*
5. Guide to neural computing applications, *L. Tarassenko, Arnold publishers*
6. Monte Carlo Basics, *K.P.N. Murthy, ISRP publishers*
7. Molecular Dynamics Simulation by *J.M. Haile, John Wiley and sons*

2. Fast Reactor Physics and Fuel Design (MS4/CH8- 30 hours)

S.No.	Course content
1.	**Basic Nuclear Physics Concepts:** Properties of nuclei. Nuclear forces, Nuclear models. Nuclear decay, Liquid drop model and nuclear stability, Nuclear reactions including fission, Compound nucleus formation, Microscopic cross-section, Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	**Chain Reaction:** four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.

5. **Reactor Kinetics:** Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.

Books Suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C. Edlund. Van Nostrand, 1952.
2. Introducation to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Physics of Nuclear Reactors, Jakeman D., English Universities Press, 1966.
4. A.E. Walter and A.B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981.

3. Metallurgical Thermodynamics(MS6- 30 hours)

S.No.	Course Content
1.	**Classical thermodynamics -** the scope of classical thermodynamics, basic concepts and definitions. First and second laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures. The chemical potential, fugacity, activities, and activity coefficients, Phase rule
3.	Solubilities of gases in liquids, and solids
4.	**Solution thermodynamics**: Integral and Partial Molar Thermodynamic Properties, Solution Models, Ideal Solution, Regular Solution, Real Solutions
5.	**Phase Equilibrium and Stability**: Phase equilibria in multicomponent systems, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations,
6.	**Chemical Reaction Equilibria**: Equilibrium constants for Homogeneous and heterogeneous reactions.
7.	Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Pourbaix Ellingham Diagrams, Phase Diagrams,
8.	**Experimental Methods**: Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.

Books Suggested:

1.D. Gaskell, Materials Thermodynamics, Talyor and Reid, 1981.
2. O. Kubaschewski, C.B. Alcock and P.J. Spencer, Materials Thermochemistry, Pergamon, 1985

4. Experimental Methods for Materials Research (MS7-45 hours)

S.No	Course Content
1	Vacuum Techniques (3): Fundamentals, Creation & Pressure Measurements, units, Pumps – fore Vacuum, high Vacuum and UHV
2	Thin Film synthesis methods- Physical, Chemical and MBE

3. X-RAY TECHNIQUES - techniques based on measuring the energy or angular distribution of scattered x-rays,

1.1 Wide angle elastic scattering (XRD): Atomistic – form factors; unit cell structure factors, Bragg equation, reciprocal lattice, Laue equations; Expwrimental methods- transmission, reflection, thin film, in-situ; Otjer information-particle size distributions.

1.2 Inelastic scattering- x-ray absorption spectroscopy: Basics- edges and extended fine structure; XANES and EXAFS quantitation; Surface sensitivity; Experimental methods

1.3 Small angle scattering-SAXS: Basics- what SAXS sees; Mathematical modeling;

1.4 X-ray fluorescence spectroscopy: Basics- core hole formation, fluorescence yield, transport ("ZAF"); Experimental realization – Bulk analysis; lab and synchrotron x-ray sources; Surface analysis – TXRF; Microscopy – x-ray beam manipulation.

4. **ELECTRON MICROSCOPIES:**

2.1 Transmission electron microscopy (TEM/STEM):

Electron interactions in solids-elastic and inelastic scatterin, phase change; Contrast generation-bright field, dark field, "high-resolution"; Images-information and resolution; Diffraction; Beam damage; Experimental methods hardware, specimen preparation; Inelastic scattering- electron energy loss; Emitted x-rays – elemental analysis, sensitivity, spatial resolution; STEM

2.2. Scanning electron microscopy:

Beam transport in bulk solids; Signals and images- backscattered and secondary electrons; Diffraction- channeling patterns – EBSD; X-ray generation and transport, detection and analysis; Other useful signals; Experimental methods;

EPMA Electron probe micro-analyzer

2.3. LEELS

5. ION BEAM TECHNIQUES

techniques using ions or neutrals made from them as the bombarding species

3.1. Ion beams – production-ion guns; manipulation- ion, filters

3.2. Rutherford (Nuclear) Backscattering Spectroscopy- (RBS):

High energy ions in solids- electronic and nuclear (Rutherford) stopping; Quantitative description; Experimental methods – energy spectroscopy

3.3. Nuclear reaction analysis – elemental specificity – depth profiling

3.4. PIXE (Proton Induced X-ray Emission) Signal to noise ratio – trace element analysis

3.5. Surface Mass Spectriscopy-SIMS:

Ejection of matter by bombardment: sputterin; Fate of ejected materials subsequent reaction, charge state; Mass dedtection – quad, magnetic sector, ToF; experimental issues

6. ELECTRON SPECTROSCOPIES -

techniques based on measuring the energy distribution of emitted electrons

4.1 Photoelectron spectroscopy:

Basics- energy balance, element identification; Not-so Basics- relaxation, chemical states, satellites; Surface sensitivity; Quantitation; UPS- the unfamiliar cousin

4.2 Auger Electron Sepctroscopy:

Electron excitation- why bother ? The Auger spectrum- energy balance; Chemical effects; Quantitation; Imaging- meaning of maps.

4.3 Experimental methods;

Surface of real-world things; Below the surface- profiling, variable energy; Hardware and software; samples and handling.

7. PROXIMAL PROBE MICROSCOPIES

Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM): Basics; Experimental methods; Spectroscopy in Scanning Probe Microscopy

8. NUCLEAR SPECTROSCOPY

Positron annihilation, Mossbauer – Application to defects, radiation damage defects in metals and alloys

9. VIBRATIONAL SPECTROSCOPIES

7.1 Vibrations in molecules and solids – normal coordinates, group frequencies

7.2 Infrared spectroscopy;

IR absorption – dipole scattering, selection rules; Optical arrangements-transmission, specular reflectance, diffuse reflectance, attenuated total reflectance, microscopy, in-situ; Signal collection and Fourier transform processing, data analysis

7.3 Raman: Energy transfer, selection rules; Normal, resonance, surface-enhances, Fourier transform, UV

10. 8.RESONANCE ABSORPTION SPECTROSCOPIES

8.1 Nuclear Magnetic Resonance (NMR):

Fundamentals; Experimental Techniques; Magnetic Resonance Imaging

8.2 Electron Paramagnetic Resonance (EPR): Fundamentals; Experimental Techniques

BOOKS FOR STUDY AND REFERENCE:

1. Cullity Addision, B.D., "Elements of X-ray Diffraction", Wesley Publishing Co., 1967.
2. Williams (D B), Carter (C B), Transmission Electron Microscopy: A Textbook For Materials Science, New York, Plenum, 1996
3. J.R. Tesmer et al 'Handbook of modern ion beam materials analysis' (MRS, Pittsburgh,1995)
4. L.C. Feldman, J.W. Mayer 'Fundamentals of surface and thin film analysis' (North-Holland, N.Y, 1986)
5. Prutton, M., "Surface Science and Technology, Volume27, "Analytical techniques for thin films", Academic Press, Inc.Newyork, 1991.
6. Bacon, G.E., "X-ray and Neutron Diffraction", Pergamon Press, 1966.
7. Concise Encyclopedia Of Materials Characterization Ed. Cahn (R W) and lifshin (E) Ed Oxfod, Pergamon, 1993
8. Advances in Materials Characterization Ed. G. Amarendra, Baldev Raj, M.H. Manghnani, University Press (India), 2007

8. Structural Materials for Nuclear Reactors (MS8)(Coordinator: –45hrs)

S.No.	Course Content
1.	Three stage Nuclear Power Program (Importance of Material Selection)
2.	**Thermal Reactors:** Concept, Selection of Materials – Core and out of core, Processing of Materials, Properties/Performance of Materials
3.	**Fast Breeder Reactors:** Concept, Selection of Materials for different systems, Brief description of different systems, Core materials, Design criteria for clad and wrapper, Radiation damage, Evolution of materials for clad and wrapper, Material performance, Material processing and fabrication, Structural materials, Design criteria, Materials processing and fabrication, Steam generator materials, Design criteria, Selection of materials, Materials processing and fabrication, Properties of materials and performance
4.	**Materials in Reprocessing Applications,** Closing of nuclear fuel cycle, Design concept of reprocessing plant component, Selection of materials, Processing and fabrication, Evaluation of properties and performance
5.	**Materials in Waste Storage Applications**

Books Suggested:

1. Materials research: Current scenario and future projections, Chidambaram R, Banerjee S Ed, Allied Publishers, New Delhi, 2003
2. High temperature reactor materials (workshop La Jolla,CA March18-21,2002), Allen T, Oak Ridge, U.S.Department of Energy, 2002.
3. Nuclear materials: Issues and concerns Vol 2., Bhaskara Rao D Discovery Publishing House, New Delhi, 2001.
4. Materials R & D for PFBR: Compilation of articles: (Eds) S.L. Mannan and M.D. Mathew, IGCAR, Kalpakkam, 2003.
5. An overview of R&D on fast reactor fuel cycle, Baldev Raj, Int. J. Nuclear Energy Science and Technology, Col.1, Nos.2/3, 2005, pp.164-177.
6. Selection of materials for PFBR, S.L. Mannan, S.C. Chetal, Baldev Raj, S.B. Bhoje, Trans IIM, Vol..56, No.2, April 2003, pp.155-178.
7. Development of fuels and structural materials for fast breeder reactors, Baldev Raj, S.L. Mannan, P.R. Vasudeva Rao and M.D. Mathew, Sadhana, Vol.27, Part 5, October 2002, pp. 527-558
8. Input of the atomic energy programme on special materials development in India, C. V. Sundaram, Trans IIM, vol. 41, No.5, Oct 1988, p.407.
9. Recent trends in fast breeder reactor materials, C.V. Sundaram, P. Rodriguez and S. L. Mannan, IE (I) Journal –MM, Vol.67, Sept. 1986, pp.1-11.
10. Radiation effects in nuclear reactor materials – correlation with structure, P. Rodriguez, R. Krishnan and C.V. Sundaram Bull. Mater. Sci. Vol. 6, No.5, May 1984, PP.339-367.

Nuclear Reactor Materials, C.O.Smith, Addison Wesley, 1967

<u>9. NDE Science and Technology (MS9 - 30 hours)</u>

S.No.	Course Content
1.	**Introduction to NDE:**Importance and need for NDE, classification of techniques, origin of defects; material processing related-casting, forging, rolling, welding etc., and service related-fatigue, creep, corrosion, irradiation etc. Detection, characterisation, sensitivity, reliability, accuracy,
2.	**Surface NDE:**Principle, instruments & sensors, capabilities, applications and limitations of visual, liquid penetrant, magnetic particle, eddy current and flux leakage techniques
3.	**Volumetric NDE:**Principle, instruments & sensors, capabilities, applications and limitations of radiography and ultrasonic techniques. Gamma, Micro-focal, LINAC and real-time radiography and tomography. IRIS, TOFD, SAFT, MEMS, Non-linear ultrasonics related to ultrasonics.
4.	**Dynamic NDE:**Acoustic emission, infrared radiography, intelligent processing of materials and continuous monitoring.
5.	**Digital NDE:**Forward and inverse problems, signal processing, numerical modeling, imaging, automation, probability of detection (POD), multiple NDE, data fusion and robotics.
6.	**Industrial NDE:**NDE for quality assurance, structural integrity, material characterization, condition monitoring and in-service inspection, reference standards for calibration, codes & standards, selection of NDE techniques
7.	**Practicals:** 1. Ultrasonic testing – detection of defects in weld/HAZ and measurement of thickness

2. X-radiography of welds and interpretation of radiographs
3. Eddy current testing of plates and heat exchanger tubes for defects
4. ***Seminar***: Preparation and submission of report on a topic in advanced NDE. Presentation and viva-voce

Books Suggested:

1. A practical NDT – Baldev Raj, T. Jayakumar and M. Thavasimuthu, Narosa, New Delhi, 1996.

2. ASNT Volumes on Visual, penetrant, magnetic particle, eddy current, ultrasonic, radiography, acoustic emission, thermography and other techniques, ANST, Ohio, Coloumbus.

3. Grandt, A. F. Jr., Fundamentals of Structural Integrity: Damage Tolerant Design and Non-destructive Evaluation, John Wiley & Sons, Inc. Hoboken, NJ, 2004.

4. Bray, D.E. and R.K. Stanley, 1997, Nondestructive Evaluation: A Tool for Design, Manufacturing and Service; CRC Press, 1996.

5. Peter J. Shull, Nondestructive Evaluation: Theory, Techniques, and Applications, Marcel Dekker Inc., 2002.

10. Physical Metallurgy (MS10- 45 Hrs)

S.No.	Course Content
1.	Structure and Properties of Materials
2.	**Crystalline solids:** Introduction: Engineering materials, materials cycle, application and selection criteria of materials. Significance of microstructure; crystalline defects:- dimensions, origin and their effect on properties; amorphous structure.
3.	**Phase diagrams**: Origin, construction, interpretation and application of binary phase diagrams with reference to a few important metallic and ceramic systems. introduction and classification of phase transformations, calculation of phase equilibria based on thermodynamic principles
4.	Correlation between Free energy, selection of a Phase and order parameter, different thermodynamic classification of phase transformations, order of a transformation
5.	**Diffusional transformations:** Diffusion in solids: phenomenological approach and atomistic approach. Nucleation and growth theories of vapour to liquid, liquid to solid, and solid to solid transformations; homogeneous and heterogeneous strain energy effect during nucleation; interface-controlled growth and diffusion controlled growth; overall transformation kinetics. Principles of solidification, evolution of microstructures in pure metals and alloys**.** Precipitation from solid solution: types of precipitation reactions, crystallographic description of precipitates, precipitation sequence and age hardening, spinoidal decomposition**.**
6.	**Iron-carbon alloy system:** iron-carbon diagram, nucleation and growth of pearlite, cooling of hypo-eutectoid, eutectoid, and hyper-eutectoid steels, development of microstructures in cast irons. Heat treatment of steels: TTT and CCT diagrams
7.	**Diffusionless transformations:** martensitic transformation, hardenability, role of alloying elements in steels. Bainitic transformation, Widmanstatten transformation, Massive transformation. Order-disorder transformation**.**

8. Diffusion, rate theory, mechanisms of, measurement techniques
9. Phase transformations in some nuclear non-ferrous metals and alloys
10. Characterization of microstructure – microscopy techniques, X-ray spectroscopy and diffraction.
11. **Metallographic techniques**: Optical metallography, image analysis, quantitative phase estimation.
12. Properties of X-rays: continuous and characteristics x-rays, absorption, filter, production and detection of X-ray Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.
13. **Electron optical methods**: (a) Scanning electron microscopy and X-ray microanalysis including electron probe microanalysis, electron optics, electron beam specimen interaction, image formation in the SEM; (b) Transmission electron microscopy and analytical transmission electron microscopy: Electron diffraction, reciprocal lattice, analysis of SAD patterns; different electron diffraction techniques, atomic resolution microscopy, analytical devices with TEM, field ion microscopy, scanning tunneling microscopy, advanced techniques.
14. **Introduction to novel materials and processes**: composites, intermetallics, cermets, metallic foams, intelligent materials, Dependence of their properties on structure, Nanocrystalline Materials: Synthesis, Structure and Properties.: Amorphous Materials; Metallic glasses, Glass forming ability, Bulk Metallic Glasses, Properties; Quasi crystalline Materials; Structure, Synthesis, Properties;
15. **Advanced Processes**: Rapid solidification processing, Laser surface Modification, Mechanical Alloying, Rapid prototyping, Self propagating High temperature synthesis, inert gas condensation etc.
16. **LABORATORY** Microstructures of alloys of Fe, Al, Cu and Ti for each type of transformation at different levels of resolution; Crystal structure by diffraction techniques; Defects of different dimensions; Advanced processes – Laser Ablation, Magnetron Sputtering and Plasma and Chemical deposition methods.

11. Fuel Cycle Physics& Introduction to Fuel Cycle (MS11/PY11 - 30 Hrs)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.

8. Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9. U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10. Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11. Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12. Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13. Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14. Isotopic separation operation of bred uranium in thorium cycles to remove U-232.
    MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Introduction to Materials Science & Engineering (MS12/CH4-40 hours)

S.No.	Course content
1.	**Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.
2.	**Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.
3.	**Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.

5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.

6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.

7. **Phase Diagrams &Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley &Sons, N.Y., 2003.
7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

13. Corrosion Science and Engineering (MS13/CH13 - 30 hours)

S.No.	Course content
1.	Thermodynamics of Aqueous Corrosion: Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.
2.	Kinetics of Aqueous Corrosion: Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.
3.	Forms of Corrosion: General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion. Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.
4.	Corrosion in Reactor and Reprocessing Plants: Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.
5.	Prevention and Control of Corrosion: Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.
6.	**Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.
7.	**Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, “Corrosion and corrosion control – An introduction to corrosion science and engineering”, Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, “Corrosion Engineering”, Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.

4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

14. Mechanical Behaviour of Engineering Materials (MS14- 30 hours)

S.No.	Course Content
1.	**Engineering Materials:** Alloys, intermetallics, ceramics, composites, polymers.
2.	**Basic Crystal Structure of Materials**: Unit cell, packing fractions, planes and directions, slip systems
3.	**Defects in Materials:** Point defect, line defect (dislocation), surface defects (grain boundary, twins, stacking faults), volume defects
4.	**Dislocation:** Types, Burger's vector, stress field and energy, stacking faults, dislocation glide and slip systems in crystal, interaction between dislocations, interaction between dislocations and point defects, dislocation pile up, dislocation climb, dislocation sources, multiplication of dislocations.
5.	**Elastic Behaviour of Materials:** Stress and strain at a point and their relationship
6.	**Plastic Behaviour of Materials:**
7.	**Tensile Deformation:** single crystal, yield point, CRSS, polycrystalline materials (Schmidt's factor), grain size effect-Hall-Petch relation, thermally activated deformation, constitutive equation for plastic deformation, strain hardening and dynamic strain ageing (DSA).
8.	**Strengthening Mechanism:**Strain hardening, strengthening from grain boundary, solid-solution strengthening, order-disorder strengthening, precipitation strengthening, dispersion strengthening, strengthening by point defects, martenisitic strengthening, and composite materials.
9.	**Creep:** Creep curve, mechanisms of creep deformation, activation energy for creep deformation, structural changes during creep, deformation mechanism map, super plasticity, presentation of creep data, prediction of long-term creep properties, irradiation creep, grain boundary sliding, nucleation, growth and coalescence on inter granular cavities, effect of impurity segregation on cavitation, creep fracture of weld joint, design of creep deformation and fracture resistance materials.
10.	**Fatigue:** Types of loading, high cycle fatigue, low cycle fatigue, thermo-mechanical fatigue, creep-fatigue interaction, fretting fatigue and corrosion-fatigue of various engineering materials, effect of surface treatment and coating, fatigue behaviour of welds, characterization of fatigue deformation and damage, fatigue under combined stresses, notch sensitivity, design criterion, life prediction techniques, alloy design against fatigue.
11.	**Fracture Mechanics:** Ductile to brittle transition, Griffith's law, strain energy release rate, introduction to linear and non-linear fracture mechanics, fracture toughness, fatigue and creep crack growth, material design against fracture.

Books Suggested

1. Physical Metallurgy Principle – R. E. Reed-Hill
2. Modern Physical Metallurgy – R. E. Smallman
3. Mechanical Metallurgy – G. E. Dieter
4. Plastic Deformation of Metals – R. K. W. Honeycomb
5. Introduction to Creep – W. W. Evans
6. Fatigue of Materials - S. Suresh, CambridgeUniversity Press.
7. Deformation and Fracture Mechanics of Engineering Materials – R. W. Hertzberg

15. Manufacturing Technology (MS15 - 30 hours)

S.No.	Course content
1.	**Nuclear materials and their melting practices**: Selection criteria for in-core, structural and steam generator materials, Radiation damage, Properties of nuclear materials. Principles of Vacuum melting & casting processes, including general descriptions of vacuum induction melting, vacuum arc re-melting and electro-slag refining.
2.	**Hot and cold working processes and tube making processes**: Fundamentals of mechanical processing, defects during manufacturing, Various techniques for producing seamless pipes, design of tooling for hot extrusion and principles of pilgering and Various presses and their characteristics.
3.	**Special metal forming processes**: High velocity forming processes like explosive forming, pertroforge forming, electro magnetic and hydraulic forming, comparison of HVF methods, Super-plastic forming.
4.	**Powder metallurgy** : Introduction, characterization of metal powders. Manufacturing of metal and composite powders. Compaction and sintering of metal powders. Secondary operations. Applications of typical P/M components.
5.	**Computer aided design:** Role of computers in design and manufacture, Solid modeling – techniques and algorithms for modelling – data structures for solid models; Surface modeling – curves and surface representation – composite surfaces – application to computer aided manufacture; Current developments in CAD – feature based modeling – Design by feature – function, feature linkages – Application of feature based models. Parametric modeling.
6.	**Metal joining principles and processes**: Fusion and non- fusion welding processes, modern welding processes, design of welded joints, Introduction to residual stresses and distortion in welds.
7.	**Weldability of materials**: Welding of austenitic stainless steels, ferritic steels, weldability tests, dissimilar welding and selection of weld consumables and welding defects, principles of post weld heat treatment and stress relieving.
8.	**Welded Fabrication**: Codes and Standards, Procedure and performance Qualification, Evaluation of the welded joints, NDT of welds.
9.	**Hard facing Technology**: Introduction, Need for hard facing, Hard facing processes, Hard facing in nuclear power plants.
10.	**Heat Treatment**: Annealing, normalizing, quenching and tempering, Precipitation hardening, Recrystallisation annealing, Importance of heating and cooling rate and hold time in heat treatment, Heat Treatment furnaces.

Books Suggested:

1.Metal Forming Handbook, Schuler, Springer Verlag, Berlin, 1998.
2.Welding Technology for Engineers, Baldev Raj, Shankar (V) And Bhaduri (A K), Narosa Publishing House, New Delhi, 2006.
3.Fundamentals of Metal Forming, Wagoner (R H), John Wiley & Sons, New York, 1997.
4.CAD/CAM from Principles To Practice, Chris Mcmahon And Jimmie Browne, Addison – Wesley, 1993.
5.Manufacturing Technology: Foundry, Forming And Welding, Rao (P N), Tata Mcgraw-Hill, New Delhi, 1987

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING I

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (MECHANICAL/CHEMICAL)

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE1	Code Design for pressure vessel and piping	30	4
2.	FRE2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	30	4
3.	FRE3	Transport Phenomena	30	4
4.	FRE4	Reliability Engineering	20	2
5.	FRE5	Process Design and Control	30	4
6.	FRE6	Vibration Engineering and Condition Monitoring	20	2
7.	FRE7	Seismic Design of Nuclear Reactors and Facilities	30	4
8.	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**210**	**26**

MODULE III- OPERATIONS

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE9	Plant Dynamics and Control	25	3
2.	FRE10	Turbine Generator Fundamentals	25	3
3.	FRE11	Mechanical and Electrical Equipments	25	3
4.	FRE12	Maintenance Engineering	25	3
5.	FRE13	Regulatory Framework for NPPs	25	3
6.	FRE14	Practical's	**6 Weeks**	**12**
		Total	**125**	**27**
		Total	**510**	**74**
1.	Viva Voce	**Grand Total**		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

31. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
32. Steam Power Station, G.A. Gassort.
33. Power Plant Engineering & Economics, Strosal & Vapet.
34. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
35. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
36. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
37. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
38. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
39. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
40. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.

2. **Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3. **Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4. **Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5. **Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6. **Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7. **Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8. **Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities
8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II - CORE ENGINEERING (MECHANICAL/CHEMICAL)

1. Code Design for Pressure Vessel and Piping (FRE1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical, spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures. Thermal stresses in plates and shells.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc (WRC-297)
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Design of tube sheets as per TEMA and ASME Sec VIII Div. 1.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Difference between Sec. VIII Div.1 & Sec III-NB.
12. Introduction to design codes (structure of RCC-MRx) both insignificant and significant creep. Service levels and design class. Introduction to shell and piping design. Thin Shell Design Against Buckling as per RCC-MR Appendix A-7, Elastoplastic instability under monotonic loading – linear elastic analysis, Elastoplastic instability under cyclic loading - elastic linear analysis -negligible creep, Elastoplastic instability in significant creep - simplified method.

Books suggested:

11. Harvey J F , 'Pressure vessel design' CBS publication
12. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
13. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
14. American standard code for pressure piping , B 31.1
15. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Heat Transfer and Computational Fluid Dynamics (FRE2) (30 Hours)

S.No **Course content**

1. **Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity, momentum and energy equations) with special reference to Navier-Stokes & Bernoulli equations.
2. **Laminar Boundary Layer and Forced Convection:** Formulation of differential equations for hydrodynamic and thermal boundary layers. Different analytical methods for reduction of boundary layer equations and theoretical formulation for boundary layer thickness. Study of jets and flow separation in the light of Boundary Layer Theory. Convective heat transfer in internal and external flows. Low and high Prandtl number limits and different thermal boundary conditions.
3. **Turbulent Flow and Heat Transfer**: Reynolds decomposition for turbulence. Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical correlations for heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy.
4. **Natural Convection**: Basic Equations of natural convection. Boussinesq approximation. Derivation of dimensionless groups from basic equations. Analytical approximations.
5. **Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Law, porosity & permeability, homogenization method, continuity equation & energy equation.
6. **Heat Transfer with Phase Change**: Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling & (b) flow boiling: Heat transfer correlations for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post-dryout heat transfer. Various

models available for calculation of heat transfer coefficient. Critical Flow. Models for single - phase and two-phase critical flows.

7. **Radiation heat transfer**: Radiation heat transfer. Reflection, absorption, transmission and emission; concept of black and grey bodies; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Shape factor & law of reciprocity; Radiation heat transfer between two grey bodies
8. **Numerical Methods in Heat Transfer**: Discretization of conduction equation with Dirichlet & Neumann boundary conditions; Temporal integration: Explicit & Implicit schemes. Discretization of convection-diffusion equations (Upwind & Exponential schemes). Estimation of flow field: stream function-vorticity formulation and primitive variable formulation. SIMPLE family of algorithms. Turbulence Modeling: Eddy diffusivity models: k-ε and k-ω models. Reynolds stress models: algebraic & differential versions. Large eddy simulation and Director numerical simulation.

Books suggested:

AHMT

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974.
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.
3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

CFD

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

3. Advanced Mass Transfer (FRE3) (30 Hours)

S.No. **Course content**

1. **Momentum Transport:**

   1.1 Viscosity and Mechanisms of Momentum Transport: Generalized Newton's Law of Viscosity, Pressure and Temperature Dependence of Viscosity, Molecular Theory of the Viscosity of Gases and Liquids, Viscosity of Suspensions and Emulsions, Convective Momentum Transport.

1.2 Velocity distributions with two independent variables: Time-Dependent Flow of Newtonian Fluids, Flow near Solid Surfaces by Boundary-Layer Theory.

1.3 Macroscopic Balances for Isothermal Flows: Macroscopic mass, momentum, mechanical energy balances; Estimation of viscous loss, Performance of Liquid-Liquid Ejector, Thrust on pipe bends.

2. **Energy Transport:**

   Fourier's Law of Heat Conduction; Thermal Conductivity, its measurement & its dependence on temperature / pressure. Theory of thermal conductivity of gases, gas mixtures and liquids, Effective thermal conductivity of composite solids, Convective transport of energy.

3. **Mass Transport:**

   3.1 Diffusivity and the Mechanisms of Mass Transport: Fick's Law of Binary Diffusion, Diffusivity, its measurement & its dependence on temperature / pressure, Theory of diffusion in gases, binary liquids, colloids etc. Molar transport by convection.

   3.2 Concentration Distributions in Solids and Laminar Flows: Diffusion through Gas Films, homogenous / heterogeneous chemical reactions, Diffusion into a Falling Liquid Films.

   3.3 Equations of Change for Multi-component Systems: Equations of Continuity for a Multi-component Mixture, Multi-component Equations of Change, Multi-component Fluxes and their applications.

   3.4 Concentration Distributions with More than One Independent Variable: Time-Dependent Diffusion, Steady-State Transport in Binary Boundary Layers, Boundary Layer Mass Transfer with complex interfacial motion. Concentration Distributions in Turbulent Flows.

   3.5 Interphase Transport in Nonisothermal Mixtures: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions, Combined Heat and Mass Transfer by Free Convection, Effects of Interfacial Forces on Heat and Mass Transfer, Transfer Coefficients at High Net Mass Transfer Rates.

   3.6 Other Mechanisms for Mass Transport: Equation of Change for Entropy, The Flux Expressions for Heat and Mass, Concentration Diffusion and Driving Forces, Applications of the Generalized Maxwell-Stefan Equations, Mass Transport across Selectively Permeable Membranes, Mass Transport in Porous Media.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Reliability Engineering (FRE4) (20 hours)

S.No	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.
3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY

5. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.

2. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.
4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

6. Vibration Engineering and Condition Monitoring (FRE6) (20 Hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; A seismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

7. Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

7. Seismic Design of Nuclear Reactors and Facilities (FRE7) (30 Hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

7. **Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.
15. **High Temperature and Creep Fatigue Interaction:** Damage mechanisms and failure modes, Time-dependent and frequency-dependent damage, Cumulative damage rules, Different approaches for life prediction under creep-fatigue conditions: Frequency-modified approach, strain range partitioning (SRP), Ductility exhaustion method, Creep-fatigue interaction Diagram, Thermomechanical fatigue, Codes and Standards

Books Suggested:

1. Chopra, A.K., “Dynamics of Structures, Theory and applications to Earthquake Engineering”, Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures”, New York, McGraw-Hill Book Company.
3. Mariopaz, “Structural Dynamic (Theory and Computation)”, CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., “Numerical Methods in Finite Element Analysis”, Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, “Seismic Analysis of Safety Related Nuclear Structures and Commentary”, ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, “Engineering Seismology”, IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, “Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, “Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites”. AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design”, BIS, New Delhi.

8. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.

- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.
- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.
- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings, Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.

- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.
- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evolution of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extension of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Independence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.

- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974

11. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

1. **Class room Training**
   a. Reactor System

      Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

   b. Sodium system

      Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

   c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

   d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

2. **Field training**
   a. Reactor Operation
   b. Maintenance Activities
   c. Technical Service Activities
   d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING II

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (ELECTRICAL/ELECTRONICS)

S. No.	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE15	Reactor Control Engineering	30	4
2	FRE16	Nuclear Instrumentation	25	2
3	FRE4	Reliability Engineering	20	2
4	FRE5	Process Design and Control	30	4
5	FRE17	Embedded System Design & Human Machine Interface	45	6
6	FRE18	Process Instrumentation	45	6
7	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**215**	**26**

MODULE III- OPERATIONS

S. No	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE9	Plant Control	25	3
2	FRE10	Turbine Generator Fundamentals	25	3
3	FRE11	Mechanical and Electrical Equipments	25	3
4	FRE12	Maintenance Engineering	25	3
5	FRE13	Regulatory Framework for NPPs	25	3
6	FRE14	Practical’s	6 Weeks	12
		Total	125	27
		Total	515	74
1	**Viva-Voce**			**2**
		Grand Total		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. El-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP) (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No. **Course content**

1. **Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.
Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**
Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**
Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.
Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors
Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection

4. **Radiation protection and measurement (External and Internal):**
Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.
Routes of intake of radioactive material,
Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**
Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**
Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**
Radiological aspects of Fuel Cycle Facilities

8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II A- CORE ENGINEERING (ELECTRICAL AND ELECTRONICS)

1. Reactor Control Engineering (FRE15) (30 Hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (FRE16) (25 Hours)

S.No. **Course content**

1. Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2. Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3. Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4. Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5. Introduction to various reactor instrumentation and radiation monitors:
6. Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (FRE4) (20 Hours)

S.No **Course content**

1. **Introduction: Reliability Engineering Applied to C&I Systems**
   Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
   Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
   Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
2. **Reliability Maths/Statistics:**
   - Mathematical and statistical expressions required for reliability study
   - Types of failures in electrical, electronic and computer components
   - Failure probability concept, statistical distribution models
   - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
   - Chi-square distribution and its use in confidence and risk factors
   - Baye's theorem
   - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
   - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions
   - Derivation of exponential reliability expression

- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

3. **Fault Tolerance and Systems Reliability:**
    - Fault tolerance concept for electronic and Computer based C&I systems.
    - Circuit hardware redundancy concept to enhance system reliability, types of redundancy
    - Series, parallel, active, passive, and voting redundancy
    - Redundancy and other fault tolerance methods for software
    - FMEA, FMECA concepts for C&I and Examples to solve
    - Concepts for the analysis of System Reliability, availability, and maintainability.
    - System reliability and availability analysis methods
    - Boolean logic
    - Digraph, cutest-tie set method
    - Fault tree model, and consideration of CCF, CMF, software errors
    - Markov Model

    Example from C&I system in the NPPs
4. **QA/QC Concepts in Brief:**
    - QA/QC Concepts in the components, systems procurement, manufacture and Site installation for C&I systems in the NPPs.
5. **Environmental Qualification and Reliability Testing:**
    - Environmental qualification, testing of the C&I systems
    - Effects of various environments on the electrical/ electronic components
    - Climatic Qualification tests: Temperature, Humidity
    - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
    - Reliability Testing of the electronic components, equipment and C&I systems
    - Reliability screening tests for electronic components
    - Accelerated environmental tests
    - Failure terminated and time terminated tests
    - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
    - Few examples to solve
6. **PSA/PRA Concepts in NPPs:**
    - Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs
    - Explain Event Tree
    - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency
    - Level-1, Level-2, Level-3 PSA studies (Brief introduction only)

7. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier
Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ.
(1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill
Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants
(2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier
Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001),
('Formal Methods' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

5. Embedded System Design and Human Machine Interface(FRE17) (45 Hours)

S.No. **Course content**

Embedded System Design

A. Microprocessor Based Hardware Design:

1. Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16-bit Micro-controllers (e.g. 80196), Overview of 8-bit Atmel Micro-controller (AT89C51), Real Time Clock, DSPs (e.g. TMS320, SHARC family) and ARM processor.
2. Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3. Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play
4. Design Case Study: Single board computer architectures, Remote Terminal Unit, Circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.

B. Computer Communication and Networks

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.);Concept of Fieldbus, fieldbus standards, Industrial networks and Protocols.

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Programmable Logic Controller Design

Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, Relevant communication protocol and standards, PLCs for package systems.

Human Machine Interface

E. Human Machine Interface (HMI)

1. Overview of plant automation, Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
2. Design of HMI, Soft Console versus Conventional control panels, Virtual Control Panel.
3. PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.
4. Guidelines for design of HMI displays.
5. Case study of a commercially available Professional HMI package.
6. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons

7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek& R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.
17. IntellutionIfix documentation
18. NPC Guidelines for development of soft consoles

6. Process Instrumentation (FRE18) (45 Hours)

S.No.	Course content
1.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.
2.	Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors - performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques. Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
3.	Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and

differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

4. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
5. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position
6. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

   Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.
7. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

   Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
8. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

   Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
9. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

   Note:Course Work -35 Hours and Practicals -10 Hours

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication

3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrument Engineer's Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Field bus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

7. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.
- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.

- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal

pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.

- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings,

Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.
- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.

- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evoluation of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extention of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Indepence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.
- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
-

6. Practicals (FRE 14) (6 Weeks)

12. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

3. Class room Training

a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

4. Field training

a. Reactor Operation

b. Maintenance Activities

c. Technical Service Activities

d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

BACK TO MAIN

Ph.D. in Engineering Science
(Program Code: ENGG04)

Syllabus
for
Doctoral Course

Variable Energy Cyclotron Centre

Department of Atomic Energy
1/AF Bidhan Nagar, Kolkata 700 064

Total credit: 60. Duration: one year. The 40 credit basic courses tabulated serially in I to XII are common to all. After completion of this 40m credit, a student may either choose: [2 advance courses from XIII to XIX (2×4=8 credit)] or [one advance course (4 credit) + Self Study Course(equivalent to 4 credit)] and finally a project equivalent to 12 credit.

04ENGG04-001-C Mathematical Physics: Credit: 3

Linear vector spaces, Linear operators and matrices, Systems of linear equations. Eigen values and eigen vectors, infinite-dimensional vector spaces: Hilbert space & Hermitian operators. Linear ordinary differential equations, Special functions. Linear partial differential equations in physics, Separation of variables method of solution. Complex variable theory; Analytic functions. Taylor and Laurent expansions, Classification of singularities, Analytic continuation, Contour integration, Method of steepest descent. Integral equations and Green functions, Ideas about nonlinear equations, Approximation methods : WKB approximation, Fourier and Laplace transforms.

Introduction to finite and continuous groups. Group representations and operations, Permutation group and its representations, Lie group and Lie algebras. SU(2), SU(3) and SU(N) groups, Poincare groups. Introduction to manifolds, Tangent Vectors and tangent spaces, Vector fields, Differential geometry, Riemannian manifolds and Gauge theories.

Suggested *Books :*

1. A Course in modern Mathematical Physics : Groups, Hilbert Space and Differential Geometry, *Peter Szekeres*
2. Mathematical Methods for Physics and Engineering: A Comprehensive Guide, *K.F. Riley, M. P. Hobson, S. I. Bence*
3. Complex Variables: Introductions and Applications, *M. J. Ablowitz* and *A. S. Focas*
4. Geometrical Methods of Mathematical Physics, *Bernard Shutz*
5. Lectures on Advanced Mathematical Methods for Physicists, *S. Mukhi & N. Mukunda.*

04ENGG04-002-C Quantum Mechanics: Credit: 3

Approximation methods in quantum mechanics : W. K. B. and variational methods and applications. Time independent perturbation theory (for non degenerate and degenerate cases) and its application to helium atom, Stark and Zeeman effects, Time dependent perturbation theory and Fermi golden rule, its applications to beta decay theory and principle of detailed balance.

Collision theory : Born series and interaction pictures : Propagator in quantum mechanics. Measurements in Quantum Mechanics, EPR paradox, Hidden variables and Bell's inequality.

Relativistic quantum mechanics : Klein-Gordon and Dirac equations and their solutions, Gamma matrices Non relativistic limit of Dirac equation; Parity inversion and time reversal, Bilinear covariants, Charge conjugation.

Lagrangian formulation : Symmetries of Lagrangian density, Noether's theorem, Energy-momentum tensor T^{uv}-its origin & physical meaning of different components.

Path integral formulation of quantum mechanics and its Applications.

Suggested Books :

6. Quantum Mechanics, *Leonard I. Schiff*
7. Quantum Mechanics, *Eugen Merzbacher*
8. Quantum Mechanics, *A. S. Davydov*
9. Principle of Quantum Mechanics, *R. Shankar*
10. Relativistic Quantum Mechanics, *James D. Bjorken and Sidney D. Drell*
11. (i) Quantum Mechanics : Non-Relativistic Theory & (ii) Classical Theory of Fields, *L.D. Landau and E.M. Lifshitz*
12. Quantum Mechanics and Path Integrals, *P. Feynman and A.R. Hibbs*

04ENGG04-003-C Classical Mechanics: Credit: 2

Newton’s Laws (Definition of inertial frames, Galilean group)

Lagrangian formulation: Lagrangian and its properties, Minimum action principle, Euler-Lagrange’s equations, Constrained motion, Cyclic coordinates, Noether’s theorem. Application: Two body problem, Restricted three body problem.

Hamiltonian formulation: Legendre transformation, Generalized momentum, Phase Space, Hamilton’s equations of motion, Liouville’s theorem, Fixed points and Linear Stability analysis, Phase portraits, Symplectic nature of Phase Space, Poisson Brackets, Canonical Transformations, Generating functions, Action-Angle variables, Hamilton-Jacobi equation, Singular Lagrangian and examples like time crystal/ Gauge field theory.

Connection of classical mechanics with quantum mechanics

Generic Scattering crosssection, crosssection with 1/r potential. Secular perturbation theory

Integrability, Kolmogorov-Arnold-Moser theorem, Elements of Chaos theory.

Suggested Books:

1. Mathematical Methods of Classical Mechanics, V I Arnold
2. Classical Mechanics, T W B Kibble and F H Berkshire
3. Classical Mechanics, H Goldstein
4. Classical Mechanics, L D Landau and L M Lifshitz

04ENGG04-004-C Statistical Mechanics Credit: 3

Distribution functions: Mean Values and standard deviations; Gaussian limit of the binomial distribution, distribution of several random variables. Gibbsian statistical ensembles: Micro-canonical, Canonical and Grand Canonical ensembles. Gibb's theorem: Information entropy: Fluctuations: Quantum statistics: Bose-Einstein statistics, Fermi-Dirac statistic and passage to the classical limit. Ising Model: Theory of phase transitions and critical phenomena-Critical exponents and universality, Phase transformation kinetics: Homogeneous and Heterogeneous nucleation, Spinodal decomposition

Non-equilibrium statistical mechanic: Liouville's equation, BBGKY hierarchy, Boltzmann equation, Fokker-Planck Equation and Brownian motion.

04ENGG04-005-C Classical Electrodynamics: Credit: 3

Maxwell equations, Macroscopic electromagnetism, conservation laws: Maxwell’s displacement current, Vector and scalar potential, Gauge transformations, Lorentz gauge and Coulomb gauge, Green’s theorem of the wave equation, Poynting’s theorem and conservation of energy and momentum, Boundary value problems and numerical techniques.

Plane electromagnetic wave and wave propagation, Wave guides and resonant cavities: Place wave in a non-conducting medium, Linear and circular polarization, Fields at the surface and within conductor, Cylindrical cavities and Wave-guides, Modes in a rectangular Wave-guide, Energy flow and attenuation in a Wave-guide.

Radiating systems, Multiple fields and radiation: Fields and radiation of a localized oscillating source, Electric dipole field and radiation, Multipole expansion and electromagnetic fields, Properties of multipole fields, energy and angular momentum of multipole radiation, Sources of multipole radiation : Multipole moments.

Relativistic electrodynamics: The special theory of relativity, The Lorentz transformation and basic kinematic results of special relativistic, Invariance of electric charge, Covariance of electrodynamics, Transformation of electromagnetic fields, Relativistic charged particles in an electromagnetic field.

Radiation by moving charges: The Lienard-Wiechert potentials and field for appoint charge, Total power radiated by an accelerated.

Suggested Books:

1. Classical electrodynamics, *I. D. Jackson.*
2. Modern Electrodynamics, A Zangwill, Cambridge University Press, 2016

04ENGG04-006-C
a. Research Methodology: Credit: 0

1. Research – meaning, characteristics and types, steps of research, research ethics and plagiarism.

2. Introduction to patent laws – patent laws, process of patenting a research finding, copy right, cyber laws.

3. Scientific presentation procedure

4. Scientific seminars by faculties'.

Suggested books:

a. Research Methodology: Methods and Techniques, C.R. Kothari

b. Computational Methods and Programming: Credit: 3

1. Scientific programming- Procedural programming and Object oriented programming (examples in Fortran and C++)

2a. Simulation techniques - Random variables, discrete and continuous, Montecarlo techniquesand application of Montecarlo tecniques, Techniques of dynamical simulations.

2b. Statistics and treatment of Statistical analysis of data: - estimation and propagation of error, curve fitting, least square methods, Confidence limit.

3. Numerical techniques – Integration, differentiation, diagonalization of matrices, root finding (bisection and Newton-Raphson method); Interpolation techniques; ODE, PDE, Runge-Kutta method, Solution of numerical problem using different numerical technique.

Suggested books:

1. Numerical Mathematical Analysis by James Blaine Scarborough, Oxford and IBH Publishing
2. Computer oriented numerical methods , V. Rajaraman
3. Data reduction and error analysis for the physical sciences, By Philip R. Bevington and D. Keith Robinson
4. An Introduction to Error Analysis (University Science Books, Mill Valley,California, 1982) by J.R. Taylor.

04ENGG04-007-C Experimental techniques and methods: Credit: 5

1. Philosophy of experimental science - laboratory safety, measurement of various physical properties with appropriate transducers, Vacuum - production methods and measurement techniques, Cryogenics - production and measurement, Workshop practice and basics of engineering drawing.

2. Material Characterization techniques – Electrical, Magnetic, and Optical property measurements, X-ray diffraction, neutron scattering and electron scattering techniques, Surface structure and topography (Scanning Electron Microscopy) and surface property measurements (Scanning Probe Microscopy), Phase changes.

(Differential Scanning Calorimeter), Mechanical property measurement: Tension and compression testing, Micro and Nano-indendation techniques, Characterization of defects and their detection (Positron Annihilation Spectroscopy, Transmission Electron Microscopy)

Suggested books:

a. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Yang Leng
b. Characterization of materials, Elton Kaufmann

Detectors and Techniques for Nuclear and High Energy Physics

(a) Interaction of Radiations with matter: Interaction of charged particles, Electrons, photons, Neutrons, Muons and neutrinos with matter.

Radiation exposure and Dose

(b)Basics of detectors: General properties of radiation detectors, Simplified detector model, Modes of detector Operation, Pulse height spectra, Energy resolution, Detector efficiency, Working principle and properties of different types of detectors - Gas detectors, Scintillation Detectors, Semiconductor Detectors

(c) Basics of nuclear electronics: Pre-amplifier, amplifier, discriminators, gate and delay generators, Analog to Digital Converter, Time to Amplitude Converter and the basics of data acquisition systems.

(d) Experimental Nuclear physics techniques and detectors: Charged particle spectroscopy and particle identifications, Gamma ray spectroscopy, Fast neutron spectroscopy and detectors related to the different techniques

(e) Experimental High Energy Physics techniques and detectors: General concept of building a HEP experiment, coverage and options, tracking detectors, calorimeters, vertex detectors, muon chambers, neutrino detectors, particle identification detectors in HEP. Data analysis in HEP: General approach of data cleanup, calibration, track reconstruction, reconstruction of events, challenges in each stage.

Suggested books:

a. Radiation Detection and Measurement, Glenn F. Knoll
b. Nuclear Radiation Detectors, S.S. Kapoor and V. Ramamurthy
c. Techniques for Nuclear and Particle Physics Experiments: A How-To Approach, William R. Leo
d. Experimental Techniques in High-energy Nuclear and Particle Physics, edited by Thomas Ferbel
e. Introduction to Experimental Particle Physics, Richard Clinton Fernow

f. Data Reduction and Error Analysis for the Physical Sciences, Philip Raymond Bevington, D. Keith Robinson
g. Data Analysis Techniques for High-Energy Physics, edited by R. Frühwirth, M. Regler

04ENGG04-008-C Basic Field Theory: Credit: 3

Lorentz invariance and Relativistic kinematics. A preview of fundamental particles and their interactions. Review of classical field theory : Principle of least action, Lagrangian formulations for continuous system and fields.

Symmetries and conservations lows, Noether's theorem, Introduction to field quantization: Canonical quantizations of scalar, Spinor and gauge fields.

Principle of gauge invariance: Global and local gauge transformations, Abelian gauge fields.

Interaction fields : Perturbation expansion of correlation functions, Wick theorems, Feynman diagrams, S-matrix and cross section, Calculations of cross section and decay rates for elementary processes.

Suggested Books :

1. An introduction to Quantum Field Theory, *M. E. Peskin and D. V. Schroeder*
2. Quantum Field Theory, *L. H. Ryder*
3. Field Theory, *P. Ramond*
4. Gauge Field theory, *S. Pokoroski*
5. Quantum field theory, *L. S. Brown*

04ENGG04-009-C Basic Accelerator physics: Credit: 3

Introduction to accelerators: History of accelerators. Types of particle accelerators. Basic principle of Cockcroft-Walton, Van-de-graaff, Tandem, Linear accelerator, Cyclotron, Synchrotron, Storage rings and Betatron. Accelerators in India.

Transverse Beam Dynamics: Two dimensional field expansion, Field calculations of magnetic focusing and bending optics, Particle equations of motion, Thin-lens and Quadrupole focusing, Edge focusing, Solenoid focusing, Hill's equation, Phase advance in periodic focusing lattices, Transfer matrix technique, Transfer matrices for drift space, dipole, quadrupole, Stability criterion, Beta function, Courant-Snyder invariant and Twiss parameters, Beam emittance.

Longitudinal Beam Dynamics: Longitudinal Equation of Motion, Off-momentum orbits in synchrotrons, Transition and Momentum compaction, Phase stability, Synchrotron oscillation, Longitudinal emittance.

Cyclotron: Basic principle of cyclotron, Resonance condition, AVF cyclotron, Synchro-cyclotron, Betatron tunes, Shape of the cyclotron magnet, Injection, Extraction, Beam quality-time structure, energy resolution and emittance. Room temperature and Superconducting cyclotron.

RF Linear Accelerator: Principle of Linear accelerator, Wideroe and Alveraz linac, Transit time factor, Accelerating field and dispersion curve, Ion linac, Empty cavity and Loaded cavity, Travelling wave and standing wave structures.

Ion Sources: Principle of ionization, Ion sources for positive ions - Duoplasmatron, PIG, ECR, Ion sources for negative ions- surface, volume and charge exchange, Beam formation, ECR ion source and beam transport line.

Synchrotron and storage rings: Basic principle of Synchrotron, Electron and ion Synchrotron, Synchrotron radiation source, Total radiated power, Properties of Synchrotron radiation, Wiggler and undulator.

Application of accelerators: Research applications, Medicine, Industry etc.

04ENGG04-010-C Basic Condensed Matter Physics: Credit: 3

Crystal structure and crystallography : Bravais lattice – Primitive vectors, Primitive unit cell, Conventional unit cell, Reciprocal lattice and Brillouin zone, X-ray diffraction, Comparison with electron and neutron diffraction.

Electronic structure of solids : Band structure of solids, Introduction to many body problem, Single particle approximation, Hartree-Fock methods, Bloch theorem, Tight binding method, Introduction to Density functionalal theory.

Lattice vibrations : Phonons-Debye model for specific heat of solids-lattice dynamics-phonon spectrum. Electrical & thermal transport in solids, Role of electron-phonon interaction-Boltzmann transport equation.

Magnetism : Origin of magnetism, Quantum theory of diamagnetism and paramagnetism, Heisenberg's exchange interaction and ferromagnetism, Introduction to superexchange, Direct exchange and double exchange,

Superconductivity & Superfluidity : Phenomenological description of superconductivity, Interaction between electron and phonon, Cooper pair, Meaning of energy gap, Meissner effect, London theory, Classification of superconductors, High temperature superconductors, Outline of the microscopic BCS theory, Ginzburg-Landau theory. Superfluidity in liquid He. Landau's critical velocity, Two-fluid model.

Dielectric properties of solids : Static dielectric constant, Electronic and ionic polarization of molecules, Ferroelectricity- dipole theory, Inter-band transitions, Kramers-Kronig relations, Polarons, Excitons, Optical properties of metals and insulators.

Defects in solids: Classification of defects, Role of dislocations in material behavior. Irradiation effects in solids, Concept of DPA, Introduction to nuclear reactor.

04ENGG04-011-C Basic Nuclear physics: Credit 3

1. Nuclear structure: Chart of Nuclide, Nuclear Ground State Properties (Mass, binding energy, moments etc.), Introduction to nuclear models, liquid drop model, mean field concept and basic shell model, Nuclear shapes and Deformed shell model, Introduction to Gamma-ray spectroscopy, Gamma ray selection rule, single particle states, collective states, Methods of production of excited states in nuclei, Present day challenges.

2. Nuclear reactions: Nuclear reaction kinematics, Nuclear radius and methods of determination of nuclear radius, Scattering theory (partial wave analysis etc.), Statistical model (compound nucleus), Fusion-evaporation, Fusion-Fission, Concept of Level density and Temperature and methods of its experimental estimation, Resonances, Breit-Wigner formula.Introduction to different nuclear reactions: Coulomb excitation, Direct reactions, Multi-nucleon transfer, Deep inelastic collision, Multi-fragmentation and spallation. Introduction to the present day interest in nuclear reaction studies.

3. Radioactive Ion Beam (RIB): What is RIB and why it is important, Basics of the methods of production of RIB, Challenges in doing experiments using RIB, RIB facilities in the world.

04ENGG04-012-C Laboratory experiments: Credit 6 (Each student will carry out minimum of 6 experiments)

The experiments that will be carried out will make the students familiar with different types of detectors and nuclear electronics required for nuclear physics experiments and high energy physics experiments. The students will also carry out specific materials science experiments.

1. Operation of vacuum pumps and gauges
2. Thickness measurement of thin foils
3. Calibration and energy resolution of different types of radiation detectors (e.g, Si, CsI(Tl), HPGe, BaF_2 , etc.)
4. Thickness uniformity test of different detectors
5. Characterization of a neutron detector
6. Characterization of a gaseous detector (Gas electron multiplier/avalanche counter)
7. Efficiency measurement of different types of γ detectors
8. Characterisation of samples using XRD (X-ray diffractometer)
9. Measurement of stored energy in deformed samples using DSC (differential scanning calorimeter)
10. Measurement of mechanical strength of different materials using universal testing machine.
11. Characteristion of samples using Scanning Electron Microscope and Energy Dispersive X-ray Analysis.
12. Nanostructuring by ion beam.
13. Preparation and characterisation of Nanoparticles by sol-gel method.
14. Measurement of muon life time
15. Characteristic study of wavelength shifter fibres
16. Fabrication and characterization of a scintillator detector.

04ENGG04-013-C Advanced Nuclear Structure: Credit: 4

Nuclear Models (HF, HFB), Microscopic-macroscopic model and total energy Calculations (Strutinsky method), Introduction to Density Functional Theory, Electromagnetic moments, Different modes of excitation in nuclei, Giant resonances, Gamma ray spectroscopy and nuclear structure, Construction of level scheme, Spin and parity assignment of nuclear levels, Lifetime measurement of nuclear levels, Observables and deduced quantities, Nuclear Isomerism, Introduction to total Absorption Spectroscopy and beta-delayed neutron emission.

04ENGG04-014-C Advanced nuclear reaction: Credit: 4

Damped nuclear collision: General features, Kinetic energy loss, Angular distribution, Angular momentum dissipation, Time scale, Phenomenological and theoretical models for heavy ion collision, Dissipative forces: one-body, two-body dissipation. Fission dynamics: Dynamical models of fission, Quasi fission, Synthesis of super heavy elements (SHE), Heavy-ion physics at low and intermediate energies: Intermediate mass fragments emission, Reaction near Fermi energy domain, Hot nucleus, Multi-fragmentation, Liquid-gas phase transition, Theoretical models of multi-fragmentations, simulations and QMD model. Nuclear astrophysics: Nuclear resonances, Deep-sub-barrier fusion, Astrophysical S-factor, Gamow peak, Calculation of nuclear reaction rates and its use in calculating primordial and Stellar abundances; Equation of State for dense nuclear matter, β-equilibrium, Compact stars.

04ENGG04-015-C Advanced Accelerator physics: Credit: 4

Introduction: Sources of charged particle, Lorentz force and equation of motion, Hamiltonian of a charged particle, Charge particle motion in electromagnetic fields, Planer diode without and with space charge.

Basic beam parameters: Definition of beam parameters, Beam energy, Beam current, Time structure, Peak and average beam current, Beam size, Transverse beam dimensions, Bunch length, Energy spread, Beam emittances, Beam formation, Buncher, Beam chopper.

Beam optics and transport elements: Accelerator coordinate system, Paraxial ray equation for axially symmetric systems, Series representation of electric and magnetic fields, Paraxial ray equation, Solutions of the paraxial ray equations, Electrostatic lenses, Solenoidal magnetic lens, Larmor frame, Aberrations, Transfer matrix of transport elements, Stability condition, Beam envelope, Beam matrix, Transport notations, Basic focusing modules and different kinds of imaging, Telescopic system, Coupled systems, Transfer matrices of solenoid and Skew quadrupoles. Quadrupole doublet and Triplet.

Transverse and longitudinal beam dynamics: Beam envelope equation, Courant-Snyder invariant and emittance, Normalized emittance, Twiss parameters, Liouville’s Theorem, Periodic system, FODO and FOFO Cell. Magnet imperfections, Dipole field and Quadrupole gradient errors, Resonances in circular accelerators. Off momentum orbit, Dispersion function, Momentum compaction, Transition energy, Negative mass, Dispersion matching, Chromaticity and its corrections. Longitudinal equation of motion, Phase stability and synchrotron oscillations, Fixed points, Bucket, Separatrix.

Beam with space charge: Space charge effects, Uniform beam model with elliptical symmetry, Applied and self fields, Beam envelope equation with space charge, Pervience, Beam transport in a uniform and periodic focusing channel, Tune shift and current limits, Envelope oscillations, modes and instabilities, Linear beam model with charge neutralization, Space charge compensation. Vlasov model, K-V and Waterbag distribution, Stationary distributions in a uniform focusing channel, RMS emittance, Concept of equivalent beams, RMS envelope equations, Sources of emittance growth, Filamentation of phase space, Wake fields and image charge effects**.**

Linear accelerators: Particle Acceleration in an RF Field, Energy Gain in an RF Gap, Transit-Time-Factor, Shunt impedance, Quality factor, Phase and group velocities, Periodic Structures, Floquet Theorem and Space Harmonics, Traveling-Wave Linac Structures, Constant-Impedance and Constant-Gradient Structure, Independent-Cavity Linacs, Wider¨oe Linac, H-Mode Structures, Alvarez Drift-Tube Linac, Coupled-Cavity Linacs, Accelerating Structures for Superconducting Linacs, Transverse dynamics in a Linac, Transverse RF Focusing and Defocusing, Quadrupole Focusing in a Linac, Longitudinal dynamics in Linac, Longitudinal Focusing, Stability analysis, Separatrix, RF Bunching, Beam dynamics in RFQ accelerator.

Storage rings and synchrotron radiation: Radiation from moving charges, Coulomb regime, Radiation regime, Radiation sources, Bending magnet radiation, Wavelength shifter, Wiggler magnet radiation, Undulator radiation, Radiation power and angular distribution, Quantum fluctuation, Beam lifetime.

Advance accelerators: Free electron laser, Plasma accelerators, Spallation neutron sources, Rare ion beam (RIB) facilities. Accelerators driven subcritical systems (ADSS).

04ENGG04-016-C Advanced High Energy Physics Credit: 4

Renormalization in quantum field theory: One loop radiative corrections in quantum electrodynamics (OED), Power counting and the index of Divergence, dimensional regularizations and renormalizations. Calculations of one loop diagrams in QED.

Quantum Chromodynamics (QCD): Non-abelian guage theory, one loop diagrams and running coupling, Pertubative QCD.

Structure of hadrons: Proton form factor, Deep inelastic scattering of electron off proton, Parton evolutions.

Heavy Ion collisions at Ultra Relativistic Energies : Quark Gluon Plasma, Hadrons in thermal bath, Thermodynamics of strongly interacting matter, QCD phase transition in the laboratory, Space time evolution and signals of quark gluon plasma.

Space time evolution of Quark Gluon Plasma and relativistic hydrodynamics.

Suggested Books :

6. An introduction to Quantum Field Theory, *M. E. Peskin and D. V. Schroeder*
7. Quantum Field Theory, *L. H. Ryder*
8. Field Theory, *P. Ramond*
9. Gauge Field theory, *S. Pokoroski*
10. Quantum field theory, *L. S. Brown*
11. Introduction to High Energy Heavy Ion Collisions, *C. Y. Wong*
12. Quark Gluon Plasma from Big Bang to Little Bang, K. Yagi, T. Hatsuda ,and Y. Miake.

04ENGG04-017-C Advanced Materials Science – I (Effects of radiation in metals and alloys): Credit: 4

Interaction of radiation with matter: Interaction of electromagnetic radiation, neutrons and charged particles with matter, Concept of nuclear and electronic energy loss, Differential cross section in projectile target collision

Radiation Damage Event: Neutron-nucleus interactions, Interaction between ions and atoms, Ionization collisions.

The displacement of atoms: Elementary displacement theory, Modification to Kinchin-Pease displacement model, Displacement cross-section

Damage cascade: Displacement mean free path, Primary recoil spectrum, Cascade damage energy and cascade volume, stages of cascade development, behaviour of defects within the cascade

Radiation induced defect formation: Point defect formation, Thermodynamics of point defect formation, Diffusion of point defects, Dislocations.

Radiation enhanced diffusion and reaction rate theory: Point defect balance equation, Radiation enhanced diffusion, Defect reactions, Reaction-rate controlled processes.

Radiation induced segregation (RIS): RIS in concentrated binary alloys and ternary alloys, Effect of local composition changes on RIS.

Phase stability under irradiation: Radiation induced segregation, Radiation induced precipitation, Meta-stable phases, Amorphization.

Unique effects of ion irradiation: Ion irradiation techniques, Composition changes, Other effects of ion implantation like grain growth, Texture, Dislocation microstructure.

Simulation of neutron damage with ions : Aspects of radiation damage relevant to ion irradiation, Advantages and disadvantages of various particle types, Emulation of neutron irradiation damage with proton, Irradiation parameters for particle irradiation, Effects on mechanical properties due to irradiation hardening, Embrittlement, Irradiation creep and growth.

04ENGG04-018-C Advanced Material Science II Credit: 4

Multi-functional materials: Ferroelectricity, Multiferroic materials, Ferroelasticity, Magnetoelectric coupling, Conducting polymer and nanocomposites.

Nano-particle Physics: Introduction to nanoscale physics, nano mechanics, nano electronics, nano photonics, spintronics, various nano structured materials and their synthesis processes, probing of nano materials by advanced tools, applications of nano materials.

Advanced oxide materials: Crystal field splitting, John Teller distortion, Zener double exchange model, Mott insulator, Theory of superconductivity, Manganites, Density functional theory, Magnetic properties of solids, d0 ferromagnetism, Defect characterization in oxides by positron annihilation techniques, Mossbauer spectroscopy in oxides.

Suggested Books:

1. Solid State Physics, A J Dekker
2. Physics of Nanostructures, Dresselhaus and Dresselhauss
3. Transition Metals Oxides: An introduction to their electronic structure and properties, P A Cox.

04ENGG04-001-E Advanced High Energy Physics (Experiment) : Credit 4

Introduction to Relativistic Heavy-Ion Collisions-Experiments: Flow-chart from beam to Physics.

Relativistic Kinematics: Lorentz transformation; frequently used reference frames, Rapidity, pseudo-rapidity, invariant cross-section Collision and decays;

Distribution Functions: particle production and measurement in high energy collisions. ;

Detector Simulation in High Energy Physics: Requirement of detector simulation, Introduction to Geant4, Illustration with an example. ;

Physics of collisions: Synchrotron and Storage ring, Energy, Cross-section, Luminosity, Event rate, beam parameters.

Introduction to data analysis: hits, primary vertex, tracks, secondary vertex, trigger and pile-up.

Raw Data processing: Concept of detector and electronic noise, Detector calibration, Acceptance and Efficiency estimation, event and physics trigger selection, analysis for physics objectives.

Particle identification in high energy experiments: dE/dx, Range, TOF technique, Transition radiation.

Different techniques of Background and Error estimation.

Yield Calculations (Including Detector effects).

Global Observables: Multiplicity, (pseudo)rapidity distributions, invariant yields. ;

Centrality of events: Glauber Model, experimental methods.

Quarkonia suppression: Quarkonium spectroscopy, dynamics of quarkonium production in elementary collisions, cold nuclear matter effects, Debye screening, experimental observables and interpretation,

Correlations and Fluctuations: Concepts, BE correlations, Two particle angular correlation, physics interpretation**.**

Collective Flow: Radial flow, anisotropic flow: different flow harmonics and methods of extraction.

Physics of Jets: Formation, Energy loss, Jet reconstruction in high energy collisions (methodology), Importance.

Books:

1. Introduction to high energy Heavy-Ion Collisions, C. Y. Wong
2. Quark Gluon plasma from Big Bang to Little Bang, K. Yagi, T. Hatsuda and Y. Miake
3. Phenomenology of Ultra-Relativistic Heavy-Ion Collisions, Wojciech Florkowski
4. A Short Course on Relativistic Heavy Ion Collisions, Asis Kumar Chaudhuri
5. Ultrarelativistic Heavy-Ion Collisions, Ramona Vogt

04ENGG04-001-P **Project work equivalent to 12 credit.**

Total credit: 60

Contact:
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Variable Energy Cyclotron Centre
Department of Atomic Energy
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Email: daps@vecc.gov.in

Ph.D. in
ENGINEERING SCIENCES

(PROGRAM CODE: ENGG04)

INSTITUTE for PLASMA RESEARCH
BHAT, Gandhinagar

Submitted to
HOMI BHABHA NATIONAL INSTITUTE
Anushaktinagar, Mumbai

Course CI – IPR, Gandhinagar: Degree to be awarded by HBNI, Mumbai

Starting time – 01 August 2015

Course pattern
1st year – 2 trimester courses, 1 trimester Mini Project
2nd year – Project thesis/Dissertation

IMPORTANT:
After 1st year, people who qualify will be given a job in IPR as per Scientist / Engineer SC – details to be mentioned in the Technical Training Programme (TTP) 2015 advt. IPR employees who have BTech/BE/AMIE/MSc degree can also take this course as per HBNI guidelines for employees.

Only BTech/ BE / AMIE in following disciplines are considered: Mechanical, Electrical/Electronics/Instrumentation. MSc – Physics is also considered.

Trimester 1:
All courses are common to all: 1 class (lecture) – 60 minutes, 3 classes a day; 2 classes a week / faculty per subject; total number of classes/subject ~ 30 (including assignment, presentation, etc.)

Subject	Credits	Marks
Basic Plasma Physics (FC1)	3	100
Experimental Plasma Physics (FC2)	3	100
Tokamaks (FC3)	3	100
Fusion Plasma Diagnostics (FC4)	3	100
Measurement Techniques (FC5)	3	100
Numerical Methods (FC6)	3	100
Mathematical Methods (FC7)	3	100
Vacuum, Cryogenics and Magnets (FC8)	3	100
TOTAL	**24**	**800**

Trimester 2:
All courses in part (A) are common to all: 1 class – 60 minutes, 3 classes a day; 2 classes a week / faculty per subject; total number of classes/subject ~ 30 (including assignment, presentation, etc.). Courses in part (B) are subject/discipline specific.

Part (A): Advanced Subjects

Subject	Credit	Marks
Fusion Neutronics (AS1)	3	100
Plasma Facing Components: First Wall, Divertors, Blankets (AS2)	3	100
Fusion Materials (AS3)	3	100
RF, Current Drive and Neutral Beam Heating (AS4)	3	100
TOTAL	**12**	**400**

Part (B): All courses in part (B) consist of 4 classes a week; 1 class – 60 minutes, 2 classes a week / faculty per subject; total number of classes/subject ~ 60 (including assignment, presentation, etc.)
Subject Credit: 30 hours – 3 Credits
60 hours – 6 Credits

<table>
<tr><th>Subject</th><th>Hours</th><th>Total Credits</th><th>Marks</th><th>Remarks</th></tr>
<tr><td>Magneto Hydro Dynamics (PH1)</td><td>60</td><td rowspan="4">21</td><td rowspan="4">700</td><td rowspan="4">For Physics</td></tr>
<tr><td>Kinetic Theory and Statistical Mechanics (PH2)</td><td>60</td></tr>
<tr><td>Advanced Heat Transfer and Cryogenics (PH3/ME5)</td><td>60</td></tr>
<tr><td>Tokamak Related Code (PH4)</td><td>30</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Code Design for Internal and External Pressure Vessel (ME1)</td><td>30</td><td rowspan="5">21</td><td rowspan="5">700</td><td rowspan="5">Mechanical Engineering</td></tr>
<tr><td>Finite Element and Volume Methods (ME2)</td><td>60</td></tr>
<tr><td>Mechanics of Solid/Vibration/Remote Handling (ME3)</td><td>30</td></tr>
<tr><td>Advanced Manufacturing Technologies (ME4)</td><td>30</td></tr>
<tr><td>Advanced Heat Transfer and Cryogenics (ME5)</td><td>60</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Advanced Data Acquisition System (EE1)</td><td>30</td><td rowspan="6">21</td><td rowspan="6">700</td><td rowspan="6">Electrical/Electronics/ Instrumentation Engineering</td></tr>
<tr><td>Advanced Tokamak controls (EE2)</td><td>30</td></tr>
<tr><td>High Voltage, DC& AC/ Power Supplies (EE3)</td><td>60</td></tr>
<tr><td>Signal Conditioning and EMI/EMC Aspects (EE4)</td><td>30</td></tr>
<tr><td>Computer Based System Design (EE5)</td><td>30</td></tr>
<tr><td>Digital Signal Processing and Image Processing (EE6)</td><td>30</td></tr>
</table>

Trimester 3: Subject/Discipline specific project work

	Credit	Marks
Mini Project	**9**	**300**

TOTAL CREDITS IN 1ST YEAR: 24 + 12 + 21 + 9 = 66
TOTAL MARKS IN 1ST YEAR - 2200

2nd YEAR: M.Tech Thesis work

	Credit	Marks
1-year project/dissertation	**30**	**1000**

TOTAL CREDITS FOR 2 YEARS: 66 + 30 = 96
TOTAL MARKS for 2 YEARS – 3200

TRIMESTER 1

FC1 - Basic Plasma Physics (30 Lectures)

- **Introduction**

Definition of plasma, description of collective behaviour in contrast to single particle behaviour, derivation of plasma frequency (slab model), Debye length (description of Boltzmann distribution), conditions for collective behaviour (Physical basis for these conditions), binary collisions (derivation of Rutherford scattering), derivation of collision frequency ν_{ei} (large angle collisions, cumulative effect of many small angle collisions, Coulomb logarithm), discussion of collective behaviour revisited with relationship between various conditions (discussion of $k\lambda_D << 1$, plasma parameter).

- **Single Particle Motion**

Lorentz force equation, Nonrelativistic motion of a charged particle in constant electric and magnetic field: motion in constant **E** field, constant **B** field (derivation of cyclotron frequency, Larmor radius), motion in crossed **E** and **B** field, general solution for arbitrary angle between **E** and **B** field (Gantmakher formula), drift in a combined magnetic field and a general force field (non-magnetic), Motion in non-uniform **B** field (guiding centre approximation): Grad B drift ($\nabla\mathbf{B}\perp\mathbf{B}$), curvature drift, $\nabla\mathbf{B}||\mathbf{B}$ (magnetic mirrors, invariance of μ, concept of adiabatic invariance), Uniform **B** and spatially varying **E** field (Finite Larmor radius effects), Time and space varying **E** field (Ponderomotive force), Time varying magnetic field (adiabatic compression), Time varying **E** field (polarization drift)

- **Fluid Description of Plasma**

Fluid equations, Equation of state, Complete set of two fluid equations, Fluid drifts parallel and perpendicular to **B** (diamagnetic drift), Plasma Equilibrium, Transport and Stability

- **Waves in Plasma**

Notion of phase and group speeds, High frequency electrostatic waves in an unmagnetized plasma (Langmuir waves, Bohm-Gross waves), High frequency electrostatic waves in a magnetized plasma (upper hybrid oscillation), High frequency electromagnetic modes in an unmagnetized and magnetized plasma, Low frequency electrostatic waves in unmagnetized and magnetized plasma: ion-acoustic wave, ion cyclotron wave, lower hybrid oscillation, low frequency electromagnetic modes: Alfven wave, magnetosonic wave.

- **MHD Description**

Derivation of single fluid equations from two fluid equations, complete set of equations of Magneto Hydro Dynamics (MHD), MHD waves, MHD energy.

FC2 - Experimental Plasma Physics (30 Lectures)

- **Fundamental Gas Processes**

Maxwell-Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization, Thermal Ionization, De-ionization, Diffusion, Different Mechanisms of Electron-Ion Recombination, Electron Attachment and Detachment Processes, Ion-Ion Recombination Processes, Formation of Negative Ions, Electronic Properties of Solids, Surface Emission Processes, Thermionic Emission, Field Emission, Photoemission, Particle Interaction with Solids, Interaction of Electrons with Surfaces, Interaction of Ions with Surfaces, Interaction of Neutrals with Surfaces, Sputtering Phenomena.

- **Charged Particles in a Gas in Electric Field of Low and High E/p**

Diffusion and Drift in an Electric Field, Redistribution of Particles through Diffusion and Drift, Ion Mobility, Ambipolar Diffusion, Electron Drift Velocity, Concept of High E/p, Primary Ionization Processes, Electron Avalanche, First Ionization Coefficient.

- **Self-sustaining Discharge**

Over-exponential Carrier Multiplication, Ionization by Positive Ion Collision, Cathode Processes, Processes in the Gas, Secondary Ionization Processes, Second Townsend ionization Coefficient, Paschen's Law, Breakdown Criterion, Limitations of Townsend Mechanism.

- **Glow Discharge**

Structure of Glow Discharge, Current-Voltage Characteristics of Glow Discharges, Physical Interpretation and Theoretical Analysis of Cathode Zone, Negative and Faraday Dark Space, Positive Column and Anode Layer, Striations, Specific Glow Discharge Plasma Sources.

- **Breakdown under Special Conditions**

Breakdown under Alternating Fields, Microwave Controlled Breakdown, Mobility Controlled Breakdown, Inductively Coupled Discharge, Capacitive Coupled Discharge.

- **Arc Discharge**

Glow to Arc Transition, Current-Voltage Characteristics of Arc Discharges, Classification of Arc Discharges, Cathode and Anode Layers, Different Models of Positive Column, Different Configurations of Arc Discharges, Bennet Pinch and Electrode Jet Formation.

- **Plasma Sheath and Diagnostics**

Basic Concepts, Bohm Sheath Criterion, High Voltage Sheath, Generalized Criteria for Sheath Formation, Electrostatic Probe Diagnostics, Single Langmuir Probe, Double Probe and Emissive Probe.

- **Experimental Plasma Devices**

Large Volume Plasma Device, BETA machine, SMARTEX, Helicon Plasma Expt., Q-machine, SYMPLE, Linear Magnetized Plasma Beam Expt., Plasma Wakefield Expt., Plasma Torch.

FC3 - Tokamaks (30 Lectures)

- **Introduction to tokamaks**

Thermonuclear Fusion reactions, Power Balance and Lawson Criteria, Tokamak as Fusion reactor, Tokamak Research, Major constituents of Tokamaks, Indian Tokamaks, Tokamak Confinement, Confinement times, Ohmic Confinement, L-mode and H-mode Confinement, Confinement scaling, Radiation loses.

- **Equilibrium and Transport**

Tokamak Equilibrium, Grad-Shafranov Equation, Safety Factor, q and Plasma Beta, Shafranov Shift and Plasma position control, Classical Transport, Neoclassical Transport.

- **Heating**

Ohmic Heating, Neutral Beam Heating, Wave Heating, Lower Hybrid Heating and Current Drive
Ion Cyclotron Resonance Heating, Electron Cyclotron Resonance Heating.

- **MHD Stability**

Ideal Kink modes, Ideal internal modes, Resistive tearing modes, Mirnov Oscillations, Saw-tooth oscillations, ELMs, Disruption scenarios.

- **Tokamak Devices and Other Fusion Devices**

Operating Regimes, Tokamak Magnetic Systems, Power systems, Plasma Production, Measurements of major operational parameters, Plasma wall interaction, Runaway electrons, Impurities, Operational experience in Aditya and SST-1, Other Fusion Devices.

FC4 - Fusion Plasma Diagnostics (30Lectures)

- **Introduction to Tokomak diagnostics**
  Introduction to all the tokomak diagnostics and related measurements.

- **Electrical diagnostics**

Langmuir probe: Single probe characterisation, explanation and other issues, Probe configurations, Double and Triple probes, Emissive probes.

- **Magnetic diagnostics**

Rogowski, flux and diamagnetic loops, Configuration and other details, plasma position and shape measurements, Introduction to MHD instabilities and Mirnov oscillations.

- **Measurements of plasma density and electron temperature**

Thomson scattering diagnostics: General concepts of Thomson scattering. Principles of Thomson scattering diagnostics. Types of Thomson scattering diagnostics used in tokamaks, Description of a typical diagnostics set up, technical features of the diagnostics set-up. Advantages and limitations of the technique.

Reflectometery: General concepts of Reflectometery. Physics principles of diagnostics. Different types of Reflectometry techniques, description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis. Advantages and limitations of the techniques.

Interferometry: General concepts of Interferometry. Physics principles of diagnostics. Description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis. Advantages and limitations of the techniques.

ECE diagnostics: Concepts of Electron Cyclotron Emission. Physics principles of the diagnostics. Description of the typical diagnostics set up, technical features of the diagnostics set-up. Data analysis, Advantages and limitations of the techniques.

- **Measurement of impurities**

Introduction to spectroscopy, basics of passive and active spectroscopy and introduction to Visible, VUV and X-ray spectroscopy. Measurements of impurities by Visible spectroscopy and VUV/X-ray spectroscopy Data analysis by using actual spectra.

- **Measurement of ion temperatures**

Charge exchange recombination spectroscopy (CXRS) : Physics principles of CXRS , typical diagnostic set up, technical features of set up and brief on analysis techniques. Estimation of ion temperature using actual data.

X –ray crystal spectroscopy : Physics principles of X-ray crystal spectroscopy diagnostics , typical diagnostic set up, technical features of set up and brief on analysis techniques.

Neutral particle analyser: Concept of charge exchange (CX) neutral flux escaping from the tokamak plasmas, introduction to the different techniques for measurement of CX flux and energy distribution, description of the diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of the techniques, presentation of data analysis and estimation of core-ion temperature, analysis of actual plasma discharge data and estimation of ion-temperature.

- **Measurements of Radiated power**

Bolometers: Concept of Bolometry, requirement of bolometric measurements for tokamak plasmas, introduction to the different Bolometry techniques available for measurement of total radiated power loss from toakamak plasma, description of the different bolometers namely: Metal foil, AXUV and Imaging Video Bolometers, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each Bolomters, presentation of data analysis and estimation of total radiated power loss, analysis of actual plasma discharge data and estimation of total radiated power loss from the plasma.

- **Measurements of operational parameters**

Soft X-ray diagnostics: Introduction to the Soft X-ray diagnostics, physics principles and measurement technique, description of the diagnostics set up, description of the technical features of the diagnostics set up, advantages and limitation of the SXR diagnostic for electron temperature measurements.

Imaging Diagnostics: Requirement of imaging diagnostics for tokamak plasma, concept of different imaging diagnostics namely: Infrared Imaging Diagnostics, Visible Imaging Diagnostics etc., physics principles involved, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each imaging diagnostics, presentation of data analysis and analysis of actual plasma discharge data available for the imaging diagnostics.

Hard X-ray monitors: Concept of runaway electrons production in tokamaks, different measurement techniques available for the runaway detections, requirements of HXR measurements on tokamaks, principles of Hard X-Ray (HXR) generation due to runaways, introduction to HXR monitors for confined and de-confined runaways, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of HXR monitors.

Motional Stark Effect diagnostics and Beam emission spectroscopy: Introduction to beam based diagnostics, description of various beam based techniques for different types of operational parameters (q profile, ne(edge),Te(edge) and neutral beam density). Description of the diagnostics setup and technical features of the diagnostics setup and data analysis techniques.

Dust and Erosion monitors and Tritium monitors : Introduction to the concept of the Dust, erosion in tokomaks. Importance of the measurement of Dust, Erosion and Tritium. Challenges involved in the measurements. Example schemes of the measurement techniques.

- **Measurement of fusion products**

Introduction to fusion product measurements and importance of the measurement and control of fusion product generation. Various techniques available for measuring fusion products.

Confined and Lost alphas: Requirements of lost alpha particle diagnostics on future fusion devices, different diagnostics techniques available for the lost alpha diagnostics, principle of detection techniques, diagnostics set up, description of the technical features of the diagnostics set-up, advantages and limitations of each techniques and future applicability to fusion devices.

Gamma ray spectroscopy: Requirements of gamma ray spectroscopy on future fusion devices, principle of detection technique, diagnostics set up, description of the technical features of the diagnostics set-up.

Neutron flux and neutron profiles: Introduction to neutron flux and neutron profile measurements, measurement principles, measurement schemes and typical diagnostics set ups and discussion on challenges involved.

- **Overview and summary of ITER Diagnostics**

Discussion on the challenges involved in diagnosing fusion grade plasmas, over view of ITER diagnostics.

FC5 - <u>Measurement Techniques</u> (30Lectures)

- **Measurement System**

Introduction, Measurement system architecture, Computer based measurement systems, Errors in measurements, Measurement Units, Standard used in measurements, Types of Measurement Systems: Differential Measurement System, Referenced and Non-Referenced Single-Ended Measurement Systems.

- **Specifications parameters of Measurement Systems**

Sensitivity, Resolution, Nonlinearity, Saturation, Dynamic Range, Offset, Drift, Electromagnetic Compatibility, Reliability.

- **Electrical Measurements and Disturbances in Measuring System**

Measurement of Electrical Parameters: Voltage, Current, Resistance, Capacitance, Impedance, Frequency, Phase shift, Power.
Disturbances in Measuring System, Leakage Current, Parasitic Capacitive Coupling, Parasitic Inductive Coupling, Disturbances caused by: Electromagnetic Field, Feeding Cables, Improper Grounding.

- **Sensors/Transducers and Their Applications to Physical Measurements**

Sensors and Transducers – Performance Parameters, Selection of Sensors/Transducers, Temperature measurements, Pressure measurements, Flow measurements, Measurement of Linear/Angular acceleration, Velocity and Displacement, Measurement of Force and Torque, Measurement of radiant energy/light with Photosensitive Devices, Physical parameters sensing with Plasma diagnostics.

- **Analog Electronics**

  Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Pre-amplifiers, Pulse Amplifier, Signal isolation, Filters, Attenuators.

- **Introduction to Data Acquisition**

  Data Acquisition (DAQ) overview, Major components in development of Data Acquisition System (DAS), PC based data acquisition system, Data plotting and analysis. DAQ Software: Overview of Graphical/command based programming for the acquisition, Data processing and presentation of data: MATLAB, LabVIEW Application development environment, Concept and importance of Data Storage System, Microprocessors/Microcontrollers based measurement system.

- **Noise in Measurement System**

  Introduction to EMI/EMC, Methods of Noise Coupling, Methods of eliminating interference, Grounding, Cabling, Shielding, Intrinsic Noise source, Digital Circuit Noise, Sensor – DAS interface, Grounded Signal Sources, Floating Signal Sources, Grounding Issues: Various Grounding schemes for measurement.

FC6 - Numerical Methods (30 Lectures)

- **Modeling, computation and error analysis:**
Mathematical modeling, numerical methods and problem solving, Introduction to MATLAB programming, Error analysis methods, Case study.

- **Solutions of Linear Algebraic equations:**
Matrix algebra, Eigen value problems, Gauss elimination and LU factorization, Matrix inverse and conditions, Singular value decomposition, Iterative methods, Case study.

- **Numerical Differentiation and Integration**
Numerical differentiation, Numerical Integration, Case study.

- **Roots, optimization and nonlinear sets of Equations**
Bracketing methods, Open methods Optimization - Case study.

- **Application of Ordinary Differential equations**
Initial Value problems, Adaptive methods and stiff systems, Boundary value problems, Case study.

•**Application of Partial Differential equations**
Methods to solve PDEs, Case study.

•**Application of Curve fitting methods**
Linear Regression analysis, Fast Fourier Transform, Power spectral analysis, Bispectral analysis, Polynomial interpolation and extrapolation, Cubic spline interpolation, Nonlinear Least **Square** methods Case study.

FC7 - <u>Mathematical Methods</u> (30 Lectures)

- Vector analysis: vector identities, Use of Levi Civita and Kronecker delta functions for the derivation of vector identities, Notion of gradient, divergence and curl. Gauss, Green's And Stokes Theorems. Laplacian Operator in Different Coordinate Systems.
- Matrix Algebra: Classification of matrices; Elementary operations; Determinant, rank and inverse of a matrix; Solution of linear equations; Eigenvalues and eigenvectors; Similarity transformation and diagonalisation of a matrix.
- Complex analysis: Complex variables, function of a complex variable, continuity and differentiability, Cauchy-Riemann conditions, Analytic functions, Taylor and Laurent Series, singularities(poles and essential singularity) , Residues, Cauchy Residue theorem, Contour integration, Conformal Mapping and its application to the solution of Laplace equation.
- Differential equations: First and second order differential equations with constant and variable coefficients; Linear differential equations: Approximate method for solving ODE's (Series method of solution; Legendre and Bessel's differential equations and their solutions); Orthogonal polynomials and Special functions - Bessel functions, Gamma functions and Beta functions.
- Partial differential equations: First order partial differential equations, complete integral and general solution, methods of solution of a first order partial differential equation, second order partial differential equations, Laplace's equation, wave equation, diffusion equations. Method of charateristics, Separation of variables.
- Integral Transforms: Fourier, Laplace Transforms and the inverse transforms, connection to physical problems. Applications for obtaining solution of ordinary/partial differential equations.

FC8 - <u>Vacuum, Cryogenics and Magnets</u> (30 Lectures)

- **Fundamental of vacuum**
- The vacuum and its applications, Gas laws, Pressure and mean free path, Flow regimes, Conductance, Throughput and pumping speed, Ultimate pressure and pumpdown time, Outgassing and permeation. Exposure to pumps and gauges.

- **Design of a vacuum system**

Selection of materials, Pumps, Gauges, Valves, Rules for operating vacuum system. Permanent seals, Demountable seals, Vacuum components, Cleaning techniques.

- **Fundamental of cryogenics**

Cryogens properties, Heat loads in Cryogenic systems, Basic Thermodynamics and Cryogenic Processes, Material properties at low temperatures.

- **Design of cryogenics system**

Design aspects of Cryostat, Dewars and Cryolines. Fundamentals of Thermo-hydraulics and distribution network, Economics of Cryogens, Recovery of Helium and Thermal insulation.
Basics of Cryogenic valves, sizing, leaks and heat load estimation, Instrumentation at cryogenic temperatures. Safety aspects in handling cryogens.

- **Applications of Cryogenics Engineering in Fusion machines**

SST-1 Magnets, Cryo pumps, pellet injectors.

- **Fundamentals of Magnet system**

Resistive and Superconducting Magnet Systems,LTS and HTS based conductors, Flux Jumps, Filament twisting, AC losses, Cryo-stability, Monolithic & Cable-in-conduit-conductor (CICC) concepts.

- **Design and fabrication of magnet system**

Magnetic field calculations (analytical & computational tools), Magnetic force calculations, Structural design for magnets, Conductor design & Magnet winding pack design. Magnet winding pack fabrication & engineering issues, Insulation systems in magnets manufacturing, Magnets winding pack consolidation, QA/QC in magnets manufacturing.

- **Magnet operation**

Sensors and Instrumentations in Superconducting Magnets, Superconducting Magnet Quench and Protection aspects, Superconducting Magnet Tests & auxiliary test facilities, SST-1 Magnet System.

TRIMESTER 2 – PART A

(Part A is common to all)

AS1 - Fusion Neutronics (30 Lectures)

- **Neutronics Basics**

Fusion Neutronics Principles, neutron production & detection techniques, nuclear interaction processes, nuclear reactions, cross section, and thermalisation, scattering & absorption processes.

- **Particle transport phenomena in matter**

Neutron & photon transport, mathematical transport problem-Boltzmann transport equation, - probabilistic particle transport simulation - MCNP Monte Carlo code, tools: MCNP, Attila, Validation of computational tools and data.

- **Basics of fusion neutronics & blanket neutronics**

Neutronics design optimization, nuclear design of reactor components (blankets, divertor, first wall, heating systems, diagnostics etc.), Nuclear design analysis – optimization, source modelling, nuclearresponsecalculations,neutronandgammafluxes,nuclearheating,tritiumproductionrates,gasproductionanddpa.Amountoftritiumrequiredforafusionreactor,TritiumBreedingRatio, activation products & decay heat assessments, radiation damage & transmutation

- **Principles of Neutron & Fusion product diagnostics**

Processes in the plasma leading to non-maxwellian fuel ion distribution, experimental neutron, gamma-ray & alpha particle detection techniques, computational techniques to extract relevant information about the velocity functions of fusing ions out of measured neutron signals. Concepts of integrated modelling to assess and analyze the neutron emission features.

- **Radiation and licensing**

Radiation units, Radiation protection standards, Biological & genetic effects of radiations, Radiation shielding principles, composite shielding materials. Concepts of licensing & decommissioning of nuclear installations.

- **Radiation damage & transmutation**

Activation & after-heat, tools for calculations EASY-2010, concept of direct one step (D1S) method and Rigorous 2 step (RS2) process (MCNP-FISPACT) in estimating the dose rate on components of a fusion reactor after reactor shut down. Generation & management of radioactivewastefromatypicalfusionreactor.Quantification&Categorizationofradioactivewaste

- **Nuclear Safety aspects**

Basic concepts in safety, reliability and RAMI analysis, loss of coolant accidents, conceptual design of safety systems, risk and reliability analysis of systems, operational safety procedures, regulatory process, introduction to safety related instrumentation, remote handling of irradiated components

- **Fusion Neutronic Activities Worldwide**

Overview &Latest neutron facilities being built all over the world and recent trends. 4th generation nuclear reactors (high temp & compact reactors), Accelerator Driven Systems (ADS), IFMIF & CTF, Spallation Neutron Source (SNS), Fus-Fis hybrid systems (breeders), Transmutation of radiation wastes

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AS2 - Plasma Facing Components: First Wall, Divertors, Blankets (30 Lectures)

- **First Wall**

  - **Firstwall Concepts :** Basic Design of Firstwall.
  - **Loads on Firswtall: I**nertial loads, Kinetic Pressure Loads, Electromagnetic loads, Thermal & Particle loads, Neutronic Loads.
  - **Challenges for Firstwall:** Material Challenges, Fabrication Challenges, Operational Challenges.

- **Divertors**

  - **Divertor Concepts:** Basic Design of Diveror, Toroidal & Poloidal Divertor, Single-Null Divertor, Double-Null Divertor.
  - **Loads on Divertor:** Inertial loads, Kinetic Pressure Loads, Electromagnetic loads, Thermal & Particle loads, Neutronic Loads.
  - **Challenges for Divertor:** Material Challenges, Fabrication Challenges, Operational Challenges.
  - **Divertor Testing:** Destructive Testing, Non-Destructive Testing, Metrology.
  - **Novel Divertor Concepts:** Helium Cooled Divertor, Liquid Divertor.

- **Blankets**

  - **Blanket Concept**: Requirement and essential features of Shield Blanket (SB) and Breeding Blanket (BB) in a fusion reactor.
  - **Shield Blanket:** Types of SB and SB material, SB Design Concept, Thermal-hydraulic and thermo-mechanical analysis of SB.
  - **Breeding Blanket:** Types of BB and blanket materials (solid and liquid), concept of Indian BB, Indian Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) for ITER, concept of LLCB-TBM design, thermal-hydraulic and thermo-mechanical analysis of SB, LOCA and LOFA analysis of BB, Diagnostics of BB.
  - **Solid Ceramic Breeder (CB) Technology:** Development of Li CB, characterization of Li CB material, characterization of Li CB pebble bed, thermal and thermo-mechanical analysis of pebble bed.
  - **Liquid Metal (PbLi) Technology: C**omposition and developmental process of PbLi eutectic alloy, Study of basic (PbLi) loop and loop components, PbLi diagnostics. Liquid

metal MHD studies – basic analytical formulation (Velocity profile and Pressure drop studies), liquid metal MHD code development (Electric potential Method and Magnetic induction method), code benchmarking, Liquid Metal MHD experiments (Experimental set up, experimental results), liquid metal (Pb-Li) Corrosion studies (Corrosion experiments, experimental results, numerical formulation).

- **Fusion Fuel Cycle:** Requirement and essential features of fusion cycle of a fusion reactor, inner & outer fuel cycle of a fusion reactor, tritium handling technologies, tritium storage & delivery system, tritium extraction system, Tokamak exhaust processing system, tritium diagnostics.
- **Blanket Safety:** Gaseous and liquid releases during normal operation and maintenance, accidental conditions – Design Basis Accidents (DBA), Beyond Design Based Accidents (BDBA), Loss of Coolant Accidents (LOCA), Loss of Flow Accidents (LOFA), complete loss of active cooling.

AS3 - Fusion Materials (30 Lectures)

- **Fundamentals of Material Science**

  - Crystalline nature of matter - Structure and bonding of atoms, atomic arrangements in materials, Structural phase formation and transition, Types of materials (Metals, Alloys, ceramics, composites, glasses, polymers, Superconductors).
  - Defects in solids – Imperfections, Frenkel pairs, Dislocation theory, Grain-boundary, Stress Fields and Strain Energy
  - Metallurgical Aspects of materials – Solid solutions, solubility, Precipitation, Diffusion in solids (Diffusion Laws), ordering in alloys, Phase diagrams, strengthening and hardening Mechanisms, Annealing and heat treatment.
  - Physical Properties of materials – Electrical, Thermal, Magnetic, Dielectric, optical and other properties of materials
  - Mechanical Behaviour of materials – Elastic and Plastic deformation, metallic Creep and fatigue, Strengthening and toughening of steels and non-ferrous alloys, fracture and DBTT , toughness
  - Introduction & Survey of Computational Tools, Multi-scale Models

- **Fusion Materials Requirements & Issues**

  - High heat flux handling – HHF source types, parameters and effects.
  - Erosion & Corrosion – Sputtering, erosion due to heat and particle bombardment, erosion and corrosion due to liquid metals, Hydrogen embrittlement, Oxidation, Pitting and crevice corrosion

- **Material Development and Joining Technologies**

- Manufacturing Methods & Processes – Steels and alloys melting, Powder metallurgy route, Ceramics preparation methods, Composites developments, Superconducting materials manufacturing.
- Structural Materials – Austenite and Ferritic Martensitic (FM) steels, ODS alloys, Vanadium and Titanium alloys, Carbon and SiCf/SiC composites
- Functional Materials – Plasma facing Materials (Tungsten, graded and other materials), Tritium Breeding & Blanket materials, special ceramics, Superconducting materials, Heat sink Materials, shielding Materials, Diagnostics and window materials, coatings
- Joining Technologies – Methods and Issues (Welding, Brazing, Diffusion Bonding, Hiping)

- **Material Characterization & Qualification**

- Structural Characterization – Crystal and Microstructural Analysis, defect structure, Phase Transition (XRD, SEM, TEM, Neutron Diffraction, PAS)
- Compositional Characterization & Surface Techniques (EPMA, EDX, ICP-MS, XPS and AES, SIMS), Impurity limits
- Particle beam Techniques (ERDA, RBS, NRA, Synchrotron Source)
- Mechanical Property Testing- Hardness, Fatigue, Fracture, Tensile, Creep
- Thermal Property Testing – High Heat Flux test, Thermal conductivity, Thermal Expansion coefficient, Electrical Property Testing & NDT, codes and standards – Resistivity (AC &DC), Radiography, Ultrasonic techniques

AS4 - RF, Current Drive and Neutral Beam Heating (30Lectures)

- **Heating and current drive physics by neutral beam**

Basic process during beam-plasma interaction, Beam injection geometry and its implication, Energy transfer mechanism from energetic neutral beam particle to plasma, Energetic particles orbits in asymmetric field structure, Physics of current drive by NBI, Role of fast ions in Neutral Beam Current Drive efficiency.

- **Neutral beam injector system design and engineering**

Basic NBI configuration, Optimization procedure of beamline configuration, Pressure profile optimization, Beam transmission optimization.I on source design and engineering, Different Plasma production mechanism, Positive ion and negative ion production, Ion extractor and accelerator system, Beamline component design and engineering, Neutralizer, Residual Ion Dump (RID), Calorimeter or V – target, Vacuum system design and engineering, Vacuum vessel, NBI – tokamak interface duct, Cryopumps and cryogenic system, Auxiliary pumping system, Diagnostic system design and engineering, Ion source plasma diagnostics, Electrical Probe based, Spectroscopy based, Negative ion diagnostic, Laser photo-detachment, Cavity ring down method, Hairpin resonator based, Ion-acoustic wave based, Beam profile diagnostic, Doppler shift spectroscopy, Thermal imaging diagnostic, Calorimetric diagnostic, Power supply system design and engineering, RF Power supply, HV power supply for ion extraction and acceleration.

- **Introduction to RF heating**

Introduction to Fusion Reactor: Why RF and Microwave Power is required for Fusion? Interaction of electromagnetic waves with plasma.

- **Waves**

Theory of waves in unmagnetized plasma, EM waves, Longitudinal waves, Transverse wave, Ion acoustic waves. Theory of waves in magnetized plasma, EM waves, X-mode, O-mode, Hybrid waves. Classification of RF regimes. RF Requirements of Fusion Reactor, Different heating, pre-ionization and current drive mechanisms. Dispersion relations. Wave propagation in toroidal plasma geometry. Power absorption, Landau damping, Current drive mechanisms in different regime.

- **RF devices and Design tools**

Introduction to general type Waveguide, RF amplifier and Oscillators, Antennas, Engineering issues, RF design software.

- **ICRH**

Introduction to RF applications in ICRH, its design and issues. Introduction to RF transmitter, Power transmission, Antenna design, Auxiliary systems for ICRH. Diagnostic system, Impedance matching unit, Control system. Important results on different tokamaks about ICRH system. Introduction to Aditya and SST-1 ICRH Systems

- **ECRH**

Introduction to RF application in ECRH its design and issues. Introduction to Gyrotron source. Power transmission, Antenna design, Auxiliary systems for ECRH. Diagnostic system. Control system. Important results on different tokamaks about ECRH system. Introduction to Aditya and SST-1 ECRH Systems.

- **LHCD**

Introduction to LHCD system its design and issues. Introduction to Klystron source, Power transmission, Antenna design, Auxiliary systems for LHCD. Impedance matching unit, Diagnostic system, Control system. Important results on different tokamaks about LHCD system. Introduction to Aditya and SST-1 LHCD System.

- **Other types of wave heating**

Alfven wave heating, Bernstein wave heating, Design and its issues, Introduction to its sources, Power transmission, Antenna design, Impedance matching unit, Diagnostic system, Control system. Important results on different machines.

TRIMESTER II – PART B

Part –B contains the details of the core subjects.

PHYSICS

PH1 - Magnetohydrodynamics (60 Lectures)

- Physical description of electrically conducting fluids
- Derivation of basic MHD equations: Continuity, Equation of motion, Energy flow, Ohm's law, Validity of MHD equations
- The low frequency dynamics of the electromagnetic field
- Some properties of MHD: Ideal MHD equations, The Frozen Flux theorem, The effect of resistivity, Similarity scaling, The Wöltjer invariants and helicity
- Equilibrium: General considerations, The Virial Theorem, Examples of simple equilibria: -pinch, Z-pinch, screw pinch, Poloidal , paramagnetic and diamagnetic states, Force-free fields, Toroidal equilibrium: the Grad-Shafranov equation, nonlinearity, Definition of q, beta, plasm ashape, etc.
- Comparison of fusion confinement systems: Spheromak, FRC, RFP, Spherical Tokamak
- Tokamak Equilibrium: In large aspect ratio limit with arbitrary choice of profile, Solovev equilibrium with finite aspect ratio and linear profile in poloidal flux, Solution with arbitrary aspect ratio and arbitrary choice of profiles (numerical)

PH2 - Kinetic theory and Statistical mechanics (60 Lectures)

- Gas dynamic way of describing an uncharged fluid – heuristic
- Recollect derivation of basic MHD equations – one fluid only (Continuity, Eqn of motion, Energy equation [thermodynamic closure], Electron equation of motion [Ohm's Law])
- Introduce ideas of Phase Space (x,v) and distribution functions f(x,v,t)
- Using heuristic arguments in single particle phase space (x,v) to obtain "fluid equations" in phase space – namely – the Vlasov-Poisson Equations
- Introduce conservation of Energy and other physical quantities as constraints.
- Using constrained variation technique demonstrate how entropy extremization leads to Maxwell-Boltzmann distribution f_mb(x,v) and importance of Maxwell-Boltzmann distribution
- Langmuir Oscillations and Waves – Vlasov-Poisson dispersion
- Linear Landau Damping – why is this not seen in fluid equations?
- Two stream instability and Phase Space structure formation
- Many stream interpretation of an equilibrium distribution f_mb(x,v)

- Stability – Newcomb-Gardner Theorems and Penrose Stability Criteria
- Nonlinear Landau damping and Theory of BGK modes – revisit Two stream instability.
- Stability of BGK modes.
- Particle correlations and need for two-body and higher order distributions
- Equations governing two body distrution f_2(x,v,t) and its relationship to f(x,v,t) the one-body or Vlasov distribution studied earlier – Introduction of pair correlations
- Construction of a N-body distribution function f_N and BBGKY Hierarchy issues.
- Klimontovich-Dupree (KD) procedure – Obtaining a "statistical N-body" distrituion from KD equation.
- Green-Kubo formalism – Transport and Correlations
- Examples of GK formalism and obtained transport
- Very cursory introduction to Onsager relationships

PH3 - Advanced Heat Transfer and Cryogencis (60 Lectures)

(PLEASE SEE ME5 – these are common courses for Physics and Mechanical disciplines)

PH4 - Tokamak related Code (30 Lectures)

- **Plasma core modelling:**

— Plasma equilibrium IPREQ

— Plasma transport TSC

— Plasma stability ERATO, PEST2

— ICRH heating TORIC

— NBI heating NUBEAMS

— Plasma start up model

— Reactor system code

— Eddy current analysis

— TF modelling EFFI

— Vertical instability analysis

- **Edge-SOL studies**

— 2D blob transport

— Divertor study SOLPS (B2+ERINE)

— 3D plasma study ERINE-3D

- **First principle simulations**
  - Low frequency (w/wc <<1) transport – what is Gyrokinetic method?
  - What are the transport processes neglected by gyrokinetic formalism?
  - What are global and local simulations – examples (flux tube modes and global models)?
  - Under what conditions do results from these two simulations are expected to match?
  - Gyrokinetic equations derived from Vlasov-Poisson equations using Bessel function procedure
  - How does Gyrokinetic formation capture the physics of Finite Larmor Radius to all orders at low frequencies?
  - Numerical Advantages of Gyrokinetic formalism – examples
  - Simulating very large scale systems (100s of larmor radii) using very large parallel computers – Issues and Advantages
  - Modelling energetic particle transport using Gyrokinetic formalism

MECHANICAL

ME1- Code Design for internal and external pressure vessel (30 Lectures)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and tori spherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div – II equations for cylindrical / Spherical shell and conical, ellipsoidal and tori spherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3.
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive

Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1and Div.2.

- Difference between metallic pressure vessel and FRP pressure vessels.
- Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Failure modes of pressure vessels, Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and piping's.

ME2 - Finite element and volume methods (60 Lectures)

Finite Elements methods (30 Lectures):

- Introduction to FEM: Weighted residual method, Galerkin's methods, Weak form formulation, piecewise approximations. Basis of Finite Element Method, Variation principles, energy principles in structural mechanics, Element libraries
- Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements
- Bar element: Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss.
- Beam element: Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- 2D plane elements – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- 2D isoparametric formulation – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress.
- Introduction and Application to 3D elements: Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Shell element: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions.
- Introduction to Nonlinear problems: Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method.

- Finite element applications for design: Finite element modelling and discretization criterion,h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

Finite Volume Methods (30 Lectures):

Basics of Fluid Flow, Heat Transfer and Numerical Analysis

- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity',momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme

Laminar Boundary Layer and Forced Convective Heat

- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Convective heat transfer for internal and external flows.
- Low and high Prandtl number limits and different thermal boundary conditions.

Turbulent Flow and Heat Transfer

- Reynolds decomposition for turbulence.
- Prandtl's mixing length theory, Mixing length models.
- Structure of turbulent boundary layer over flat plate and through circular cylinder.
- Calculation of friction factor and drag coefficient.
- Analytical and semi-analytical correlations for calculating heat transfer coefficients.
- Reynolds analogy & Low Reynolds number models.
- Turbulence Modelling.
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model.
- Reynolds stress models: algebraic and differential models.

Natural Convection

- Basic Equations of natural convection.
- Derivation of Dimensionless groups from basic equations.
- Analytical approximations.
- Numerical solution of approximate equations.

Numerical Solution of Complete Fluid Flow and Energy Equation

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation.
- Primitive-Variable (P-V-T) formulation.
- Pressure velocity coupling for incompressible flow
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE, SIP and SIMPLEN family of Methods.
- Simple grid generation techniques for structured grid.
- Elliptic, parabolic and hyperbolic equation method.
- Domain decompositions in CFD and heat transfer.

ME3 - Mechanics of solid/vibration/ remote handling (30 Lectures)

Mechanics of solids

- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of stress

- Description / Notations of Forces & Stress.
- Component of stress.
- Reciprocity of shear stress in 3D.
- Stresses Transformation using direction cosines.
- Stress Traction Vectors or Traction Vectors.
- Stress component on an arbitrary plane.
- Principal stresses & Mohr's Diagram for 3D state of stress.
- Stress Invariants.
- Hydrostatic and Deviator components of stress.
- Principle planes and their orthogonally.
- Octahedral plane, Octahedral stresses.
- State of pure shear.

Analysis of strain

- Description / Notation of Strain in 3D.
- Components of strain.
- Strain Transformation using direction cosines.
- Principle Strains, Strain Invariants.
- Strain Deviator Tensor.

Principles and fundamental Equations of Elasticity

- Strain and displacement relations (Cauchy's equations).
- Compatibility equations (Saint-Venant's Equations).
- Generalized Hook's Law.
- Anisotropy and Isotropy of elastic behaviour.
- Stress and strain relationship.
- Equations of equilibrium (Navier's Equations, Lame's equations).
- Strain Energy.
- Uniqueness theorem.
- Bounds on elastic constants.
- Superposition Principles.
- Saint-Venant's Principle.
- General Solution Procedures for an elasticity problem.

Vibrations

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations underdamped, overdamped and critically damped systems; Response to harmonic loading -complementary solution and particular solution; Response to periodic loadings using Fourier Series
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems;Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration).

Remote handling

- Automation and introduction to remote handling.
- Industrial manipulators.
- Kinematics of manipulators specifying position and orientation of rigid bodies, Euler angles, homogeneous coordinate transformations, D-H representations of kinematic linkage, velocity analysis of manipulators.

ME4 - Advanced Manufacturing Technology (30 Lectures)

ADVANCE MANUFACTURING PROCESSES

- INTRODUCTION: Unconventional Machining Process, Need – clarification – Brief overview of all techniques.
- MECHANICAL ENERGY BASED PROCESSES: Abrasive Water Jet Machining, Water Jet Machining, Ultrasonic Machining (AJM / WJM/ USM). Working principles – equipments used – process parameters – MRR – Variation in techniques used – Applications.
- ELECTRICAL ENERGY BASED PROCESSES: Electro Discharge Machining, Working principles – Equipments – Process parameters – MRR – electrodes/ tools / power circuits – tool wear – Dielectric- flushing- Wire cut EDM – Applications.
- CHEMICAL AND ELECTRO-CHEMICAL ENERGY BASED PROCESSES: Chemical Machining, Electro- Chemical Machining – Etchants- maskant-Techniques of applying maskants – Process parameters – MRR –Applications. Principles of ECM-MRR-Electrical circuit – process parameters – ECG and ECH applications.
- THERMAL ENERGY BASED PROCESSES: Laser Beam Machining, Plasma Arc Machining and Electron Beam Machining. Principles – equipments – types – beam control techniques applications.

ADVANCED MATERIALS JOINING AND TESTING

- INTRODUCTION: Classification – heat sources – metallurgical effect of weld – residual stresses: formation and relieving – capillary and welding action – temperature range – filler material and fluxes – types of joints and welding positions – weldability: design, process and metallurgical consideration – testing and improvement.
- JOINING TECHNIQUES: Bolting – riveting – soldering – blazing – adhesive bonding – diffusion bonding – mechanical joining. Fusion welding: Oxyacetylene welding – SMAW – GTAW – GMAW – FCAW – SAW – ESW – High energy beam welding: EBW, LBW, PAW – friction stir welding. Output parameter variation – advantages and disadvantages – applications.
- RESPONSES OF MATERIALS TO WELDING: Microstructural changes – distortion – defects: undercuts –overlaps – grain growth – blowholes – inclusions – segregation – lamellar tearing – porosity. Remedies: Edge preparation – alignment – control of heat input – preheating – peening – heat treatment – jigs and fixtures – number of passes.
- DESTRUCTIVE AND NON-DESTRUCTIVE TESTS FOR WELDS: Introduction – need – principles – applications –destructive tests: tensile, bend, impact, hardness, fatigue, cracking,

etching. Non-destructive tests: Visual, dye penetrants, magnetic particle, acoustics, pressure, radiographic, ultrasonic, eddy current.

ME5 - Advanced Heat Transfer and Cryogenics (60 Lectures)

Computational Fluid Dynamics

- Basics of fluid flow and heat transfer, Mathematical description of fluid flow, conservation equations for mass and momentum, Classification of partial differential equations, discretization techniques using finite difference and Finite volume methods, Taylor's series and control volume formulations, stability, consistency and Convergence of numerical schemes, application of numerical methods to model equations.
- Natural convention and Forced convection heat transfer and calculation heat transfer coefficient for different geometrical configurations and analytical approximations relations
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and adiabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio.

Heat Transfer

Conduction:

- Derivation of energy equation for conduction in three dimensions – Initial and boundary conditions. Solution of simple problems in steady state conduction with analytical solutions – Concept of electrical analogy – fin heat transfer and concept of fin efficiency and fin effectiveness.
- Concept of Biot number – Lumped capacitance formulation – simple problems – unsteady conduction from a semi-infinite solid- solution by similarity transformation method. Solutionof the general 1D unsteady problem by separation of variables and charts- example problems.
- Laplace equation – solution by variable separable method – concept of superposition and homogeneous boundary conditions. Phase change problems – The Stefan and Neumannproblems – analytical solutions.

Convection:

- Natural Convection heat transfer: Governing equations for natural convection, Bossiness approximation, Dimensional Analysis, Similarity solutions for Laminar flow past a vertical plate with constant wall temperature and heat flux conditions, Integral method for natural convection flow past vertical plate, effects of inclination, Natural convection in enclosures, mixed convection heat transfer past vertical plate and in enclosures.
- Laminar External flow and heat transfer:
  Similarity solutions for flat plate (Blasius solution), flows with pressure gradient(Falkner-Skan and Eckert solutions), and flow with transpiration,

Integral method solutions for flow over an isothermal flat plate, flat plate with constant heat flux and with varying surface temperature (Duhamel's method), flows with pressure gradient (von Karman-Pohlhausen method).

- Laminar internal flow and heat transfer:
  Exact solutions to N-S equations for flow through channels and circular pipe, Fully developed forced convection in pipes with different wall boundary conditions, Forced convection in the thermal entrance region of ducts and channels (Graetz solution), heat transfer in the combined entrance region,
  Integral method for internal flows with different wall boundary conditions.

Radiation:

- Fundamental of thermal radiation and electromagnetic wave theory
- View factors.
- Radiative exchange between grey and diffuse surfaces.
- Radiation between non-ideal surfaces.
- Surface radiative exchange in the presence of conduction and convection.
- The equations of radiative transfer in participating media.
- Radiative properties of molecular gases.
- Introduction to monte Carlo method for thermal radiation.
- Governing Equations: Continuity, Momentum and Energy Equations and their derivations indifferent coordinate systems, Boundary layer Approximations to momentum and energy.

Cryogenics

- **Basic Principles of Cryogenics:**

Thermodynamics, Heat Transfer, Heat Leak, Pressure drop, Cool down, Applications of cryogenics, Properties of cryogenic fluids, Properties of materials (Structural & thermal) at cryogenic temperature, Material selection criteria

Gas-Liquefaction and Refrigeration Systems:
Refrigeration and Liquefaction, Recuperative cycles, Liquefaction of gases, Inversion temperature, Expansion processes, Refrigerator efficiency, Refrigeration and Liquefaction Methods, Regenerative cycles, Ultra low temperature refrigerators, Cryo-coolers.

Cryogenic Insulations:
Types of insulations, Vacuum Insulation, Evacuated Porous Insulation, Gas-filled Powders and fibrous materials, Solid foams, Multilayer Insulations, Liquid and vapor shields, Composite insulations, Placement of insulation systems, Comparison of insulations

Instrumentation in Cryogenics:
Measurement: Strain, Displacement and position, Pressure, Temperature, Flow, Liquid level, Density

Cryogenic Equipment and Cryogenic System Analysis:
Introduction, Compressors, Pumps, Expansion Engines, Valves, Heat Exchangers, Storage, Transfer of liquefied gas

Safety with Cryogenic Systems:
Physiological Hazards, Suitability of materials and construction techniques, Explosions and Flammability, Excessive pressure gas, Special considerations for Hydrogen and Oxygen, General Safety Principles, Safety Checklist

Electrical/Electronics/Instrumentation

EE1 - Advanced Data Acquisition System (30 Lectures)

- **Theory of Quantization**
  Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, antialiasing filters.

- **Advanced Data Acquisition Systems**

  Modular Data Acquisition Systems in Nuclear Instrumentation: CAMAC, VME, PXI, PXIe. DAQ system architecture and major components. Data Archival and Retrieval. DAQ Data server architecture and interface, Data plotting and analysis tools

- **Data Acquisition Interface**

  Sensor – DAQ interface: Grounded Signal Sources, Floating Signal Sources, Grounding Issues: Various Grounding schemes for accurate measurements, Types of Measurement Systems: Differential Measurement System, Referenced and Non-Referenced Single-Ended Measurement Systems, Graphical/command based programming for the acquisition, processing, and presentation of data: MATLAB, LabVIEW Application development environment.

- **Analog Input/output**
  Analog Input Circuitry, Anti-aliasing Filters, sampling and DAQ device architecture, Analog Output Architecture, Analog Output Circuitry, Update rate and output interface.

- **DAQ Clock and Trigger**
  Theory and concepts of analog and digital triggering, Continuous and event-based acquisition, Clock and trigger input and output to DAQ device for timing and synchronization, Counter I/O: Edge Counting, Pulse Generation, Pulse Measurement, Frequency Measurements.

- **Synchronization**
  Single Device Synchronization: Simultaneous sampling, Multiple Device Synchronization: Clock and trigger synchronization, Introduction to Timing system.

- **SST-1 Data Acquisition System**

  Architecture of SST-1 Data Acquisition System: overview and major components, System requirements, Various DAQ interfaces: CAMAC, PXI, PXIe, digitization requirements, Signal-conditioning system: Channel requirements, various stages in signal conditioning system, CAN bus interface, DAQ Software: LabVIEW based GUI for remote operation, Networking requirements and TCP/IP based communication with subsystems, distributed system, DAQ NAS server, Central Data storage server, server management, data plotting utilities.

EE2 - Advanced Tokamak Controls (30 Lectures)

- **Fundamentals of Control System**

  Systems and their representation: Terminology and basic structure of control system, Open loop and Closed loop systems, servomechanism, regulatory system, analogous systems, electrical analogy of physical systems, Physical Systems and their models, transfer function, Block diagram representation of physical systems, Block diagram algebra, Signal Flow graph. Systems in state space: Concept of states and state model, State equation from transfer function, modelling of dynamical systems, State space representation of multivariable systems, Building blocks of state space models. Advanced control system: Cascade control, ratio control, feed forward control. Over-ride, split range and selective control. Multivariable process control, interaction of control loops Process Control System: Terms and objectives, piping and Instrumentation diagram, instrument terms and symbols. Regulator and servo control, classification of variables. Process characteristics: Process equation, degrees of freedom, modelling of simple systems – thermal, gas, liquid systems. Process lag, load disturbance and their effect on processes. Self-regulating processes, interacting and non-interacting processes.

- **Different types of Control Systems**

  Feedback control system, Real-time control system, Nonlinear and Adaptive Control, Robust control system, Embedded Systems: Hardware and software architecture, Neural Networks, Fuzzy Logic Systems

- **Introduction to Plasma Control**

  Plasma Position Control, Shape Control, Density Control, modelling aspect, simulations, Plasma Control case studies: D-III-D, JT-60, JET, SST-1, EAST, ITER.

- **ITER Instrumentation & Control**

  CODAC (Control, Data Access and Communication) System, Central Interlock System (CIS), Central Safety Systems (CSS), Plant Control System, Plant Interlock System, Plant Safety System, CODAC Core Systems, EPICS, SNL, CSS, MDS Plus, LabVIEW, Matlab Simulink, Python, Grid Computing, Parallel Processing, Diagnostic Data Analysis Tools and Codes, Real-Time OS.

- **SST-1 Operation &Control**

Architecture of SST-1 Operation &Control System, System requirements, system overview and major components. Signal-conditioning system: Channel requirements, various stages in signal conditioning system, CAN bus interface, GUI based remote operation, TCP/IP based communication with subsystems, distributed system. Data Acquisition System: System overview, various interfaces, CAMAC, PXI, PXIe based technology; LabVIEW based GUI, digitization requirements, system architecture, technical requirements, network storage server, server management, data plotting utilities. Operation and Control System: Timing system, Central Data storage server, Interlock system, Tokamak operation and subsystem control, VME based control system

- **Monitoring and Control of Auxiliary Systems**

Monitoring& Control for ICRH, ECRH, NBI. Vacuum System, RHVPS and Switching scheme, Cryogenic Cooling Plant, CWS, BMS, Access Control, Super conducting Magnet Quench detection and protection.

EE3 - High Voltage DC & AC/ Power Supplies (60 Lectures)

- **Overview of Electrical systems in Fusion machines**

Basic introduction to electrical systems in Tokamak, Stellarator and Z-machine; Tokamak as a transformer, Electrical systems for plasma formation – Ohmic discharge, Arc discharge, RF discharge, MW discharge; Electrical systems for plasma confinement – Magnet power supplies, Electrical systems for plasma acceleration – Accelerator power supplies for charged particles. Use of other HV equipment in Fusion Technology: Capacitor bank, Van-de-graf generator, Pulse forming lines, Marx generator, Power supply systems applications in fusion machines.

- **High Voltage DC & AC**

High Voltage Generation, High AC, DC and Impulse Voltages, High Voltage Components, Basic design features of High Voltage Power Transformer: Basic design of HV Transformer, Transformer insulation requirements, dielectric strength and voltage conditions, winding arrangements, surge behavior, behavior of liquid dielectric, electrode surface phenomena, gas evolution, processing techniques, construction of EHV transformer, short circuit behavior. High Voltage Circuit Breakers: Air break, SF6 and vacuum circuit breakers. Gas Insulated Substation (GIS): Advantages of GIS, comparison of GIS and air insulated substations, design and layout of GIS, description of various components of GIS. High Voltage Measurement: CVT, Peak voltmeters, sphere gaps, impulse recording, Over-voltage and protection, Insulation coordination, High voltage testing methods using Partial discharge (PD), Causes and effects of PD, PD diagnostic techniques. HV and UHV systems: Fusion Technology Applications. Basic Overview of Pulse Power Technology.

- **Power Supplies**

- DC Power Supplies: Linear and switching power supplies, DC to DC converters and their operating characteristics, Selection of Power Semiconductor Devices, Magnetic component behavior and

selection. Control pulse generation and control techniques, Feedback isolation techniques, Auxiliary power supply generation, Parallel operation.

- AC Power Supplies: Linear mode AC power supplies. Switching mode Inverters, Sine wave inverters, Parallel operation, AC voltage regulators, UPS systems.
- Special Power Supplies: Power supplies for pulsed gas discharge tubes, High current power supplies. Power supplies for heating and current drive: Power Supply for Neutral beams, Power Supply for Ion cyclotron & Electron Cyclotron heating.
- Power supplies required for RF amplifiers or Oscillators. HV supplies, their interconnections for RF applications. Specific requirements of power supply protections etc., General topologies with emphasis on conventional and modular topologies, Performance requirements, Critical protections, Remote control and Monitoring requirements.
- Requirement for arc fault protection, Protection by crowbar, Deices used for crowbar applications, Importance of fault energy and techniques to limit the fault energy, wire-burn test.
- Auxiliary supplies: Screen grid, Control Grid, Filament and ion pump power supplies, General topologies for each of the supply. Performance requirements, important performance requirements, Critical protections, monitoring and remote control requirements.
- Safety and System Grounding: Power supplies inter connection at load end. Issues related to system grounding, choices available for system grounding. Safety of system and personnel for RF system.
- Integrated operation, Protection and Monitoring: HV isolation for input power of auxiliary supplies. Monitoring power supplies' status and performance. Remote and local control of power supplies. Fast and slow interlocks.

- **Power Electronics and design through modelling & simulation**

Junction Transistors (BJT, HBT), Field Effect Transistors (JEFT, MESFET, MOSFET, HEMT), Power semiconductor devices, IGBT, GTO and MCT: AC-DC Converters; Forced commutation; synchronous link converters, DC-AC converters, buck, boost, buck-boost, cuk, flyback configuration, resonant converters, PWM inverters; active filters. Machine modelling, DC machines, induction motor and synchronous machines; simulation of transients; Simulation tools: SABER, PSPICE, and MATLAB-SIMULINK; Simulations of converters, inverters and cyclo-converters etc.

EE4 - <u>Analog Signal Conditioning and EMI/EMC Aspects</u> (30 Lectures)

- **Analog Signal Conditioning**

Principles of Analog Signal Conditioning, Signal Conditioning Configuration, Signal Conditioning Functions, Amplification, Transducer Excitation, Filtering, Isolation, Signal Conditioning for Plasma Diagnostics, Operational Amplifiers, Op-amps/ integrated circuits in instrumentation, Phase-sensitive rectifiers, Industrial Electronics.

- **Signal Processing and Applications**

Review of signals and systems: Introduction, advantages and limitations of Analog and Digital Signal Processing, Advantages and Disadvantages of Digital Filters over Analog Filters, Introduction to Infinite Impulse Response Filters and Finite Impulse Response Filters, Applications of digital signal processing in measurement and control systems.

- **EMI/EMC**

Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Fusion Devices, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards, Testing Standards for Emissivity & Susceptance.

- **EMI Modelling**

Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling &Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EE5 - Computer Based System Design (30 Lectures)

- **Computer Fundamentals**

Personal computer architecture, memory organization, industrial PC, Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications, Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL).

- **Communication**

Asynchronous and synchronous communication, Standards like RS232, RS422, RS485, USB, Encoding schemes.

- **Networking**

Local Area Networks, OSI 7 layer model and TCP/IP reference model, Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth, Networking hardware – cables, hub, switch, router etc. Role of fibre optics in communication, Fieldbus standards, Deterministic communication techniques, Case study: various techniques used in Tokamak/Fusion devices for communication and networking.

- **Real-time systems**

Real-time Systems, their characteristics and applications, Real-time Operating Systems, Concepts of Process and threads, Concurrency, Latency, context switching, Scheduling policies, Inter process communication, Semaphores, Priority inversion, Shared memory, Common systems calls, Communication features in RTOS, Comparative study of various RTOS, Integrated software development environment

EE6 - Digital Signal Processing & Image Processing (30 Lectures)

Digital Signal Processing

- **Introduction**
  Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**
  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT

- **Fast Fourier Transform**
  Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- **Digital filters**
  FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- **DSP Applications**
  Applications of digital signal processing in fusion and other fields.

Image Processing

- **Introduction**
  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format.

- **Image Enhancement**
  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing.

- **Image Segmentation and Analysis**
  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation, Boundary extraction and representation.

- **Morphological operations**
  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy based Methods, Image Compression Models, Error free compression, Lossy compression, Standards.

LIFE SCIENCES

Programme Code: LIFE04

Programme Outcome:

- At the end of the course work pursued, the Ph. D. student will be well versed in the recent advances in crucial areas of Life Sciences such as Immunology, Cell Biology, plant Sciences, Microbiology and Cancer biology, in addition to gaining hands on experience in several techniques related to these fields as well as structural Biology and Bioinformatics. This will help the student to have a broader outlook of their research work and be able to judge and use techniques for a superior outcome and higher impact publications.

List of Courses

Course Structure Under BARC:

Sr. No.	Old Course Code	New Course Code	Subject Title	Lectures (Hours)	Credits	Marks
CORE COURSES						
1	B-LS1	01-LIFE04-601-C	Biochemistry, Microbiology and Molecular Biology	44 L	6	
2	B-LS2	01-LIFE04-602-C	Genetics and Plant Sciences	42 L	6	
3	B-LS3	01-LIFE04-603-C	Animal Cell Biology, Immunology and Radiation Biology	42 L	6	
4	B-LS4	01-LIFE04-604-C	Biostatistics, Bioinformatics and Laboratory Techniques	42 L	6	
ELECTIVES						
5	E-LS1	01-LIFE04-601-E	Advanced Course in Genetic Engineering	20 L + 30 P	4	
6	E-LS2	01-LIFE04-602-E	Advanced Course in Plant Breeding	20 L + 30 P	4	
7	E-LS3	01-LIFE04-603-E	Advanced Course in Stem Cell Research and Therapy	20 L + 30 P	4	
8	E-LS4	01-LIFE04-604-E	Use of radioisotopes and molecular methods in diagnosis and therapy of infectious diseases, cancer and metabolic diseases	20 L + 30 P	4	
9	E-LS5	01-LIFE04-605-E	Advanced Course in Instrumentation	20 L + 30 P	4	
10	E-LS6	01-LIFE04-606-E	Structural Biology: Methods and Applications	20 L + 30 P	4	
11	E-LS7	01-LIFE04-607-E	Advances in Genome Biology	20 L + 30 P	4	
MANDATORY COURSE						
12	M-LS1	01-LIFE04-605-C	Research Methodology	15	0	
13	M-LS2	01-LIFE04-606-C	Safety in Life Science Research	10	0	

RESEARCH PROJECTS						
14		01-LIFE04-601-PR	Common projects at different divisions	8 weeks	8	
15		01-LIFE04-602-PR	Projects under thesis supervisor	8 weeks	8	
			TOTAL		**60**	

CORE COURSES

B-LS1: Biochemistry, Microbiology and Molecular Biology (01-LIFE04-601-C) (44 Lectures, 6 Credits)

Course Outcomes:

- The student will get to learn the basics followed by recent advances on biochemical pathways, food biochemistry, different fields of microbiology, DNA repair and both prokaryotic and eukaryotic molecular biology and genetic engineering. This would render them versatile to work in any of the three systems i.e. with microbes, plants or animals.

Course Details:

BIOCHEMISTRY

Basic Biochemistry

Proteins: post-translational modification and protein targeting – types of post translational modification and organelle targeting

Enzymology

Enzymes: Mechanism of action, kinetics (equation and modeling: Michaelis-Menten, Lineweaver-Burk, Eadie-Hofstee)

Inhibitors and types of inhibition and regulation: competitive, non-competitive and uncompetitive

Metabolism

Overview of linking of central metabolic pathways such as glucose, lipid and amino acid metabolism (anabolism and catabolism).

Plant Biochemistry

Overview of energy yielding metabolic pathways in microbes, chloroplast and mitochondria

Oxidative phosphorylation, Photosynthesis and photo phosphorylation

Food Biochemistry

Definition and scope of food chemistry, Major food constituents (carbohydrates, fats and proteins) and their functional properties with respect to food processing, Physical and chemical properties (water activity, pH, thermal conductivity, viscosity, color), Chemical changes in food farm to fork.

Food Processing: Standards and regulations, FSSAI regulations regarding food irradiation, Radiation processing of food products, applications, chemical changes and wholesomeness, Basic process of food irradiation, Isotopes and technologies used for food irradiation, Low medium and high dose applications of food irradiation, Effect of radiation on macro and micro nutrients in food products, Newer methods of food processing (high pressure processing, pulsed white light, ohmic heating, ultrasonic treatment, pulsed electric field) and their applications

MICROBIOLOGY

Basic Microbiology

Introduction to microbiology, classification of micro-organisms, microbial growth. Classical and molecular identification of prokaryotic and eukaryotic micro-organisms.

Mechanism of genetic exchange in microbes (vertical and horizontal gene transfer), Industrially important microbes

Microbial Survival in Natural Environments

Biofilms: structure and detection of biofilm, quorum sensing; persister cells; viable but non-culturable cells (VBNC)

Molecular Pathogenesis

Pathogenicity islands, virulence factors (cellular structures, degradative enzymes, toxins, secretion systems)

Microbiome and antimicrobial resistance

Overview of microbiome and its importance, plant and animal microbiome, human intestinal viriome

Antimicrobial resistance (definition, mechanism and current scenario), Antibiosis, Chromosome and plasmid coded resistance

Food Microbiology

Overview of food-borne pathogens, spoilage and fermentative organisms. Industrially relevant spoilage and fermentation process, Microbial death kinetics during processing, Concept of D10 value (during thermal and irradiation processing), Calculation of D_{10} value and its application during food processing.

MOLECULAR BIOLOGY

Genome organization

Organization of prokaryotic and eukaryotic genome: Comparative overview on genome architecture in prokaryotes and eukaryotes

Gene Expression and Genetic Engineering

Gene expression, epigenetics and regulation: An overview. Plasmids, different types of vectors, cloning, Genetic manipulation techniques: Mutagenesis, Overexpression, genomic integration, Experimental approaches to understanding DNA-protein and protein-protein interactions

DNA Repair Mechanisms

Different DNA repair pathways (Homologous, NHEJ, UV repair), Regulation, A comparative study in prokaryotes and eukaryotes

RNA Biology

Different types of RNA, role of RNAs. Structure-function aspects of tRNA. Regulatory roles of siRNA, snRNA, interference RNA

References:

1. Principles of Biochemistry Global Edition -- by Donald Voet, Judith G. Voet, Charlotte W. Pratt
2. Principles of Biochemistry: International Edition -- by David L. Nelson, Michael Cox
3. Enzymology (HB 2016) by Krintel C.
4. Basic Concepts in Enzymology by Dr. P. Palanivelu.
5. Posttranslational Modification of Proteins: Tools for Functional Proteomics edited by Christoph Kannicht
6. Prescott's Microbiology – 10th Edition
7. By Joanne Willey, Linda Sherwood and Christopher J. Woolverton, McGraw-Hill Education
8. Microbiology by Tortora, Funke and Case, Pearson Education India, 11th edition
9. The Biofilm Mode of Life – Mechanisms and Adaptations, by Staffan Kjelleberg and Micahel Givskov
10. Horizon Bioscience, 2007

11. Quorum Sensing and its Biotechnological Applications, Edited by: Vipin Chandra Kalia, Springer Nature
12. Molecular Biology of the Cell (6th edition),2014, Bruce Alberts, Alexander Johnson, Julian Lewis, David Morgan, Martin Raff, Keith Robertsand Peter Walter, Garland Science:New York;
13. Molecular Biology of the Gene (7th edition),2017, James Watson., Pearsons Education, India.
14. Molecular Cell Biology (4th edition), 2000, Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. W. H. Freeman: New York;

B-LS2: Genetics and Plant Sciences (01-LIFE04-602-C) (44 Lectures, 6 Credits)

Course Outcomes:

- This course is oriented towards introducing the concept of plant genetics, understanding linkages which is crucial in the development of plant varieties through different breeding forms. It also touches upon the plant infections and how to overcome them, which is crucial for having low wastages during the harvest season. For full understanding of plant science, recent advances in plant development are also dealt with.

Course Details:

GENETICS

Basic and quantitative genetics

Mendelian genetics, deviation from Mendel's findings: allelic variation and gene function, gene interactions and epistasis [multiple alleles, allelic series, testing gene mutations for allelism, incomplete dominance and co-dominance, pleiotrophy, Quantitative genetics [Theory of allele frequencies, the Hardy-Weinberg (H-W) principle, application of H-W principle, natural selection, random genetic drift, factors affecting H-W equilibrium]

Linkage and mapping

Concepts of linkage and crossing over, chromosomal mapping in eukaryotes [linkage, genetic test for linkage, chiasmata and crossing over, two point test cross, three point test cross, mapping functions, genetic mapping in plants], complementation test

Molecular markers

Concept of markers, development of genome-based markers, application of markers in plant breeding. Map position-based cloning of genes, marker assisted selection (MAS) in plant breeding, examples in specific crops, outcome of MAS breeding

GENETIC IMPROVEMENT OF PLANTS

Basic concepts in plant breeding

Plant introduction: procedure, types and important achievements. Cytoplasmic inheritance, male sterility and apomixis. Genetic nature of self- and cross-pollinated crops, pollination behaviour of different crops, self-incompatibility, homozygous and heterozygous balance, methods for improvement of self- and cross-pollinated crops: mass selection, pureline Selection, pedigree method, back-cross breeding, bulk method, recurrent selection

Plant host-pathogen interactions

Gene for gene concept, molecular basis of pathogenesis, mechanisms of host defence, approaches to developing disease resistant plants and gene pyramiding

Mutagenesis in plants

Molecular basis of mutagenesis [tautomerism, mode of action of different mutagen (physical and chemical mutagen), mutation induced by transposable elements, phenotypic effects of mutations], induced mutation breeding in crop plants: principles and methods, outcome: examples and impact of plant mutant varieties

PLANT DEVELOPMENTAL BIOLOGY

Plant developmental biology

Floral induction and development, photoperiodism and its significance, vernalization and hormonal control, inflorescence and floral determination

Plant tissue culture – fundamentals and applications

Plant tissue culture and differentiation: totipotency, micropropagation, direct and indirect regeneration pathways, zygotic & somatic embryogenesis, organogenesis, embryo and anther culture, somaclonal and gametoclonal variation, industrial application of plant tissue culture, hairy root cultures, large scale propagation of plants, bioreactors, secondary metabolite production

References:

1. Principles of Genetics. EJ Gardners, MJ Simmons and DP Snustad. John Wiley & Sons
2. Genetics. MW Strickberger. Pearson, IN
3. Fundamentals of Genetics. PJ Russell. Benjamin Cummings
4. Plant Breeding principle and methods. B.D. Singh, Kalyani Publishers.
5. Plant Physiology. L Taiz and E Zeiger. Sunderland: Sinauer Associates.
6. Plant Tissue culture: Theory and practice, a revised edition. SS Bhojwani and MK Rajdan. Elsevier, Netherland.
7. Plant Propagation by Tissue Culture-Handbook and Directory of Commercial Laboratories. EF George and PD Sherrington, Exegetics limited, Eversley, Basingstoke, Hants, England.

B-LS3: Animal Cell Biology, Immunology and Radiation Biology (01-LIFE04-603-C) (44 Lectures, 6 Credits)

Course Outcomes:

- The course deals with animal cell biology and cancer biology including recent advances, therapeutics and genetic manipulation of animal cells. Basic and advanced immunology with advances in applied and clinical immunology is included as part of this course work. Radiation biology is a new concept which is introduced to the students and they get insights in to the effect of different radiation doses on cellular matter and how the cells deal with it, with inputs from information available from regions which have high background radiation.

Course Details:

ANIMAL CELL BIOLOGY

Basic Animal Cell Biology

Fundamentals of cell structure and organization in plants and animals, Origin of cell, Cell Structure, Cell Membrane/Cell Wall, Cellular Components and their function, ECM

Cell communication, cell cycle and differentiation

Cell to cell communication, Types of signaling - Surface and intracellular receptors, Amplification of signal etc; Cell cycle, Cell cycle regulation, Phases, Check points, Latest techniques to detect cell cycle phases; Cell death – Apoptosis, Necrosis, Autophagy.

Differentiation and Development - Basic processes of development, Signals guiding development, Differentiation, Determination and Stem cells, Experimental approaches.

Cancer Biology

Cancer cell biology, causes (genetic and environmental), Tumor suppressors, Oncogenes, Hallmarks and enabling characteristics of a tumor, Metastasis, Targets for therapeutic interventions, Tumor microenvironment, Latest developments in diagnosis and treatment

Genetic manipulation techniques for animal cells and animals

Methods for genetic manipulation of mammalian cells and animals, Recent advances in transgenic, congenic and conditional knockout mice, Ethical issues related to genetic manipulation and research in experimental rodents and stem cells.

IMMUNOLOGY

Immune System

Introduction to immune system: Cells and Organs of the Immune system and systemic functions of immune system, Innate immunity, Non-specific host immunity, Cells of the innate immune system, Complement system, Pattern recognition by innate immune system, Antigen presentation, Major Histocompatibility complex, Antigen presenting cells, Endogenous and Exogenous antigen presenting pathways, Humoral immunity, Antibody structure and diversity, Antibody mediated effector functions, Antibody classes and biological activity.

Cell Mediated immunity

T-cell receptor, alloreactivity, T-cell maturation, and Thymic selection, T-cell activation and differentiation, dynamics of adaptive immunity, Properties of effector T-cells and T-cell mediated cytotoxicity

Advances in applied and clinical immunology

Immunotherapy for treatment of cancer- using inhibitors or antibodies; Vaccines and personalized therapy for immune disorders, Chimeric antigen receptor T cells for treatment of lymphoma

RADIATION BIOLOGY

Basics in radiation biology

Physics and Chemistry of radiation absorption, Radiation types, units, doses and measurements, Interaction of radiation with matter, Free radical biology, Radiation biology – Cell survival curves, Radiosensitivity and its factors, Oxygen effect, Radiomodulation, Linear Energy transfer and Radiobiological Effectiveness (LET and RBE)

Genetic effects of radiation

Genetic effects of radiation, Biological and clinical dosimetry, Cytogenetics and molecular biomarkers

Biological effects of radiation

Biological effects of radiation (Deterministic, stochastic), Radiation safety and protection: Personal Protective Equipment, regulatory guidelines and exposure limits, Adaptive response, Radiation hormesis, Application of different types of radiation in diagnosis and therapy, Fractionation in radiotherapy

International bodies related to radiation safety, High natural radiation areas and their significance.

References:

1. Molecular Biology of the Cell by Bruce Alberts, Dennis Bray, James Watson, Julian Lewis, Keith Roberts, and Martin Raff
2. Gerald Karp Cell and Molecular Biology
3. Developmental Biology by Gilbert Hallmarks of Cancer: The Next Generation- Cell Review| Volume 144, ISSUE 5, P646-674, March 04, 2011
4. Programmed cell death pathways in cancer: a review of apoptosis, autophagy and programmed necrosis. Cell Proliferation. 2012 Dec;45(6):487-98.
5. Basic Clinical Radiobiology; Michael Joiner and Albert van der Kogel -Fourth Edition

B-LS4: Biostatistics, Bioinformatics and Laboratory Techniques (01-LIFE04-604-C) (44 Lectures, 6 Credits)

Course Outcomes:

- Biostatistics and bioinformatics are the backbone of most biology work. In this course the students are taught the different aspects and methods involved in biostatistics and bioinformatics along with a few insights into research tools and techniques.

Course Details:

Biostatistics

Standard statistical distribution (e.g., normal, binomial and Poisson) and their application in biology, Measure of central tendency; mean, median and mode, Measure of dispersion: range, variance, standard deviation, standard error,

Correlation and regression,

Graphical representation of data

Statistical test of significance: Design of experiments

t-test, ANOVA, chi-square test

Software program for statistical analysis

Tutorials

Bioinformatics

Sequence Analysis/Alignment techniques: Pair wise sequence alignment: local and global alignment, consensus sequence (sequence logo), frequency matrices (PAM, BLOSUM), log odds score, penalty.

Introduction to graphical, dynamic programming and heuristic methods, database similarity, searches-BLAST/FASTA algorithms.

Multiple sequence alignment: Clustering, Dendrogram/tree construction, Molecular phylogeny.

Introduction to the protein structural databases (PDB, CATH, SCOP etc.), structure prediction methods with particular focus on homology/comparative modeling

Structural validation approaches, protein structures in biotechnology (drug design/protein engineering etc.)

Big data, data analytics, machine learning, deep learning

Research Tools and Techniques

Microscopic techniques: Light, compound, phase-contrast

and Animal Tissue Culture

Image analysis

Chromatography, Electrophoresis

Spectroscopy: Fluorescence, FTIR, NMR, ESR,

Flow cytometry and high throughput screening

Proteomics

High throughput sequencing

Confocal laser scanning microscopy (CLSM)

References:

1. Introduction to Bio-Statistics, Banerjee Pranab Kumar, S. Chand
2. Biostatistics: Basic Concepts and Methodology for the Health Sciences, Wayne. Daniel, Wiley

3. Bioinformatics: A Practical Handbook of Next Generation Sequencing and Its Applications
4. Low and Tammi, World Scientific Publishing Co
5. Understanding Bioinformatics, Zvelebi and Baum, Garland Science
6. Principles and Techniques of Biochemistry and Molecular Biology 8th Edition, Wilson & Walker, Cambridge University Press
7. Introducing Proteomics: From Concepts to Sample Separation, Mass Spectrometry and Data Analysis, Lovric Josip, Wiley
8. Principles and Practice of Animal Tissue Culture, Sudha Gangal, Sudha Gangal

ELECTIVE COURSES

E-LS1: Advanced Course in Genetic Engineering (01-LIFE04-601-E) (20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- Recent methodologies in genetic manipulation of microbes, plants and animal cells along with hands on experience. While imparting knowledge on these aspects the students are also given a brief on the ethics to be followed for genetic manipulation, which is an important aspect.

Course Details:

Plant Genetic Engineering

Ethics of Genetic Engineering: What is right and what is wrong? What is GMO and what is not? Approvals required for their release

Selectable marker and reporter genes: Antibiotic resistant marker genes, Herbicide marker genes, Reporter genes, removal of marker genes, alternate selectable marker systems

Methods of plant genetic transformation: Direct gene transfer methods, particle bombardment, electroporation, sonication, electrophoresis, liposome delivery, microinjection, whisker mediated transfer; Agrobacterium-mediated, strains, virulence genes, mechanism of T -DNA transfer and integration, different methods of Agro- transformation, vectors used in Agro transformation; Genome editing in plants

Enhancing and stabilizing transgene expression: Transgene silencing and activation – mechanism and results

Metabolic engineering of plants

Practical aspects of animal cell manipulation

Types of vectors for mammalian transfection

Methods of transfection / transduction

Generation of antibiotic kill curve in mammalian cells

Practical demonstration of transfection in mammalian cells

Visualization, identification and selection of transfected cells

Microbial genetic engineering

Essence of plasmid incompatibility, copy numbers, selectable markers, origin of replication: Its influence on designing of cloning strategies.

A practical guide for cloning: Choice of vectors, different ligation strategies and bacterial strains used for cloning and expression

Ways to get DNA inside cells - choosing the right method.

The CRISPR toolkit and how it can advances your research.

Lambda Red Recombineering system – what it can and cannot do.

Protein expression and purification – getting the fold right

Notable genetically engineered microbial strains: Applications for biotechnology

E-LS2: Advanced Course in Plant Breeding (01-LIFE04-602-E) (20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- Hands on experience with theoretical knowledge on the different plant breeding methods practiced and statistical evaluation of the results. The students gain experience on the importance of evaluation of field trials before release of different varieties.

Course Details:

Principles of Plant Breeding

History of Plant Breeding; Objectives of plant breeding, characteristics improved by plant breeding; Patterns of Evolution in Crop Plants- Centres of Origin-biodiversity and its significance. Plant introduction and role of plant genetic resources in plant breeding. germplasm collection, exchange and quarantine

Breeding for self pollinated crops- Pure line theory, pure line selection and mass selection methods; line breeding, pedigree, bulk, backcross, single seed descent method.

Breeding methods in cross pollinated crops- Population breeding-mass selection, progeny testing, progeny selection schemes, recurrent selection and development of synthetics and composites; Hybrid breeding - genetical and physiological basis of heterosis and inbreeding, production of inbreds, breeding approaches for improvement of inbreds.

Breeding methods in asexually/clonally propagated crops.

Malesterility in crop plants and their commercial exploitation; Concept of designer crop - plant ideotype and its role in crop improvement; Transgressive breeding.

Mutation breeding: Mutation and its history - Nature and classification of mutations: spontaneous and induced mutations, micro and macro mutations, pre and post adaptive mutations, mutagenic agents, Molecular basis of mutagenesis [automerism, mode of action of different mutagen (physical and chemical mutagen), mutation induced by transposable elements, phenotypic effects of mutations], Observing mutagen effects in M1 generation: plant injury, lethality, sterility, chimeras etc., - Observing mutagen effects in M2 generation - Estimation of mutagenic efficiency and effectiveness – spectrum of chlorophyll and viable mutations -– Mutations in traits with continuous variation. Mutation breeding in cereals, pulses and oilseeds – Achievements made

Principles of quantitative genetics: Genetic basis of breeding self- and cross - pollinated crops including mating systems and response to selection - nature of variability, components of variation; Heritability and genetic advance, genotype-environment interaction; General and specific combining ability; Types of gene actions and implications in plant breeding; Principles of Analysis of Variance (ANOVA) - Expected variance components, Comparison of means and variances for significance, Designs for plant breeding experiments – principles and applications; Genetic diversity analysis – metroglyph, cluster and D2 analyses - Association analysis - phenotypic and genotypic correlations; Path analysis and Parent - progeny regression analysis; Discriminant function and principal component analyses; Selection indices - selection of parents; Simultaneous selection models- concepts of selection - heritability and genetic advance.

Breeding for abiotic and biotic stresses.

Importance of plant breeding with special reference to biotic and abiotic stress resistance; **Classification of biotic stresses** – major pests and diseases of economically important crops - Concepts in insect and pathogen resistance; Analysis and inheritance of resistance variation; Host defence responses to pathogen invasions- Biochemical and molecular mechanisms; Acquired and induced immunity and systemic acquired resistance (SAR); Host-pathogen interaction, gene-for-gene hypothesis. Types and genetic mechanisms of resistance to biotic stresses –Horizontal and vertical resistance in crop plants. **Classification of abiotic stresses -** Stress inducing factors –moisture stress/drought and water logging & submergence; Acidity, salinity/alkalinity/sodicity; High/low temperature, wind, etc. Stress due to soil factors and mineral toxicity; Physiological and Phenological responses; Emphasis of abiotic stresses in developing breeding methodologies. Genetics of abiotic stress resistance

Breeding for quality trait

Developmental biochemistry and genetics of carbohydrates, proteins, fats, vitamins, aminoacids and anti-nutritional factors - Nutritional improvement. Molecular basis of quality traits and their manipulation. Breeding for quality improvement in cereals, pulses and oilseeds.

Biotechnology for crop improvement

Biotechnology and its relevance in agriculture; Definitions, terminologies and scope in plant breeding.

Tissue culture- History, callus, suspension cultures, cloning; Regeneration; Somatic embryogenesis; Anther culture; somatic hybridization techniques; Meristem, ovary and embryo culture; cryopreservation.

QTL mapping; Strategies for QTL mapping - desired populations for QTL mapping - statistical methods in QTL mapping - QTL mapping in Genetic analysis; Marker assisted selection (MAS) - Approaches to apply MAS in Plant breeding - selection based on marker - simultaneous selection based on marker and phenotype - factors influencing MAS. Use of mutagens in genomics, allele mining, TILLING

Maintenance breeding and concepts of variety release and seed production Cultivar development-testing, release and notification, maintenance breeding, Classes of seed, Participatory Plant Breeding, Plant breeders' rights and regulations for plant variety protection and farmers rights.

E-LS3: Advanced Course in Stem Cell Research and Therapy (01-LIFE04-603-E) (20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- The students are introduced into a new and upcoming area of research of stem cells with insight into its generation and uses in animals, plants and bacteria

Course Details:

Stem Cells: Introduction and estimation

General concepts in stem cell biology and their role in research and therapy

Surface marker analysis

Dye efflux and aldehyde dehydrogenase-based assays

In vitro differentiation and culture-based characterization

Embryonic, umbilical cord and adult stem cells

Embryonic stem cells

Umbilical cord blood stem cells

Wharton's Jelly Mesenchymal stem cells Adult tissue stem cells: intestinal stem cells, hematopoietic stem cells, neural stem cells, skeletal muscle stem cells, skin epithelial and hair follicle stem cells and heart stem cells

Isolation, identification and enumeration of hematopoietic stem cells

Isolation, identification and enumeration of skin epithelial and hair follicle stem cells

Enumeration of stem cells in human blood

Stem cells for tissue regeneration and therapy

In vitro expansion of stem cells Human induced pluripotent stem cell derivation, mouse and human embryonic stem cell derivation, and the mechanisms underlying ICM cells differentiation

Adoptive transfer and in vivo manipulation of stem cell differentiation

Mammalian gene transfer and genome engineering

In vivo manipulation of hematopoietic stem cells in mice

Gene expression pattern and genetic manipulation of stem cells

Stemness associated genes

Dedifferentiation and re-differentiation of stem cells

Genetic manipulation of stem cells for therapy

Use of stem cells for mitigation of radiation injury

Isolation, identification, enumeration and cryopreservation of Human Wharton's Jelly Mesenchymal Stem cells

In vitro culture, real time monitoring of cell growth, induced differentiation and genetic manipulation of stem cells

Organoids

Stem cell characteristics in T lymphocytes

Cancer stem cells

Enumeration of breast cancer stem cells by surface phenotyping and side population based high content screening

Stem cell applications

Ethics in stem cell research

Biofilm formation in bacteria, Similarities with malignant tumours

Plant stem cells, vitality and bioprocess engineering

Identification and characterization of plant stem cell

E-LS4: Use of radioisotopes and molecular methods in diagnosis and therapy of infectious diseases, cancer and metabolic diseases (01-LIFE04-604-E) (20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- In this course students are exposed to techniques used for detection of several important and highly prevalent disease such as tuberculosis and thyroid cancer with emphasis on easier, sensitive and reliable immunological techniques.

Course Details:

Molecular Biology methods in tuberculosis diagnosis and prevention

Introduction to TB, its evolution and comparison with other infectious diseases

Molecular biology techniques in diagnosis of tuberculosis

Understanding of molecular epidemiology in tuberculosis

Drug used in tuberculosis and molecular mechanisms of drug resistance in TB

Use of immune-modulators in TB treatment

Prevention of TB: new vaccines

Molecular Biology methods in thyroid cancer diagnosis and prevention

Introduction to thyroid cancer (TC)

Molecular Pathways in TC & their diagnostic importance, molecular mechanisms of resistance to treatment in thyroid cancers

Genetics & Transcriptomics & their relevance in TC

Post translational modifications & their role in TC prognosis

Metabolomics in cancer diagnosis

Molecular Mechanisms of Resistance to treatment &newer treatment options

Use of RIA and other immunological methods in detection of analytes in biological fluids

Introduction of Immunological methods: Ag-Ab interactions (RIA, IRMA, ELISA)

Production of polyclonal and monoclonal antibodies

Affinity calculation, titre estimation of antibodies

Immobilization of antibodies and their uses

SCFV antibodies, Abzymes and phage display libraries

Nanobody production

Radiopharmaceuticals in diagnosis and therapy of cancer and other metabolic diseases

Introduction to radiopharmaceuticals (sourcing of radioisotopes, types of radioisotopes, methods of radiolabelling, BFCA concept)

Quality control of radiopharmaceuticals, targeted use of radiopharmaceuticals.

BIO QC of Radiopharmaceuticals.

Diagnostic applications of radiopharmaceuticals (SPECT, PET)

Therapeutic applications of radiopharmaceuticals (use of β- emitting radioisotope-based therapy, α radionuclide therapy)

Types of therapy (Radio-immunotherapy, Receptor-based therapy, etc.) in various cancers

Radiological Safety regulations related to preparation, transport, storage, use and disposal of Radiopharmaceuticals and Radioisotopes used in Radionuclide therapy.

E-LS5: Advanced Course in Instrumentation (01-LIFE04-605-E)
(20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- In this course the students are exposed to several modern-day instruments used for studying cell surfaces, DNA-protein interactions and protein-protein interactions. The students are also exposed to several analytical instruments.

Course Details:

Overview of advanced Instrumentation in biological research

Principle, instrumentation and application of:

Inductively Coupled Plasma Spectrophotometer (ICP),

Fluorescence Microscopy

Gas Chromatography Mass Spectrometry (GCMS)

Biosensors

Scanning Electron Microscopy (SEM)-EDS

X-ray Diffraction (Powder)

Rheometer

Atomic Force Microscopy (AFM)

Transmission Electron Microscopy (TEM)

Surface Plasmon Resonance (SPR)

E-LS6: Structural Biology: Methods and Applications (01-LIFE04-606-E) (20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- In this course the students learn more about protein structure and different software available for predicting structures and protein-ligand interactions, which is very important in the field of drug discovery.

Course Details:

Overview of structural biology—structural features of biomolecules in three-dimensional space, structure determination methods and recent developments

Troubleshooting the recombinant protein expression and purification

Principles and methods of protein crystallization, Crystal symmetry

Theory of diffraction and Fourier synthesis, X-ray sources

Diffraction data collection and processing

Diffraction data to structure: Solving the crystallographic phase problem

Diffraction data to structure: Electron density map and model building

Diffraction data to structure: Refinement and validation

Structure-based drug design - a rational approach

Principles of CD and fluorescence spectroscopy in protein structure analysis

E-LS7: Advances in Genome Biology (01-LIFE04-607-E) (20 Lecture + 30 Practical, 4 Credits)

Course Outcomes:

- The take home message of this course is deeper understanding about genome organization, integrity, maintenance, segregation and sorting in microbial, plant and animal cells.

Course Details:

Genome structure with certain examples

Genome packaging in bacteria, plants and animals

Genome maintenance and integrity

Mechanisms of genome segregation

Factors affecting genome dynamics

Various approaches for creating genomic alteration in plant and bacterial systems, particularly ploidy

Usefulness of genomic perturbation in quality and strain improvements and harmful implication in mammalian cells

Pulsed field gel electrophoresis to analyse genome from plants, animals and multipartite genome harboring bacteria.

Visualisation of real time dynamics of genome segregation in bacterial and mammalian cells during stressed growth by fluorescence microscopy (Time lapse).

Isolation of protoplast of plants with different levels of ploidy and visualization of DNA organization in these crop plants by DNA staining and fluorescence microscopy.

MANDATORY COURSES

M-LS1: Research Methodology (01-LIFE04-605-C) (15 Lectures)

Course Outcomes:

- This deals with formulation and presentation of research projects, selection of appropriate research ideas, experimental design and statistical analysis for the same.

Course Details:

Objectives and types of research: Motivation and objectives - Research methods vs. Methodology. Types of research – Descriptive vs. Analytical; Applied vs. Fundamental; Quantitative vs. Qualitative; Conceptual vs. Empirical.

Research Formulation – Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem - Literature review – Primary and secondary sources - reviews, treatise, monographs-patents - web as a source - searching the web - Critical literature review - Identifying gap areas from literature review - Development of working hypothesis.

Research design and methods - Research design – Basic Principles - Need of research design - Features of good design – Important concepts relating to research design - Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

Value of Statistics; Errors and Statistics - Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimisation of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results - students' t test; F-test; Chi Square test; propagation of errors.

Reporting and thesis writing – Structure and components of scientific reports - Types of report - Technical reports and thesis - Significance - Different steps in the preparation – Layout, structure and Language of typical reports - Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation - Planning - Preparation - Practice - Making presentation - Use of visual aids - Importance of effective communication, Usage of packages such as, Excel, AIM2000, etc. Manuscript drafting based on 'Experimental data and Literature Survey'.

Application of results and ethics - Environmental impacts - Ethical issues - ethical committees - Commercialization - Copy right - Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights - Reproduction of published material - Plagiarism - Citation and acknowledgement - Reproducibility and accountability.

References

1. Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction to Research Methodology, RBSA Publishers.
2. Kothari, C.R., 2000, Research Methodology: Methods and Techniques. New Age International.
3. Sinha, S.C. and Dhiman, A.K., 2002. Research Methodology, Ess Publications (2 volumes)
4. R. Paneer Selvam - Research Methodology Prentice Hall India Learning Private Limited; Second edition (2013)
5. Anthony, M., Graziano, A.M. and Raulin, M.L., 2009. Research Methods: A Process of Inquiry, Allyn and Bacon.
6. Day, R.A., 1992.How to Write and Publish a Scientific Paper, Cambridge University Press.
7. Vogel's Text Book of Quantitative Inorganic Analysis, ELBS.

M-LS2: Safety in Life Science Research (01-LIFE04-606-C) (10 Lectures)

Course Outcomes:

- To familiarize with various safety aspects while conducting life science related research.

Course Details:

1. Cyber Safety and Security (2 lectures)

<u>Cyber safety and security:</u>

Introduction to cyber safety, sources of threat and ways to prevent them: Web browsing, Email, Malware, Identity theft, Social networking, mobile phones, Passwords, online transaction frauds, cyber hacking, phishing attacks, bots, mobile hacking, cyber frauds, cyber terrorism, digital foot prints, National Cyber Safety & Security Standards (NCSSS)

2. Fire Safety (2 lectures)

Introduction, the fire triangle, major causes of fire, classification, prevention, protection and control of fire, types and use of fire extinguishers, fire hazards, fire emergency and preparedness

3. Radiation Safety (2 lectures)

<u>Radiation hazards:</u>

Introduction, types of radiation and its effect, general principles and techniques of monitoring, types of radiation dosimeters, assessment and control of radiation hazards

Environmental release, management of solid, liquid and gaseous wastes

<u>Radiation Emergency Preparedness:</u>

Discussion of type of incidents/accidents likely to be encountered, procedures for handling such events

4. Chemical Safety (2 Lecturers)

Introduction, routes of entry and its effect, types of hazardous chemicals, Material Data Sheets, labelling and storage, incompatible chemicals, hazard control-fume hood, local exhaust, personal equipment, chemical spill, emergency measures, precaution in handling hazardous chemicals

5. Biosafety and Animal Ethics (2 Lectures)

Introduction to biosafety, Institutional Bio-Safety Committee (IBSC)-scope and objectives, pathogenic organism, Genetically Modified Organisms (GMOs) - recombinant DNA technology, microorganisms, plants and animals, release to the environments, role of Genetic Engineering Approval Committee (GEAC)

Indian act for animal welfare and Prevention of Cruelty to Animal act (PCA, 1960), use of animals in research and animal care, Animal Ethics Committee (AEC), Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA)

References

1. National Cyber Crime Reference Hand Book published by National Cyber Crime Reference Hand Book (third edition)
2. https://www.udemy.com/course/cyber-security-and-internet-safety/
3. https://ncdrc.res.in/organization-profile.php
4. https://rcsindia.co.in/KVFILES/CyberSafety.pdf
5. Indian Standard (IS) 4209-1987 Code of Safety in Chemical Laboratories.
6. Manufacture, Storage and Import of Hazardous Chemicals Rules -1989.
7. Chemical Risk Analysis- Bernard Martel
8. Hazards in Chemical Laboratory- G. D. Muir
9. http://www.iitb.ac.in/safety/sites/default/files/Chemical%20Safety_0.pdf
10. Bioethics and Biosafety, by M. K. Sateesh Published by IK International, ISBN: 337-3-69266-815-1

BACK TO MAIN

SINP

SYLLABUS FOR
Ph.D. in LIFE SCIENCES
(PROGRAM CODE: LIFE04)

SemesterI

17 weeks during August–December, out of which 16 weeks are classes and 1 week for exams.

2weeks festival holidays

Sl No	Course code	Name of the courses	Credit
1	PBC	Principles of Biochemistry	6
2	PPC	Principles of Physical Chemistry	6
3	SCB	Structural and Computational Biology	6
4	ALP	Advanced Laboratory Practices	6

Calculation of credit

Each class credit (PBC/PPC/SCB/ALP): 1.5 hr x 2 classes + 2 hr tutorial + 7 hr assignment and self study = 12 hr. 12 hr x 16 weeks = 192 hr = 6 credit. Lab credit = 12 hr. 12 hr x 16 = 192 hr = 6 credit. Total credit = 6 x 4 = 24.

SemesterII

17 weeks during January–April, out of which 16 weeks are classes and one week for exams.

Sl No	Course code	Name of the courses	Credit
1	RM	Research Methodology	6
2	OPT1	Optional Course1	6
3	OPT1	Optional Course2	6
4	OPT1	Optional Course3	6

Calculation of credit

Each class credit: 1.5 hr x 2 classes + 2 hr tutorial + 7 hr assignment and self-study = 12 hr. 12 hr x 16 weeks = 192 hr = 6 credit. Total credit = 6 x 4 = 24

1st & 2nd weeks of May are Holidays

SummerSemester

11 weeks during mid May–July.

Sl No	Course code	Name of course	Credit
1	PRO	Project	12

Presentation of project thesis in the 3rd week of July.

Calculation of credit

Project work per week = 30 hr, Self-study = 4 hr, Total = 34 hr. In 11 weeks = 11 x 34 = 374 hr = 12 credit.

Syllabus

Semester I

1. Principles of Biochemistry (PBC)

Basic Biochemistry – Biomolecules in water, protein and carbohydrate (complex) solutions, pH, pK, shifts in pK, enzymes, co-enzymes, vitamins, glycolysis, ATP cycle, TCA cycle, oxidative phosphorylation, biosynthesis / degradation of amino acids & proteins, biosynthesis of lipids and carbohydrates, hormone and growth factors.
Cell as unit, identification, characterisation, function of cellular organelles, Golgi, ER, lysozome, mitochondria, cell-membrane, Cell-cell communication, cell-signalling, basics of immune system.
DNA as the Genetic material, Mutations in the genetic material, Mendelian inheritance, Chromosomal inheritance, Eukaryotic genome organization, Gene, Introns, Repetitive DNA seq, Gene duplication and Pseudogenes, Core Histones and Linker histones, Euchromatin vs. Heterochromatin, DNA methylation, Introduction to epigenetics.
Replication, Transcription and Translation.
Chemical Thermodynamics and its application in Biological Processes (biomolecular recognition, protein folding etc), Use of energy in cellular reactions, Chemical equilibrium and kinetics and its application in biological processes (gene regulation, kinetic proof reading, cancer pathways, enzyme kinetics, biological switch, circadian rhythm), Application of chemical tools in biology.
Diffusion, Osmosis, Osmotic pressure, osmoregulation, surface tension, dialysis, adsorption, viscosity, thermal conduction, colloids, sedimentation.

2. Principles of Physical Chemistry (PPC)

Definition of life from chemical and physical perspective, Basic thermodynamics, chemical equilibrium of reactions in gas & solution phase chemical reaction dynamics (Introduction to reaction kinetics, complex reaction, Steady-State, equilibrium, chain reaction, catalysis, etc.), and reaction rate theory (Transition State and Collision theory).
Introduction to quantum mechanics: Historical development of quantum theory, properties of particles and waves, wave mechanics and applications to simple systems—the particle in a box, the harmonic oscillator, the rigid rotor and the hydrogen atom.
Basic Principles of Spectroscopy: Absorption, Emission, and Scattering of light; Excited State Properties; Acidity; Basicity; Polarization; Anisotropy; Solvent Relaxation; Quenching; Energy Transfer, and Electron Transfer.
Nanoscience and Nanotechnology: What is nanoscience and nanomaterials? Historical background of the field nanoscience and nanotechnology; Optical, electrical, and magnetic properties of nanomaterials; different nanomaterials (organic vs. inorganic); common roots of nanomaterials synthesis; Surface modification for specific targeting, Principle of photon therapy, Surface Plasmon Resonance (SPR), Nanomaterials based optics and spectroscopy, applications in sensing, diagnostics, and remediation.
Recapitulation about radioactivity - classification of the nuclides, natural decay chain; Radioactive decay modes - secular and transient equilibrium; Introduction to Nuclear Reactions - Q-values, threshold energy, cross section, excitation functions; Different types of detectors, Nuclear Activation and its applications; Clinical and other applications of radionuclide, radiotracer technique.
Interaction of electromagnetic radiation with matter – Cross-sections –Attenuation and mass energy absorption coefficients
Radiation quantities and units –Particle & Energy flux and fluence–flux and fluence –Interaction of Radiation with Cells, LET – Biological Effects of Radiation, Dosimetry – Energy imparted – Absorbed dose – Kerma-Exposure –Dose equivalent – Charged particle equilibrium (CPE) –Ambient and directional dose equivalents [($H^*(d)$ and $H'(d)$)]

3. Structural and Computational Biology (SCB)

Nucleic acids, Watson-Crick and non-Watson Crick basepair, DNA double helical and multistranded structures, RNA structural features.

External and internal coordinate system, non-covalent interactions stabilizing biomolecules, amino acids, peptide, proteins, secondary, tertiary, quaternary structure of protein.

Structure determination: Basics of Crystallography, NMR, Site-directed spin labelling and EPR (SDSL-EPR)

Brief introduction to Bioinformatics and Biological databases, Sequence Alignment (Pair-wise and Multiple), Scoring matrices (BLOSUM62, PAM etc.), Database similarity searching by available tools like FASTA, BLAST etc., Phylogenetic Tree construction; Next Generation Sequencing. Introduction to biological databases.

Perl Programming Language and its application in Bioinformatics.

Molecular modelling software, basic statistics, regression and curve-fitting, some probability and statistical methods (such as Measures of central tendency, probability, probability distributions, Binomial distribution, Normal distribution, Poisson distribution, calculation of errors etc.). Introduction to Computation with Matlab. Matrix handling, plotting, statistical analysis.

4. Advanced Laboratory Practices (ALP)

i. Biochemical and Molecular Biology Techniques (BMBT)

Separation techniques: Electrokinetics methods: electrophoresis, electrophoretic mobility (EPM), factors affecting EPM, Paper, PAGE, Capillary, Iso-Electric focusing, applications in biology and medicine. HPLC: mobile phase systems, modes of operations, application, Hydrodynamics method: fundamental principles, Centrifugation, Ultracentrifugation and their applications in molecular weight, size determination. Viscosity and its application.

Technique in molecular biology: DNA detection, RNA detection, Protein detection, cloning, PCR, and related methods.

ii. Spectroscopy and Imaging Techniques (SIT)

Circular dichroism, Infrared spectroscopy including basic principles of FTIR, Raman spectroscopy.

Basic principles of imaging techniques: SEM, TEM, wide-field fluorescence microscopy, confocal scanning microscopy and fluorescence correlation spectroscopy.

iii. Radiological safety (Radiation Protection Standards, Principles of Monitoring and Protection).

iv. Biostatistics.

Semester II

1. Research Methodology (Compulosory)

What is a PhD thesis, psychological and social factors during PhD, student's role in thesis work, supervisor's role in thesis work, overview of research planning, time management, fair scientific practices.

Ethics in natural sciences, avoiding research that cause unjustified risk to people, jeopardizing the environment or convert public resources into private profits, striving for objectivity (in the research process and in presentation of results), handling uncertainties.

Literature survey, critical use of existing knowledge, finding out a research problem, scientific publishing, classification of conferences and journals, judging whether a material is publishable, refereeing process, criticizing own and others work.

How to give seminars, how to use various softwares, how to use various instruments, how to interact with people, how to apply for jobs, plagiarism in science – what to do and not to do.

As a concrete example, each student will be asked to produce a “prototype thesis” in a given area under a “prototype supervisor”. The student will apply the knowledge, ethics and best scientific practices to produce the thesis. Students will be evaluated based on the thesis and its defence.

2. Advanced Level Optional Courses (to choose any 2 from each Group - A, B and C)

A. Advanced Biophysical techniques (OPT1)

(i) Macromolecular crystallography
Structure factors, Atomic scattering factor, temperature factor, structure factor calculation, Phase problem and electron density calculation. Advanced phasing techniques (like MAD/SAD). Phasing by MR, Model building and refinement. Fiber Diffraction.
High throughput crystallography; Cryo-crystallography and its application in trapping reaction intermediates; X-ray crystallography to elucidate structure-function relationship for some important biological pathways; crystallography of large macromolecular assembly.
Crystallization techniques, handling protein crystals using cryo techniques, diffraction data collection, electron density map interpretation, crystallographic data analysis.

(ii) Chromatography and Mass Spectrometry
Chromatography: General principles of chromatography, common types of chromatography[1], factors affecting chromatographic separation and considerations for choosing mode of chromatography, applications.
Mass Spectrometry: General principles, ion source[2], types of mass analyzers[3], ion fragmentation and rearrangements, mass spectrometry of protein and peptides, mass spectrometry of small molecules, imaging mass spectrometry, applications.

[1]normal phase, reverse phase, HILIC, ion exchange, size exclusion, affinity, GC and chiral.
[2]ESI, APCI, MALDI, EI, DESI, LAESI, FAB, SIMS, NIIMS.
[3]quadrupole, TOF, ion trap, orbitrap, ICR.

(iii) Spectroscopic techniques
Nanosecond to Femtosecond Laser Spectroscopic Techniques and their application to the various prototype and diverse bio-molecules of different sizes related to Biophysical Sciences. The spectroscopic methods we will cover are the following: (i) Time Resolved Fluorescence and Absorption (ii) Circular Dichroism.

(iv) Imaging techniques
Concepts in Microscopy and imaging: Basic Principle of Optics, Family of Microscope , Optical Microscope Aberrations, Polarized light and its interaction with matter, Detection system image formation and image analysis, Point spread function, Principle of TEM &SEM: development, architecture, vacuum system, power supply, Sample preparation techniques and Application

Single molecule detection (SMD) by fluorescence: Single molecule fluorescence spectroscopy/Microscopy, Technical Challenges, Methods in single molecule detection, Total Internal reflection (TIR) spectroscopy, Types (PTIR, OTIR), Data Processing, analysis and interpretation. Principle of trapping, Design Considerations, Trapping force, Microscope, Objective, Position detection.

B. Topics in Cell Biology (OPT2)

(i) Cell cycle
Regulation of cell cycle by cyclin-Cdk, Regulation of Initiation of eukaryotic DNA replication, Replication Licensing, Cell cycle checkpoints, Protein degradation by ubiquitination during cell cycle progression.

(ii) Mechanobiology
Cytoskeleton and nucleoskeleton, mechanics of cell-cell adhesion and migration, gross cell mechanics, experimental set ups to study biomechanics, disease models.

(iii) Chromatin and epigenetics
Methods to study chromatin structure, Epigenetics and gene regulation, DNA repair mechanisms in chromatin context, Chromatin dynamics in Stem cell differentiation and cancer, Chromatin as drug target.

(iv) Intracellular trafficking
Protein translocation, protein trafficking (endocytosis, exocytosis, transcytosis), de novo organelle biogenesis, protein quality control (role of internal vesicles), lysosomal biogenesis and degradation.

(v) Neuroscience
Paring Back, Critical Periods, SENSATION AND PERCEPTION: Vision, Hearing, Taste and Smell, Touch and Pain, LEARNING AND MEMORY, MOVEMENT, SLEEP: The Stuff of Sleep, Sleep Disorders, How is Sleep Regulated? STRESS: The Immediate Response, Chronic Stress, AGING: Aging Neurons, Intellectual Capacity, CHALLENGES & ADVANCES: Pain, Epilepsy, Major Depression, Manic-Depressive Illness, Addiction, Learning Disorders, Stroke, Neurological Trauma, Anxiety Disorders, Neurological AIDS, Spinal Cord Injury.

C. Topics in Modern Biology (OPT3)

(i) Membrane Biophysics and Structural Dynamics of Membrane Proteins
Models of biomembranes, Hydrophobic effect, Membrane organization and dynamics, Phase transition of membranes, Model membranes: micelles, reverse micelles, liposomes and Nanodiscs, Membrane proteins & cell surface glycoconjugates, Membrane Dynamics: Edidin & Frye experiment, heterocaryons, Diffusion of membrane components, Membrane domains and lipid rafts: membrane biophysics to cell biology, Hydrophobic mismatch, Membrane asymmetry and lipid polymorphism, Membrane cholesterol and its relevance in health and disease
Techniques in membrane biology
Structures of membrane proteins, How membranes shape protein structures? Lipid-protein interactions, Ion channels and Transporters, G-protein coupled receptors (GPCR).
Books:
1. Biomembranes : A Molecular approach by R.B. Gennis, Springer-Verlag.
2. Membrane Structural Biology – with biochemical and biophysical foundations by Mary Luckey, 2^{nd} edition, 2014, Cambridge University Press.

(ii) Introduction to Space Bioengineering and Medicine
Manned and unmanned space missions; space as an extreme environment, microgravity, space radiation; physiological and biological effects of microgravity and space radiation on human, plants and microbes; Effect of microgravity at the level of genes and cells; Ground based facilities to simulate microgravity and cosmic radiation; space bioreactor, simulated microgravity reactor; space medicine: current status and future challenges; Bioengineering solution for long duration space flight

and international space station (ISS), biological hazards in ISS and its remediation; In-situ resource utilization; space agriculture, space as a solution for earth based biomedical and bioengineering challenges; Challenges in human MARS exploration and its bioengineering solutions, concepts of terraforming; concept of space synthetic biology; space medicine and biotechnology on Indian context.

(iii) Drug Discovery: Modern Day Approach

Pre 20th century drug discovery. Drug discovery pipeline, drug targets and target validation. Methods of lead identification and optimization. Early prediction of ADMET (Absorption, Distribution, Metabolism Excretion and Toxicity). QSAR (Quantitative Structure Activity Relationship) predictions. Lipinski rule of 5. Polar surface area. Blood brain barrier crossing model. Predicting toxicity. Introduction to drug docking and pharmacophore modeling.

(iv) Nanobiomaterials :

Principles of bio-inspired nanomaterials, common biologically active molecules as suitable ligand for nanomaterials synthesis, separation procedure of different biological components from organic-mass and bio-mass, principles and function of gel electrophoresis & qPCR, concept of antigen and antibody, antigen specific aptamers, what is cancer? Different pathogens, surface modification of nanomaterials for highly specific targeting, biomarker detection and quantification for early stage detection, different therapeutic methods: photon, photodynamic, micro pH and photothermal therapy and their advantages over chemo and radiation therapy. PET scan, Magnetic separation, complete blood count (CBC), blood protein testing, tumor marker testing along with spectroscopic (UV-vis, Fluorescence and Raman techniques) and imaging techniques (TEM and AFM). Bi-metallic nanomaterials with programmable crystal defects for bacterial cytoskeleton targeting.

Semester III (Summer Semester)

Project (PRO)

Each student chooses one topic from an offered list and carries out an extensive review of literature and experiments with specific scientific aims under the supervision of a faculty. The student submits a dissertation describing the literature survey and reporting the experimental findings which will be evaluated by two faculties. Finally, the student presents and defends the work in an open forum.

TMC

BACK TO MAIN

SYLLABUS FOR
Ph.D. in LIFE SCIENCES
(PROGRAM CODE: LIFE04)

Annexure - I

1. Salient features of core course and electives
Students at ACTREC are required to do a core course and take elective courses, which are determined by them in consultation with their thesis supervisor.

A] The core course is for 1000 marks which are equal to 500 Hrs (30 Credits) to and was re-configured at the beginning of the current academic year in the following manner:
a. There are two courses that cover Basic Cancer Biology and one course covering Tumor Immunology, Structural Biology and Biophysics.
b. The students are evaluated in a written exam for each course and have take-home assignments for each course.
c. The students also have to present two assigned papers over the period of the core course.
d. The courses also include lectures on advanced techniques that introduce the students to new methodology.

B] Eight electives are offered at ACTREC and the students have to pick 4 for a total of 400 marks which are equal to 200 Hrs (12 Credits) Each elective has a course co-ordinator/co-ordinators who designs the course and determines the process by which the students are examined over the course.

C] Core course includes Special lectures on Epidemiology and Bioinformatics (5 lectures), Intellectual Property rights (1 lecture) and Research Methodology (6 lectures). All these lectures have no separate credit points.

D] Research Methodology (6 lectures) is a separate module with no separate credit points. Laboratory Work all through the year carries 200 marks which are equal to 100 Hrs (6 Credit) Scientific writing assessed at the final seminar is for 100 marks which are equal to 50 Hrs (3 Credit)

E] Final Seminar presentation on the topic of Ph.D. dissertation carries 200 marks which are equal to 100 Hrs (6 Credit) and

F] Oral General Comprehensive Examination (OGCE) is for 100 marks which are equal to 50 Hrs (3 Credit)

Total course work is of 2000 marks which are equal to 1000 Hrs (60 Credits).

2. Choice based credit system
ACTREC follows the HBNI guidelines on how many academic hours correspond to how many marks. While the core course is mandatory for all students, the students do have a choice of electives. Similarly, the credits for the Final seminar, lab work and scientific writing are based on the choice of project that will be pursued by the student.

3. Modification in course work if any and when was it modified (after 2013) and modifications done.
The core course was last modified at the beginning of the academic year 2017-18. It was re-organized to divide the course into appropriate subject areas. The elective Angiogenesis and

Metastasis was discontinued in 2014 and a new elective in Biostatistics was added in 2014. As per HBNI guidelines a module on research methodology was added in 2014. Further, lectures on cancer metabolism have been added in 2017 as this is a new and interesting area in the field of cancer biology. A new elective on Metastasis was added in the academic year 2018-19 after approval by the BOS. All faculties keep revising their lectures so as to stay current given the constantly changing nature of the field while ensuring that the basics are taught to the graduate students.

HBNI Orientation Course on Basic and Cancer Biology for Junior Research Fellows, ACTREC

Proposed Lectures / Marks of Coursework: 1st year of the Ph.D. program
[Total: 2000 marks]

Orientation		No. of Lectures	Marks
1	Laboratory Safety Lectures	3	-
2	Visits to Library, Common Instrument Room and Laboratory Animal Facility	3	-
3	Orientation to the Cancer Clinic	4	-

A] Core Course 50 lectures / 200 academic hrs / 1000 marks
50 lectures / 200 academic hrs / 1000 marks

S. No.	Core Course Topics	No. of Lectures	Marks
09LIFE04-001-C	Cell Biology & Cancer Biology	8	Written Test 140 marks Home Assignments: 150 marks
09LIFE04-002-C	Cell Proliferation and Cell death	4	
09LIFE04-003-C	Oncogenes and Tumor Suppressors	5	
09LIFE04-004-C	Metastasis and Angiogenesis	4	Written Test 140 marks Home Assignments: 150 marks
09LIFE04-005-C	Cancer Epigenetics and Genetics	7	
09LIFE04-006-C	Carcinogenesis	5	
09LIFE04-007-C	Tumor Immunology	5	Written Test 120 marks Home Assignments: 100 marks
09LIFE04-008-C	Structural Biology and Biophysics	5	
	Presentations 1 & 2	7	200 marks
		50	**1000 marks = 500 Hrs = 30 credits**

B] Electives (Any 4) 40 lectures / 80 academic hrs / 400 marks
40 lectures /80 academic hrs / 400 marks

S. No.	Elective Topics	No. of Lectures	Marks
09LIFE04-001-E	Biostatistics	11	Exam 100 marks
09LIFE04-002-E	Animal Models in Cancer Research	10	Exam 100 marks
09LIFE04-003-E	Cancer Therapeutics	10	Presentations 100 marks
09LIFE04-004-E	Carcinogenesis, Chemoprevention and DNA Repair	10	Presentations 100 marks
09LIFE04-005-E	Deregulation of Cell Growth in Cancer	10	Presentations 50 marks Assignment 50 marks
09LIFE04-006-E	Structural Bioinformatics, Biophysics & Structural Biology	10	Exam 100 marks
09LIFE04-007-E	Tumor Immunology	10	Presentations 100 marks
09LIFE04-008-E	Metastasis	10	Presentations 100 marks
		40	**400 marks = 200 Hrs = 12 credits**

C] Special Lectures: a) Epidemiology & Bioinformatics — 5 lectures — No marks
b) Intellectual Property Rights (IPR) — 1 lecture — No marks

D] Research Methodology

	a) Lectures	6 lectures	No marks
	b) Laboratory work	All through the year	200 marks=100 hrs=6 Credits
	c) Scientific Writing	Assessed at final seminar	100 marks=50 hrs=3 Credits
E]	**Seminar Presentation on the topic of their Ph.D. dissertatic**	10	200 marks=100 hrs=6 Credits
F]	**First Thesis Committee Meeting / Comprehensive Examination**		100 marks=50 hrs=3 Credits
		Grand Total:	**2000 marks = 1000 Hrs = 60 credits**

Core Course

Research Methodology	
RM1	The flow and structure of a paragraph - case study. Grammar, common unscientific terms used in writing, the common pitfalls seen - direct translation of words from mother tongue to English
RM2	Literature review - where to get material, the quality and quantity of content. Establishing a background for a research project
RM3	Laboratory notebook maintenance - Do's and don'ts, Good research practice, ethics, plagiarism
RM4	The art and science behind manuscript writing and successful research proposal Ideas, their formulations, what are aims and objectives, What constitutes results and discussions
RM5	The fine art of power point presentation
RM6	Preparing figures for manuscripts and grants

Core Course	**09LIFE04-001-C: BASIC CANCER BIOLOGY – I**	**[Modules 1 – 3]**
	Module 1: Cell Biology and Cancer Cell Biology	
	Module 2: Cell Proliferation and Cell Death	
	Module 3: Oncogenes and Tumor Suppressors	
Core Course	**09LIFE04-002-C: BASIC CANCER BIOLOGY – II**	**[Modules 4 – 6]**
	Module 4: Metastasis and Angiogenesis	
	Module 5: Cancer Epigenetics and Genetics	
	Module 6: Carcinogenesis	
Core Course	**09LIFE04-003-C: TUMOUR IMMUNOLOGY, STRUCTURAL BIOLOGY & BIOPHYSICS**	**[Modules 7-8]**
	Module 7: Tumour Immunology	
	Module 8: Structural Biology and Biophysics	

Annexure - III

ELECTIVES OFFERED AT ACTREC: 2019

CODE	Elective Topics
09LIFE04-001-E	**Biostatistics** (*Compulsory)*
09LIFE04-002-E	**Animal Models in Cancer Research**
09LIFE04-003-E	**Cancer Therapeutics**
09LIFE04-004-E	**Carcinogenesis, Chemoprevention and DNA Repair**
09LIFE04-005-E	**Deregulation of Cell Growth in Cancer**
	Structural Bioinformatics, Biophysics & Structural Biology
	Tumor Immunology
09LIFE04-008-E	**Metastasis**

IMSc

SYLLABUS FOR

Ph.D. in LIFE SCIENCES
(Program Code: LIFE04)

Syllabus

Candidates should take all core courses (exemptions can be granted on case-by-case basis but an assessment must be made), as well as at least two electives and experimental components (workshops or lab rotations at collaborating institutes.)

CORE COURSES (Semester 1)		
10-LIFE04-001-C Biology-1 (24 lectures), 100 marks		
1	Basic molecular biology	Biomolecules, DNA, RNA, proteins; genetic code; "central dogma"; gene transcription, translation; packaging of DNA in eukaryotes; introns/exons, splicing
2	Cell biology	Cellular metabolism, cell motility, cytoskeleton, intracellular transport, membrane transport, channels, receptors, signalling, cell cycle
3	Genetics	Mendelian genetics, definitions (genes, loci, alleles), dominance; replication, mitosis/meiosis, linkage/crossover
4	Gene regulation	Transcriptional regulation, miRNA and RNAi
5	Developmental biology	differentiation, early development of drosophila via gradients, gap and pair-rule genes, role of hox genes, Williston's "law", other organisms
6	Evolutionary biology	Molecular evolution, evolution of DNA, genes, proteins and regulation. Molecular mechanisms of evolution -- mutation, recombination, duplication, mobile elements
10-LIFE04-002-C Protein Structure (24 lectures, 100 marks)		
1	Taxonomy	Primary, Secondary and tertiary structure, fold types
2	Protein folding	The Anfinsen experiments, Protein database (PDB), Helix-helix packing in globular proteins, Beta-sheet packing, Folding pathways, thermal denaturation, partially folded intermediates, misfolding and aggregation
3	Membrane proteins	Cell membranes, simple and facilitated diffusion across membranes, membrane protein structural biology, ion channels and receptors, transport via membrane proteins, membrane channels:potassium channel, aquaporins, G-coupled protein receptors, ligand/voltage gated ion channels
4	Enzymes	Biological catalysts, Gibbs free energy, transition state complex, substrate, products, active sites, activation energy barrier, induced-fit hypothesis, cofactors, coenzymes, Michaelis-Menten enzyme kinetics
5	Electrostatics in biology	Continuum methods, solvation and ions, implicit solvent models, Poisson equation, Poisson-Boltzmann equation, solvation free energy
6	Structural characterization	x-ray crystallization, circular dichroism, spectroscopy, NMR, single molecule experiments

7	Homology modelling	Homology Modeling, Visualization
10-LIFE04-003-C Mathematics and statistics for biologists (30 lectures, 100 marks)		
1	Differential equations	introduction to ODEs and PDEs, linear and non-linear, properties, how to solve analytically and numerically; examples -- Hodgkin-Huxley, reaction-diffusion equations, Volterra equations
2	Essentials of linear algebra	vectors, matrices, eigenvalues and eigenvectors; orthogonal bases of functions, Sturm-Liouville theory and differential equations; Fourier series and Fourier transforms
3	Probability theory and statistics	basic concepts -- random variables, mean, variance, moments; conditional probabilities, hypothesis and data, likelihood, Bayes' theorem; probability distributions -- binomial, multinomial, Poisson, normal; the central limit theorem; hypothesis testing, significance testing (orthodox and Bayesian methods); parameter estimation
4	Simulations	Introduction to Markov Chain Monte Carlo for exploring space of hypotheses: ergodicity, detailed balance, convergence. Metropolis and Gibbs sampling
5	Machine learning	decision tree learning, artificial neural networks, support vector machines, Bayesian learning and Bayesian networks
6	Other topics	Game theory, applications to evolutionary biology, agent-based modelling of complex systems
10-LIFE04-004-C Physical Methods for Biologists (37 lectures, 100 marks)		
1	Basic physics of soft matter	What is soft matter, length scales and time scales, biological matter as soft matter, self-organization and self assembly, illustrative examples - DNA, microtubules and/or actin and lipid membranes, coarse-grained representations, interactions and bonding in soft matter systems (including van der Waals forces, hydrogen bonding, electrostatics and screening), what can be measured, energy scales
2	Thermodynamics and statistical mechanics	Thermal equilibrium, the idea of entropy, laws of thermodynamics, free energies, Legendre transformations, different ensembles and relation to computational biology examples, Boltzmann distribution, harmonic oscillator, equipartition theorem, virial theorem, thermodynamics of self assembly, simple ideas of phase transitions, Poisson-Boltzmann theory, dealing with electrostatics
3	Noise, diffusion and drift	Thermal fluctuations and noise, random walk, diffusion equation as continuum limit of the random walk, probability density, continuity equation, Fick’s law, drift-diffusion equation, Stokes-Einstein formula, example of receptor clustering
4	Mechanics of continuous media	Elasticity of isotropic solids, estimates for elastic constants of biological materials, fluids in biology, basics of fluid mechanics, Pascals law, Euler’s equation, viscosity, Reynolds number, Navier-Stokes equation, flow through narrow pipes, dimensionless groups, swimming of microorganisms, hydrodynamic interactions, rheology of biological matter, introduction to viscoelasticity, Maxwell model
5	Polymers, membranes and gels	Simple ideas of polymers and membranes, polymer elasticity, polymer dynamics (Rouse and Zimm model) qualitative discussion, scaling ideas in polymers, semi-flexibility, membrane elasticity, membrane fluctuations, passive gels

6	Out of equilibrium	Active matter, simple examples, what do we need to model them, polymerization forces, cell streaming, molecular motors and models, active gels
7	Other topics	Interfacial tension in biological systems, Laplace pressure, wetting and spreading, osmotic effects, capillary effects in biology, micro-rheology
		for biological systems

CORE COURSES (Semester 2)

10-LIFE04-005-C Biology-2 (25 lectures, 100 marks)

1	Epigenetics	DNA packaging, heterochromatin and euchromatin, methylation, histone tail modifications and gene regulation
2	Basics of neuroscience	Neurons, synapses, neural architecture in various organisms, action potential, Hodgkin-Hoxley equation, firing rates, plasticity, artificial neural networks
3	Introduction to ecology	Ecology and evolution, ecosystems, food webs, large-scale ecology
4	Experimental techniques	PCR, southern/northern/western blots, chromatin immunoprecipitation, microarrays, high-throughput sequencing, ChIP-chip and ChIP-seq, high-resolution microscopy (fluoroscence imaging, confocal, FRET, PALM etc), GFP and reporter gene assays
5	Other topics	Basics of: Intercellular communication, epidemiology, physiology, immunology

10-LIFE04-006-C Biological sequence analysis (30 lectures, 100 marks)

1	Biomolecules	Basics (DNA, RNA, proteins)
2	Probability theory	Basic laws -- joint probabilities, conditional probabilities, likelihood, Bayes' theorem
3	String algorithms	finding common substrings and subsequences: Boyer-Moore algorithm, suffix trees, finding strings with mismatches
4	Sequence alignment	algorithms for pairwise and multiple sequence alignment -- scoring model, Needleman-Wunsch and Smith-Waterman algorithms, BLAST and other heuristic algorithms, significance of scores, structural alignment
5	Sequence assembly	assembling short reads, with and without scaffold; ChIP-seq algorithms
6	Markov models	Markov chains, hidden Markov models, Baum-Welch and Viterbi algorithms, profile HMMs and software (HMMer, etc)
7	Transcriptional regulation	Transcription factor binding sites, position weight matrices, sequence logos, motif-finding via expectation maximisation (MEME) and Gibbs sampling
8	Phylogenetic trees	building a tree from pairwise distances, neighbour-joining, parsimony
9	Transformational grammars	regular grammars, context-free grammars; RNA structure analysis

10-LIFE04-007-C Systems Biology (30 lectures, 100 marks)

1	Networks in biology	The diversity of networks across space and time in biological systems Intra-cellular networks: The gene network and protein-protein interaction network Intra-cellular networks: The metabolic network Intra-cellular networks: signaling networks - pathways and	
		enzyme-substrate reaction cascades The signaling network coordination of immune response to infection Reconstructing biological networks from lab experiments Structural analysis of networks: Global properties Structural analysis of networks: Motifs and Modules Dynamics on biological networks: Modeling signaling pathways Inter-cellular networks: Neuronal networks Inter-organism networks: Contact structure and contagion propagation Inter-species networks: Stability-instability of food webs	
2	Patterns in Biology	Temporal patterns: Biological clocks and circadian rhythms Oscillatory activity in Pancreatic beta cells and insulin secretion Pattern formation during development Development in Drosophilia Development of the vertebrate body plan Modeling developmental patterns: Reaction-diffusion models and Turing Patterns Spatial patterns: Linear stability analysis and Fourier modes Autocatalysis and lateral inhibition: Gierer-Meinhardt and related pattern generation mechanisms in biosystems, center-surround principle in retina and cortex Modeling genesis of functional patterns: Ocular dominance columns Development of plants and L-systems modeling Cell differentiation and Random NK Boolean Networks Morphogenesis Fractals in biology: Examples (1/f noise, circulation system), characterization Fractals in biology: Generation mechanisms	
3	Waves in biology	Importance of waves in biology for communication and coordination Intra-cellular waves: Calcium waves, targets and spirals Inter-cellular waves: Waves in the brain, heart and uterus Excitable media models of physiological systems Ionic basis of excitation: Hodgkin-Huxley formalism Simple and complex models of excitability Excitability, Oscillatory and Bistability regimes of systems Wave propagation through inter-cellular gap junctions: Diffusion approximation Genesis and dynamics of spiral waves: kinematic approach Nonlinear dynamical aspects of spiral waves: Restitution and dispersion Excitation-contraction coupling and the role of organ structure in wave dynamics Bidomain models of biological electrical activity Waves in single populations: Fisher waves Waves in interacting populations: Propagating epidemics, spiral waves in host-parasite spatial dynamics	

ELECTIVE COURSES (semester flexible)

10-LIFE04-001-E Biophysics of Macromolecular Structures (32 lectures)

I. Structure and Biophysics of Biomolecules (10 lectures)

Introduction to macromolecular chemistry, building blocks for macromolecular structures, biophysical methods for structure analysis, nucleic acid structure, protein-nucleic acid interactions, membrane proteins, microtubules and other supramolecular assemblies, investigative methods from the atomic to cellular levels, including X-ray crystallography, NMR spectroscopy, molecular dynamics, electron and light microscopy, AFM, single molecule techniques and simulations

II. Kinetics (5 lectures)

Chemical kinetics and application to dynamical processes in proteins, self assembly processes, classical kinetics, transition state theory, unimolecular decomposition, potential energy surfaces, scattering processes and photodissociation processes, enzyme kinetics

III. Biophysical approaches to Biopolymers (6 lectures)

Basics of polymers, protein folding problem, protein aggregation, DNA, DNA electrostatics, DNA force extension relations, RNA folding, polymerization, polymerization forces, dynamic instability, tread-milling and their physical description

IV. Biophysical Approaches to Membranes (5 lectures)

Lipids and Membranes: Structure of various cell membranes, surface tension and curvature energies, Helfrich theory, clustering, phase separation, nanoscale structures i.e. rafts, multicomponent membranes.

SPECIAL TOPICS

V. Kinetics and statistical mechanics of helix coil transitions; physical approaches to the refolding and assembly of multi-subunit proteins; fluorescence spectroscopic studies of macromolecules, molecular basis of enzyme catalysis, antibody structure and function, virus structure and assembly (6 lectures)

10-LIFE04-002-E Simulation Techniques in Biology (32 lectures)

I. Molecular Dynamics (8 Lectures)

Introduction to MD and applications in biology and drug design; Basic Statistical mechanics: Basic thermodynamics, Ensembles (microcanonical, canonical, grand canonical, isothermal-isobaric), Virial theorem, Nose-Hoover chains; Forcefields and interaction potential: Many body potentials, Born-Oppenheimer approximation, electrostatic interactions including Ewald sum, interaction potential for organic molecules; popular forcefields: AMBER, CHARMM, OPLS etc.,;Integration methods and Liouville time operators Phase space concepts, Liouville theorem, Equilibrium solution of Louiville equation, Trotter factorization; Integration algorithms: Verlet, Velocity-Verlet, Gear-Predictor, multiple-time step algorithm, holonomic constraints (RATTLE/SHAKE)

II. Monte Carlo Simulations (6 lectures)

Importance Sampling, Random variables and stochastic processes,lattice models, Random walks, Gibbs sampling, sampling errors, configurational-bias Monte Carlo method, Markov chain Monte Carlo, Advanced Monte Carlo methods: Parallel tempering, simulated annealing

III. Reaction Diffusion (4 Lectures)

Predator Prey Models, Reaction Kinetics, diffusion-limited reactions, Population dynamics, Reaction-diffusion Equations

IV. Brownian/Stochastic simulations (8 lectures)

Stochastic reaction-diffusion models:Compartment-based reaction-diffusion algorithm, reaction-diffusion master equation, pattern formation; Diffusion:

Brownian motion, On/Off-Lattice models, diffusion to adsorbing surfaces, reactive boundary conditions, Einstein-Smoluchowski relation; Stochastic models of transport processes in cells: Fokker Planck Equations, Brownian rachet models, Chapman
-
Kolmogorov equation, Gillespie algorithm, chemical master equation

SPECIAL TOPICS

V. Free energy methods (3 lectures)

Potential of mean force, umbrella sampling, Adaptive bias force method,

thermodynamic integration

VI. Binding and Docking (3 lectures)

Enzyme-substrate recognition process, Search Algorithms (simulated annealing, steepest descent, genetic algorithms), Scoring Functions, Applications of Docking, Softwares for docking

10-LIFE04-003-E **Population Biology, Ecology and Evolution (30 lectures)**

1. Single species population (10 lectures)

Continuous and discrete-time models of population growth (Logistic and related models)
Models of age-structured populations
Population dynamics in the presence of noise
Time-series analysis of data
Flies: Model experimental organism for studying population dynamics
Modeling migration of populations
Territorial behavior
Fundamentals of game theory
Evolution of cooperation between individuals
Spatial dynamics of strategies (Example: Spatial Prisoners Dilemma)

2. Interaction between multiple populations (10 lectures)

Introduction to food webs and ecological interactions between species
Predator-prey interactions: Lotka-Volterra and related models
Functional response
Competition
Cooperation
Multiple prey and predators: Generalized Lotka-Volterra and related models
Stability vs complexity in ecosystems: Single trophic level
Stability vs complexity in ecosystems: Multiple trophic levels
Experimental techniques for studying impact of diversity on stability
The robustness of complex ecological networks

3. Evolution and population genetics (10 lectures)

Fundamentals of population genetics: Random mating and Hardy-Weinberg principle
Classical mathematical genetics: Single locus with multiple alleles
Classical mathematical genetics: Multiple loci
X-linked genes; Linkage and its distribution
The molecular basis of classical genetics
Fitness landscapes and mathematical models of evolution
The major transitions in evolution
Mutation and natural selection
Random genetic drift
Neutral theory of evolution
Coevolution and evolutionary game theory
Evolutionary ecology

10-LIFE04-004-E **Computational Neuroscience (30 lectures)**

1. Neurons, Synapses, Gap Junctions and Small Circuits (10 lectures)
   Introduction to the biological components of the nervous system
   Types of Neurons and Glial cells
   Neuronal activity: Action potential and Graded potential
   Ion channels and electrical activity of neurons
   Dynamics of graded potential neurons (Example: retina)
   Dynamics of action potential neurons, spikes and spike trains
   Dynamics of inter-neuron communication: Synaptic transmission
   Dynamics of inter-neuron communication: Gap junctions
   Introduction to GENESIS/NEURON simulation platforms
   Neuron-Glial interaction
   Small neuronal circuits and motifs

2. Systems Neuroscience (10 lectures)
   Introduction to the computational perspective for studying the brain
   Introduction to Neural Network Models: McCulloch-Pitts paradigm
   Associative Memory and the Hopfield Network
   Storage capacity and stability of memories in Hopfield Network: Mean-field theory
   Learning: Donald Hebb's Hypothesis, Long-Term Potentiation and STDP
   Perceptron and related models: learning to generalize
   Dynamics of Learning: Hebbian and Competitive principles
   Information theory and neuro-communication
   Development of the nervous system in a growing organism
   Evolution of the nervous system: from single cells to the brain
   Invertebrate neuroscience: C. elegans as a model organism
   Modeling the nervous system of invertebrates
   Sensory-motor integration in the nervous system

3. Vision and cognitive neuroscience (10 lectures)
   Introduction to Sensory Processing in the Nervous System
   Components of the Visual System
   Dynamics of Early Visual Processing at Retina
   Receptive fields and centre-surround principle (Mach bands, etc.)
   Processing at the Primary Visual Cortex and Higher Brain Areas
   Modeling edge detection, shape from texture and motion detection
   Visual binding: Synchronization of neuronal activity
   Optical illusions as tool for studying vision
   Information theory of vision
   Introduction to cognitive neuroscience
   Experimental tools of cognitive neuroscience: fMRI, PET, etc.
   Linguistic ability: A model system for cognitive neuroscience

10-LIFE04-005-E **Modeling of Infectious Diseases (28 lectures)**

1. Genomics & evolutionary biology of pathogens (8 lectures)

Dynamics of molecular evolution
Vertical and horizontal gene transfer
Genomic landscape of pathogens, vectors and humans (Example: malaria); Coevolution and Red queen hypothesis
Gene regulation, pathogenesis and immune response
Evolution of virulence

2. The biology and modeling of host-pathogen interactions (8 lectures)
The immune system: design, phylogeny and ontogeny
The functional anatomy of immune response
Analysis of idiotypic network interactions
Systems biology principles for intra-cellular sigaling in immune response
Systems-level modeling of Mycobacterium tuberculosis host-parasite protein-protein interactions
Micro-edipdemiology: population dynamics of viruses and host cells, May-Nowak and related models; application to HIV

3. Epidemiology: data analysis and mathematical modeling (12 lectures)
Epidemics: Dynamics and basic reproductive ratio R0
Estimation of R0 from data - statistical technqiues
Immunization and other public health intervention strategies
SIR model of epidemics: derivation and solution
Variants of SIR model: SEIR, SIS and SIRS
Modeling vector-borne diseases
Host-parasite models (example: Nicholson-Bailey model)
Cellular automata models
Eco-epidemiological models
Contact network: structure and dynamics
Agent-based models of infection propagation

BACK TO MAIN

NISER

SCHOOL OF BIOLOGICAL SCIENCES

Ph.D. LIFE SCIENCES (PROGRAM CODE: LIFE04)

DETAILED COURSE STRUCTURE FOR

Ph. D COURSE
Revised Jan 2017

Approved Feb 27, 2019

***HBNI OM No. HBNI/NISER/AKD/2019/305 dated Feb. 27th, 2019*.**

National Institute of Science Education and Research
HBNI | JATNI, BHUBANESWAR - 752050

Structure of Course Work

List of Compulsory Courses

Course No	Course Name	Credits
B601	BIOINFORMATICS AND COMPUTATIONAL BIOLOGY	6
B602	BIOTECHNIQUES	6
B701	ADVANCED MOLECULAR BIOLOGY	6

List of Elective Courses

Course No	Course Name	Credits
B651	ADVANCED CELL BIOLOGY	6
B652	GENETIC ENGINEERING	6
B653	ADVANCED BIOCHEMISTRY	6
B654	ADVANCED MICROBIOLOGY	6
B655	ENZYMOLOGY	6
B656	ADVANCED NEUROBIOLOGY	6
B657	CHEMICAL BIOLOGY	6
B658	VIROLOGY	6
B659	PLANT PHYSIOLOGY	6
B660	DEVELOPEMENTAL BIOLOGY	6
B751	ADVANCED IMMUNOLOGY	6
B752	INFECTIOUS DISEASE BIOLOGY	6
B753	CANCER BIOLOGY	6
B754	ADVANCED GENETICS	6
B755	IMMUNE REGULATION AND INFECTION	6
B756	MACROMOLECULAR CRYSTALLAGRAPHY	6
B757	QUANTITATIVE BIOLOGY	6
B758	ION CHANNELS	6
B759	CONCEPTS IN MECHANOBIOLOGY	6
B760	MOLECULAR ERRORS IN DIESEASE	6
B761	PLANT DEVELOPEMENTAL BIOLOGY	6

List of Research Project Assignments

Course No	Course Name	Credits
B699	*Research Project Assignment – 1	12
B799	*Research Project Assignment – 2	12

*Two research project assignments relevant to the Ph. D topic

Detailed Syllabus – Compulsory Courses

Bioinformatics (B601)

Course Title : **Bioinformatics**
Course Code : **B601**
Credits : **6 Credits**
Course Category : **Core**
Course Prerequisites : **Biochemistry, Molecular Biology, Genetics, Biostatistics**
Contact Hours (28/42/56) (including tutorials) : **56**

Outcome of the Course:

- Application of bioinformatics knowledge in understanding relationships at sequence, structure and network-level.
- Demonstration of popularly used bioinformatics tools for research work
- Help understand the patterns of life and rhythms

Course Contents:

1. Introduction to bio-informatics (2 Lectures)
   - Introduction,
   - History and importance
   - Field and scope

2. Databases and Database searching (2 Lecture + 1 demo)
   - Importance, classification
   - Annotation and File formats
   - Demo : NCBI, SWISS-PROT, PDB

3. Locating Coding regions and Gene prediction (3 Lecture)
   - 6-frame translation,
   - parameters governing prokaryotic and eukaryotic translation,
   - Concept, neural networks and its importance in gene prediction as example

4. Alignments (2 Lectures)
   - Significance and importance, types, classification
   - Dot-plot matrix

5. Substitution Matrices (3 Lectures + tutorial)
   - Significance, types,
   - derivation of BLOSUM and PAM

- Application of Substitution Matrices

6. Algorithms behind pairwise sequence alignments (6 Lecture + 1 demo + 1 tutorial)
   - Dynamic programming,
   - Smith-Watermann,
   - Needleman-Wunsch,
   - Heuristic, BLAST, FastA
   - applications, statistical parameters governing BLAST results
   - Demo : database searching using BLAST

7. Multiple sequence alignments (1 Lecture + 1 demo)
   - Importance, progressive sequence alignment, ClustalW, statistical parameters governing clustalW, applications
   - Demo : ClustalW

8. Phylogenetic tree construction and different approaches (5 Lecture + 1 demo)
   - Introduction, importance, classification and parts of tree,
   - predicting number of root and unrooted trees, orthologs and paralogs, transitions and transversions, susbstitutions matrices,
   - different methods to construct phylogenetic tree,
   - Neighbour-Joining (star decomposition method),
   - Bootstrapping
   - Demo : MEGA software

9. Pattern matching/position specific scoring matrices (1 Lecture + 1 demo)
   - Importance of patterns, motifs, deriving PSSM, sequence logo
   - Demo : Prosite, Pfam

10. Structural Bioinformatics (5 Lecture + 2 demo)
    - Introduction to structural bioinformatics and protein structure, Ramachandrean plot
    - Secondary structure prediction and methods
    - Hydropathy plot, helical wheel, signal peptide prediction, transmembrane prediction,
    - Demo :
    - Tertiary structure prediction : RMSD and Homology modelling
    - Demo : Swiss Model and evaluation
    - Concepts related to Drug design : Lipinski Rule of 5 and Molecular docking

11. Systems Biology (4 Lecture + 1 demo)
    - Introduction, need for computers in system biology
    - High-throughput and *omic* approaches, difference and application
    - Graph theory
    - Gene Ontology

- Demo: KEGG and gene ontology

Text Books (if any):

a) Introduction to bioinformatics – Arthur M. Lesk
b) Bioinformatics – David Mount
c) Essential bioinformatics – Jin Xiong

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Biotechniques (B602)

Course Title : **Biotechniques**
Course Code : **B602**
Credits : **6**
Course Category : **Core**
Course Prerequisite : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:
Basic principle behind the biophysical, and biochemical experiments. Troubleshoot the experiments, interpretation of results, plotting of graphs, design the experiments.

Course Contents (with both Lectures + Tutorials marked:

1. Techniques use in DNA characterization: Construction of genomic & cDNA library; Agarose gel electrophoresis; Northern blotting; Southern blotting; RFLP; AFLP; microarray.
   (6 Lectures + 2 Tutorials)
2. Techniques use in DNA manipulations: PCR and its application; Restriction digestion; Ligation; Site directed mutagenesis. (3 Lectures + 1 Tutorial)
3. Enzymes used in genetic engineering experiments: DNA polymerases; Ligase; Reverse transcriptase; Restriction endonucleases and other enzymes. (3 Lectures + 1 Tutorial)
4. Techniques use in protein characterization: SDS-Gel electrophoresis; Western blotting; IEF-2D gel electrophoresis; FRET; Co-Immunoprecipitation; CHIP; Protein-ligand interactions and affinity studies by Surface Plasmon resonance; Density gradient separation.
   (3 Lectures + 1 Tutorial)
5. Spectrophotometry (UV-Vis, CD, Fluorescence). (3 Lectures + 1 Tutorial)
6. Principles of Centrifugation. (3 Lectures + 1 Tutorial)
7. Uses of radioactive isotopes and autoradiography. (3 Lectures + 1 Tutorial)
8. Biophysical techniques: X-ray crystallography; NMR; ORD. (3 Lectures + 1 Tutorial)
9. Principals of chromatography: Ion exchange; Gel filtration; Affinity; Reverse flow; HPLC
   (6 Lectures + 2 Tutorial)
10. Immunological techniques: Generation of hybridoma and production of Ab; FACS; ELISA.

(3 Lectures + 1 Tutorial)

11. Microscopy (light, Fluorescence, UV, Atomic absorption; Confocal). (3 Lectures + 1 Tutorial)
12. Cell culture and developmental biology techniques (FISH); Genetic crosses in model organism. (3 Lectures + 1 Tutorial)

Text Books (if any):

a) "Immunology Laboratory Manual" by Myers and Richard L

b) "Molecular Cloning" by Sambrook and Russel

c) "Genetic Engineering" by Reece

d) "The tools of Biochemistry" by Terrance G. Cooper

e) "Biophysical Chemistry" by Alan Cooper

f) Wilson and Walker's Principles and Techniques of Biochemistry and Molecular Biology

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Molecular Biology (B701)

Course Title : Advanced Molecular Biology
Course Code : B701
Credits : 6 Credits
Course Category : Core
Course Prerequisites : NIL
Contact Hours (28/42/56) : 56
Outcome of the Course:
Understand the recent advancements in molecular biology, structure-function analysis and regulation. Reading research articles, designing experiment and data analysis.
Course Contents:
1. Signaling pathways and regulation (8 Lectures + 2 Tutorials)

- Translation initiation, translation control in metabolic
- Genetic disorders and development.

2. Importance of cis regulatory elements (8 Lectures + 2 Tutorials)

- mRNA, CAP, 5'UTR, 3'UTR Poly A tail
- IRES structure and function
- trans-acting factors in protein expression, examples of Iron homeostasis.

3. General amino acid control mechanism, translation in developmental decision, GAIT mediated translational silencing, translation silencing by microRNA. (6 Lectures + 2 Tutorials)
4. Yeast mating type switch: Mating type locus, experimental evidence for cis regulatory elements, experimental evidence for transacting factors in mating type switch, donor preference, recombinant enhancers. (7 Lectures + 2 Tutorials)

5. Long term evolution experiment: Evolution of Cit+ function, potentitation of Cit+ function, actualization of Cit+ function, refinement of Cit+ function and molecular mechanism. (5 Lectures + 1Tutorials)

6. Molecular mechanism of PRK action and host-virus evolution. Role of dimerization domain, kinase domain activation independent of dimerization domain, substrate recognition motif, evolutionary pressure on PRK and pox virus pseudosubstrate. (5 Lectures + 1 Tutorials)

7. How do new protein arise: Minimal sequence code for switching protein structure-function, domain rearrangement give rise to new function, horizontal gene transfer between the genome, intergenic region as a potential site for new gene, gene duplication and refinement of its function.
(5 Lectures + 1 Tutorials)

Recommended Books:

a) “Molecular Cell Biology” 6th Edition By Lodish
b) “Gene X” By Lewin
c) “Translational Control in Biology and Medicine” By Michael B. Mathews, Nahum Sonenberg, John W.B. Hershey. CSH press
d) “Prokaryotic Gene Expression (Frontiers in Molecular Biology)” Oxford University Press, USA; First edition (July 29, 1999)
e) Class notes and research articles.

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Detailed Syllabus – Elective Courses

Advanced Cell Biology (B651)

Course Title : Advanced Cell Biology
Course Code : B651
Credits : 6
Course Category : Elective
Course Prerequisite :
Contact Hours (28/42/56): 56
(including tutorials)

Outcome of the Course:

* Understanding the basic principles governing cell structure and functions
* Biochemcial, biophysical, genetical basis of cell and its response
* Key concepts in maintenance of cell structure
* Evolution of cell organelles, importance in health and disease.
* Importance of ion channels in health and disease, pharmacology and applications
* Advanced knowledge of details of microscopy
* Bridging the gap between theory and research methodology

Course Contents (with both Lectures + Tutorials marked:

A: Understanding the cell (7 Lectures + 2 Tutorials)

1) Various cell types as model systems
2) Different sub-cellular structures and their function
3) Ultra structure of subcellular organelles
4) Others

B)Microscopy as tools for understanding cellular structure function (7 Lectures + 2 Tutorials)

1) Biological sample preparation. Difficulties and advancements
2) Various fluorescence proteins and their applications
3) Other fluorescence probes
4) Autofluorescence and its application
5) Others

C) Principle, uniqueness and application of different microscopes (7 Lectures + 2 Tutorials)

1) Fluorescence microscope
2) Phase contrast microscope,
3) DIC microscope
4) Confocal microscope, Spectral detection
5) Total internal reflection fluorescence microscope (TIRF),

6) Electron microscope,
7) Atomic force microscope,
8) Others

D) <u>Application of microscopes</u> (7 Lectures + 2 Tutorials)

1) Live cell imaging difficulties and advantages
2) FLIM application
3) FRET
4) FRAP
5) Photo-activation
6) Metal imaging
7) Others

E) <u>Understanding cellular dynamics</u> (10 Lectures + 3 Tutorials)

a) Cell division
b) Cytoskeletal reorganization, microtubule and actin cytoskeleton
c) Vesicle trafficking and recycling, endocytosis and exocytosis
d) Nuclear dynamics
e) Efflux and influx of ions and others
e) Others

F) <u>Super resolution</u> (4 Lectures + 1 Tutorials)

a) STED
b) PALM
c) STROM
d) Others

Text Books (if any):

Molecular Biology of the Cell: Alberts, Bruce; Johnson, Alexander; Lewis, Julian; Raff, Martin; Roberts, Keith; Walter, Peter, New York and London: Garland Science

Suggested References:

Important research articles and reviews as suggested in the class by the instructor. Nature cell biology, Journal of cell Biology, Journal of cell Science

Genetic Engineering (B652)

Course Title : Genetic Engineering
Course Code : B652
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : NIL
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding the basic principles of Recombinant DNA technology
- Knowledge of various tools and techniques used in genetic engineering
- Applications in the generation of transgenic models

Course Contents:

1. Growth and maintenance of bacterial cultures, bacteriophages plasmids (1 Lecture + 1 Tutorial)
2. Growth and maintenance of animal cells and viruses (2 Lectures)
3. Mutation, mutagenesis and mutant screening (3 Lectures + 1 Tutorial)
4. Enzymes used in genetic engineering experiments, DNA, polymerases, ligase, reverse transcriptase, restriction endonucleases and other enzymes (3 Lectures + 1 Tutorial)
5. Oligonucleotides synthesis & purification (1 Lecture)
6. Antisense DNA/RNA in genetic engineering (2 Lectures + 1 Tutorial)
7. Radiolabelling of nucleic acids (2 Lectures)
8. Transformation & transfection (1 Lecture + 1 Tutorial)
9. Construction of genomic & cDNA library (3 Lectures + 1 Tutorial)
10. Genomic DNA & cDNA cloning (3 Lectures + 1 Tutorial)
11. Analysis of DNA of cloned genes (3 Lectures + 1 Tutorial)
12. Analysis of protein sequencing products & cloned genes (3 Lectures + 1 Tutorial)

13. Nucleic acid & protein sequencing technology (3 Lectures + 1 Tutorial)
14. Protein nucleic interaction and the methods to study those (3 Lectures + 1 Tutorial)
15. Polymerase Chain Reactions, types of PCRs and analysis of PCR, products; Application of PCRs. (3 Lectures + 1 Tutorial)
16. Site directed mutagenesis (1 Lecture)
17. Recombination, site specific recombination (2 Lectures + 1 Tutorial)
18. Transgenic plants (1 Lecture)
19. Transgenic animals (1 Lecture + 1 Tutorial)
20. Other transgenic life forms (1 Lecture)
21. Ethics and economics of GM crops and GM organisms (2 Lectures + 1 Tutorial)

Recommended Books:-

a) "Genetic Engineering" by Reece

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Biochemistry (B653)

Course Title : **Advanced Biochemistry**
Course Code : **B653**
Credits : **6 Credits**
Course Category : **Elective**
Course Prerequisites : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Understanding the mechanism of protein folding
- In depth knowledge about Post translational modifications of proteins
- Mechanisms and implications of protein turn over in cells

Course contents:

1. Protein secretion (8 Lectures + 3 Tutorials)
2. Protein folding: In vivo - In vitro (8 Lectures + 3 Tutorials)
3. Conditional enzyme kinetics (10 Lectures + 3 Tutorials)
4. Post translational modification (8 Lectures + 3 Tutorials)
5. Protein degradation (8 Lectures + 2 Tutorials)

Recommended Books:

a) Lehninger Principles of Biochemistry, Fourth Edition by David L. Nelson and Michael M. Cox

b) "Fundamentals of Biochemistry" *by Voet and Voet*

c) "Biochemistry" *by JM Berg, JL Tymoozko, L Stryer*

Suggested References:

Journals
Annual review of Biochemistry, Trends in Biochemical Sciences, Other suggested Journal.

Advanced Microbiology (B654)

Course Title : **Advanced Microbiology**
Course Code : **B654**
Credits : **6 Credits**
Course Category : **Elective**
Course Prerequisites : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Develop understanding of bacterial responses to various stimuli
- Gain insights into bacterial biofilm formation and quorum sensing mechanisms

Course contents:

1. Molecular microbial genetics (10 Lectures + 4 Tutorials)
2. Molecular medical microbiology: microbial pathogenesis & infectious diseases, study of selected pathogenic organisms with emphasis on recent insights into their mechanism of pathogenesis (10 Lectures + 4 Tutorials)
3. Environmental microbiology (11 Lectures + 4 Tutorials)
4. Microbial interactions (11 Lectures + 4 Tutorials)

Recommended Books:

a) Brock's Biology of Microorganisms by Madigan et al.;
b) Fundamental bacterial genetics by Trun & Trumphy;
c) Molecular medical microbiology by Sussman M;
d) Microbiology: diversity, disease and the environment Salyers, AA;
e) Colonization of mucosal surfaces by Nataro JP;
f) Medical microbiology by Murray PR;
g) Environmental microbiology by Maier RM;
h) Environmental microbiology by Varnam, AH;
i) Annual review of microbiology by Gottesman, Susan,
j) Marine microbiology: ecology and applications by Munn, CB

Suggested References:

Journals

Nature Review's Microbiology, Trends in Microbiology, Critical Reviews in Microbiology, PNAS, Molecular Microbiology, ASM Journals and others

Enzymology (B655)

Course Title : **Enzymology**
Course Code : **B655**
Credits : **6 Credits**
Course Category : **elective**
Course Prerequisites : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Build comprehension on nature and functioning of enzymes.
- Make students understand kinetics of enzyme mediated reactions and enzyme inhibition kinetics
- Develop basic understanding on enzyme engineering

Course Contents:

1. General properties of enzymes (3 Lectures + 1 Tutorial)
2. Enzyme nomenclature (3 Lectures + 1 Tutorial)
3. Activation energy and reaction coordinates (3 Lectures + 2 Tutorials)
4. Denaturation of Enzyme (3 Lectures + 1 Tutorial)
5. Enzyme purification (4 Lectures + 1 Tutorial)
6. Enzyme kinetics: Michaelis Menten Equation, Line-Weaver Burk plot (4 Lectures + 1 Tutorial)
7. Enzyme catalytic mechanism: Acid-Base catalysis, covalent catalysis, Metal ion catalysis (3 Lectures + 1 Tutorial)
8. Enzymes in food technology (3 Lectures + 1 Tutorial)
9. Immobilization of enzyme, biosensor, Bioreactor (3 Lectures + 1 Tutorial)
10. Structure and function of specific enzymes: Lysozyme, serine protease (3 Lectures + 1 Tutorial)
11. Enzyme inhibition: Competitive inhibition, non-competitive inhibition, uncompetitive inhibition (4 Lectures + 1 Tutorial)
12. Allosteric regulation of enzyme activity: Carbonic anhydrase, Chymotrypsin, ATCase (3 Lectures + 1 Tutorial)
13. Allosteric enzyme inhibition (3 Lectures + 1 Tutorial)

Recommended Books: -

a) "Fundamentals of Biochemistry" *by Voet and Voet*
b) "Biochemistry" *by JM Berg, JL Tymoozko, L Stryer*

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Neurobiology (B656)

Course Title : **Advanced Neurobiology**
Course Code : **B656**
Credits : **6 Credits**
Course Category : **Elective**
Course Prerequisites : **Nil**
Contact Hours : **56**
(including tutorials)

Course Outcome:

- Develop understanding about the central nervous system-controlled process and their mechanism of regulation.
- In-depth understanding of the neural circuits and behavior.
- Understand and analyze the recent updates in the field and significance.

Course Contents:

1. Autonomic nervous system and regulation of body functions (6 Lectures + 2 Tutorials)
2. Somatic sensory system and Neurobiology of pain (6 Lectures + 2 Tutorials)
3. Regulation of sleep and wakefulness (3 Lectures + 1 Tutorial)
4. Reproductive brain, sex difference and age-related changes in the brain and neural circuitry (9 Lectures + 3 Tutorials)
5. Neurodegenerative disorders (6 Lectures + 2 Tutorials)
6. Neural basis of learning and memory (3 Lectures + 1 Tutorial)
7. Basal ganglia and the neural control of movement (3 Lectures + 1 Tutorial)
8. Blood supply to the brain and cerebrovascular attack, ventricular system in the brain (3 Lectures + 1 Tutorial)
9. Neuro-immune interaction and nonthyroidal illness syndrome (3 Lectures + 1 Tutorial)

Text book (if any):

a) Zigmond, M.J., Bloom, F.E., Landis, S.C., Roberts, J.L., Squire L.R. (2008) Fundamental Neuroscience. Academic Press.

b) Kandel, E., Schwartz, J., Jessell, T. (2000) Principles of Neural Science. McGraw Hill.

c) Guyton, A. and Hall, J. (2006) Text book of medical physiology. Elsevier

Suggested References:

Relevant research/review articles as decided by the Instructor to update the knowledge in the field.

Chemical Biology (B657)

Course Title : Chemical Biology
Course Code : B657
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : None
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Introducing the concept of chemical biology
- Application of chemistry to advance the study of biological systems
- Understanding biology to do new chemistry?
- How is chemical biology used to advance science and human health?
- Understanding chemical structures of bio-molecules
- Comparative understanding of biosynthesis and laboratory synthesis
- Understanding energetics of biochemical pathways and processes
- Be competent in reading and interpreting primary literature in the areas of chemical biology

Course Contents:

- Introduction: (3 Lectures + 1 Tutorial)
    - Structure
    - Chemistry and the Synthesis of Life
    - Central Dogma
    - What is Chemical Biology?
- Proteins and protein folding (6 Lectures + 3 Tutorials)
    - Describe different strategies for the production and isolation of proteins
    - Experimentally determine the physicochemical and functional properties of proteins including laws of photochemistry
    - Analyse and interpret protein sequences and structures and use such information to predict protein function
    - Protein folding--an overview
- Peptide sequencing (6 Lectures + 3 Tutorials)
    - Peptide sequencing, principles and biological databases
    - Pairwise, motifs and domains
    - Mass spectrometric analysis
- Peptide synthesis (6 Lectures + 3 Tutorials)
    - peptide design, synthesis and execution
- Protein synthesis (6 Lectures + 2 Tutorials)
    - genetic code, amino acids, polypeptides

  - nucleotide sequence and mutations
- Natural product synthesis (6 Lectures + 2 Tutorials)
  - Intro, NRPS & PKS
- Nucleic acids and DNA synthesis (2 Lectures + 1 Tutorial)
  - Oligonucleotide synthesis
  - Bioconjugate synthesis
- Molecular Evolution & Chemical Genetics (2 Lectures + 1 Tutorial)
  - classical genetic and chemical genetic procedures, genotype-based and phenotype-based genetic methods
  - explain and contrast how gene expression is controlled by both proteins and small molecules, including regulatory RNA molecules
  - biology and chemistry of RNA
- Protein-protein interactions & proteomics (2 Lectures + 1 Tutorial)
  - introduction, databases
  - principles, methodologies and applications of proteomics and synthetic biology

Suggested reading:

- Blackburn, G.M. & Gait, M.J. Nucleic Acids in Chemistry and Biology. Oxford (1996)
- Branden, C. & Tooze, J. Introduction to Protein Structure.
- Garland (1999) Creighton, T.E. Proteins: Structures and Molecular Properties.
- Freeman (1993) Fersht, A. Structure and Mechanism in Protein Science. Freeman (1999)
- Miller and Tanner (2008). Essentials of Chemical Biology, Wiley

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Virology (B658)

Course Title : **Virology**
Course Code : **B658**
Credits : **6 Credits**
Course Category : **elective**
Course Prerequisites : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:
At completion of the course, student is expected to

- comprehend structural organization, and different biological processes of viruses
- Develop basic knowledge of biology and pathological manifestation of few important human and animal viral pathogens
- Develop comprehension of tools and approaches to study viral biology.

Course Contents:

1. Scope and outline of the course, history and introduction to virology (1 lecture)
2. Virus structure and classification: viral genome, capsid and envelope; different classification schemes and ICTV database (4 lectures +1 tutorial)
3. Techniques in virology (2 lectures +1 tutorial)
4. Viral biology: entry to egress (4 lectures +1 tutorial)
5. Virus-host interactions: cell receptors for viral entry, host proteins for replication, translation and processing of viral proteins (3 lectures +1 tutorial)
6. Host cell response to virus infection (2 lectures +1 tutorial)
7. Pathogenesis of viral infection and epidemiology (2 lectures)
8. Cell transformation by viruses (2 lectures +1 tutorial)
9. Vaccines and antiviral drugs (2 lectures +1 tutorial)
10. Use of viruses in gene delivery, molecular biology & as oncolytic agents (2 lectures)
11. Plant viruses and important plant pathogens of relevance to India (1 lecture +1 tutorial)

12. Bacteriophages and insect viruses (2 lectures +1 tutorial)
13. Specific virus families of importance: (13 lectures + 5 tutorials)
    i. Orthomyxoviridae (Influenza virus)
    ii. Paramyxoviridae (Measles, Mumps, New Castle disease viruses and Respiratory syncytial virus)
    iii. Togaviridae/Alphavirus genus (Chikungunya virus)
    iv. Flaviviridae (Dengue, Japanese encephalitis, Tickborne encephalitis, West Nile and Hepatitis C viruses)
    v. Coronaviridae (SARS virus)
    vi. Retroviridae (HIV)
    vii. Papillomaviridae (Human Papilloma viruses)
    viii. Reoviridae (Rotavirus)
    ix. Picornoviridae (common cold and Polio viruses)
    x. Herpesviridae (Herpes Simplex, Chickenpox, Kaposi's sarcoma and Epstein-Barr viruses)
14. Emerging viruses: SARS, Chikungunya, Dengue, Hendra and Nipah viruses and Crimean-Congo hemorrhagic fever virus (2 lectures)

Reference books:

1. Basic Virology, 3rd edition by Edward K. Wagner, Martinez J. Hewlett, David C. Bloom, David Camerini. Year: 2007; Publisher: Wiley-Blackwell. ISBN: 978-1-4051-4715-6
2. Principles of virology, 3rd edition (vol.1) by S. Jane Flint, Lynn W. Enquist, Vincent R. Racaniello and Anna Marie Skalka. Year: 2008; Publisher:ASM press.ISBN: 978-1-55581-443-4
3. Virology: Molecular Biology and Pathogenesis by Leonard Norkin. Year: 2010; Publisher: ASM press. ISBN: 978-1-55581-453-3
4. Fields Virology, 5th edition. Edited by David. M. Knipe and Peter M. Howley. Year: 2007;Publisher: Lippincott Williams & Wilkins. ISBN/ISSN: 9780781760607

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Plant Physiology (B659)

Course Title : **Physiology II (Plant)**
Course Code : **B659**
Credits : **6 Credits**
Course Category : **Core**
Course Prerequisites : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Entrain the students with different hormone physiology and it's interaction.
- Learning light physiology, transformation and photosynthesis.

Course Contents:

1. Gross anatomy of plants and Plant Cell architecture (3 Lectures + 1 Tutorials)
2. Transpiration (1 Lecture)
3. Mendelian Genetics (1 Lecture)
4. Plant transformation (1 Lectures + 1 Tutorials)
5. Photosynthesis (2 Lectures + 1 Tutorials)
6. Respiration (2 Lectures + 1 Tutorial)
7. Protein trafficking in plants, (1 Lecture)
8. Macromolecular complexes in plants (1 Lecture)
9. Gene expression and transgene Silencing mechanisms in plant (3 Lectures + 1 Tutorial)
10. Phytochrome, Photomorphogenesis (3 Lectures + 2 Tutorials)
11. Cryptochromes, Phtotrophins and UV light responses (3 Lectures + 1 Tutorial)
12. Plant growth regulators: auxins, gibberellins, cytokinins, ethylene abscisic acid (7 Lectures + 2 Tutorials)
13. Plant photoreceptors and light signaling in plants (4 Lectures + 1 Tutorial)
14. Control of flowering time (4 Lectures + 2 Tutorials)
15. Ethylene signaling and fruit ripening (2 Lectures + 1 Tutorial)
16. Stress response in plants (1 Lecture)
17. Plant pathogen interaction, Symbiosis vs. Parasitic (1 Lecture)
18. Leaf Senescence (1 Lecture)
19. Medicinal plants and its importance (1 Lecture)

Recommended Books:

a) “Plant Physiology” by Taiz & Zeiger Sinaue,
b) “Plant Physiology” by Salisbury and Ross

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Developmental Biology (B660)

Course Title : **Developmental Biology**
Course Code : **B660**
Credits : **6 Credits**
Course Category : **Core**
Course Prerequisites : **Genetics, Cell Biology, Molecular Biology**
Contact Hours (28/42/56) (including tutorials) : **56**

Outcome of the Course:

- Understanding the principles governing development of an organism from conception to birth.
- Key concepts in maintenance of growth of an organism and aging.
- Implications in Evolution, Health and disease.

Course Contents:

1. Key concepts and techniques (6 Lectures + 2 Tutorials)
   - Principles and excitements of Developmental biology
   - Developmental events and differential gene expression
   - Developmental Genetics - approaches & techniques
   - Cell fate determination in *C. elegans*

2. Early embryonic development (9 Lectures + 3 Tutorials)
   - Gametogenesis
   - Fertilization
   - Cleavage
   - Gastrulation

3. Axial patterning (9 Lectures + 3 Tutorials)
   - Axis formation in Amphibian
   - Anterior posterior patterning in Amphibians
   - Anterior posterior patterning in Drosophila
   - Homeotic gene regulation
   - Early mammalian development
   - Left right patterning

4. Later embryonic development (9 Lectures + 3 Tutorials)
   - Patterning in Central nervous system
   - Ectoderm
   - Mesoderm

- Endoderm

5. Post embryonic development (6 Lectures + 2 Tutorials)
   - Sex determination in Drosophila, mammals and other species
   - Regeneration
   - Aging & Senescence

6. Implications of Developmental Biology (3 Lectures + 1 Tutorial)
   - Medical implications
   - Cancer as a developmental disease
   - Environmental regulation and development
   - Developmental mechanisms and evolutionary change

Text Books (if any):

a) "Developmental biology" by *Scott Gilbert*
b) "Principles of Development" by *Lewis Wolpert*

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Immunology (B751)

Course Title : Advanced Immunology
Course Code : B751
Credits : 06
Course Category : Elective
Course Prerequisite : NIL
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:
Understating the current concepts of immunological processes associated to infection immunity, tumor immunity, autoimmunity and other immuno-regulatory states of altered host immune system.

Prerequisite: Basic understanding of cell biology, animal physiology, molecular biology, biochemistry, microbiology, immunology

Course Contents:

1. Basics of Immune system: Cells and organs of Immune system; Innate and Adaptive Immune Response (5 Lectures + 1 Tutorial)

2. Humoral and Cell Mediated immune response (6 Lectures + 2 Tutorials)

3. MHC and Antigen presentation (6 Lectures + 2 Tutorials)

4. Cellular interaction in immune system (6 Lectures + 3 Tutorials)

5. Signal transduction in immune system (4 Lectures + 2 Tutorials)

6. Cooperation of Innate and Adaptive immunity (6 Lectures + 2 Tutorials)

7. Immune-regulation (6 Lectures + 2 Tutorials)

8. Translational Immunology: Immuno-therapy and Vaccine strategy for Infection Immunity, Cancer Immunity and regulation of Autoimmunity.

(3 Lectures + 2 Tutorials)

Text Books (if any):

a) Kuby IMMUNOLGY 6th Edition by Richard A. Goldsby, Barbara Anne Osborne, Janis Kuby. Publisher: W.H. Freeman

b) Cellular and Molecular Immunology by Abul K. Abbas, Andrew H. Lichtman, Shiv Pillai. Publisher: Saunders/Elsevier

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor

Infectious Disease Biology (B752)

Course Title : **Infectious Disease Biology**
Course Code : **B752**
Credits : **6 Credits**
Course Category : **Elective**
Course Prerequisites : **Nil**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Develop understanding infection process, infection epidemiology, host-pathogen interactions and evolution of pathogens

1. Introductory lectures to IDB – (**4 classes + 1 tutorial)**
What is infection, what is disease, Microbes Causing Infectious Diseases- bacteria, viruses, fungi, protozoa, helminthes, prions. Present scenario of IDs worldwide. (General lectures based on journals)

2. Host pathogen interactions **(6 classes, 2 tutorials)**
Host-pathogen relationship, Toxins, Disease establishment, Disease transmission- zoonotic, nosocomial, epidemiology, Molecular Aspects of *Host-Pathogen Interactions, Effect of nutrition on infectious diseases, Viruses and cancer*

3. Host defense & Immunopathology **(5 classes, 2 tutorials)**
Microbial Flora of the Healthy Human Host, Natural Resistance and Nonspecific Defense Mechanisms, Basic and Theoretical Aspects of the Immune Response

4. Evolutionary Biology of Infectious Diseases- **(6 classes + 2 tutorials)**
Emerging, Reemerging and Deliberately introduced infectious diseases, Factors that Contribute to the Emergence of a New Pathogens- role of evolution, ecology, genetics-HGT or LGT, clustered, regularly interspaced, short palindromic repeats (CRISPER), some EIDs and REIDs- malaria, Tb, influenza (SWINE flu), SARS, chikunguniya, HIV, west nile virus, marburg virus, bioterrorism, anthrax, CJD.

5. Bacterial infections- **(5 classes, 1 tutorial)**
This will focus on the major bacterial infections. The infections can be considered in groups related to the body systems infected.

6. Viral infections- (**5 classes, 2 tutorials)**
Molecular biology of the different types of virus, the different strategies that are involved in their replication and the ways in which they cause disease. Consideration is given to the prevention, treatment and control of virus infections.

7. Parasitic infections- (5 classes, 1 tutorial)

Biology of parasites and the ways that they can cause disease. The organisms responsible for the major parasitic diseases will provide the main focus for instruction as they have also been the main focus for research.

8. Molecular Epidemiology and control of infectious diseases (6 classes, 2 tutorials)

Topics include analytic methods, study design, outbreak investigations, surveillance, vaccine development and evaluations, screening, modeling, and infectious causes of cancer or chronic diseases. Background on important infectious diseases will be presented.

Books/Journals:

a) Alcamo's fundamentals of Microbiology by Jeffrey C. Pommerville,
b) General Microbiology by Roger E Stanier et al.,
c) Brock Biology of Microorganisms by Michael T Madigan
d) General Microbiology by Roger Y Stanier et al.
e) Microbiology 5th ed, Michael Z Pelczar Jr.
f) Other suggested Journals

Cancer Biology (B753)

Course Title : Cancer Biology
Course Code : B753
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : NIL
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding basic molecular and cellular mechanisms of carcinogenesis.
- Integrating knowledge to understand therapeutic approaches.
- Stimulate research interest.

Course Contents:

1. Cancer origin and terminology (3 lectures + 1 tutorial)
   - Molecular and cellular origin of cancer
   - Clonal vs. mutational origin of cancer
   - Stem cells and cancer

2. Different classes of cancers (3 lectures + 1 tutorial)
   - Carcinoma, Sarcoma
   - Leukemia, Lymphoma and myeloma
   - Central nervous system cancers

3. Malignant transformation of cells (6 lectures + 2 tutorials)

   - General causes of cancer, mechanisms
   - Characteristics and phenotypes of cancer cells
   - Process of metastasis and its significance

4. Cancer induction and oncogenes (6 lectures + 2 tutorials)

   - Stages in the development of tumorigenesis: initiation and promotion
   - Tumor-suppressor genes and oncogenes and their differences
   - The connection between oncogenes and proto-oncogenes
   - Cancer stem cells

5. Cellular response to Tumors (6 lectures + 2 tutorials)

- Signal transductions in cancer, G protein coupled-receptors and secondary messengers
- Receptor tyrosine kinases and SH2-containing proteins
- Ras protein and the MAP kinase cascade in the control of cell function and aberrations in cancer
- Convergence, divergence and crosstalk among different signaling pathways
- Concept of apoptosis and its role in cancer

6. Tumor Antigens and tumor immunity (6 lectures + 2 tutorials)

- Tumor-specific transplantation antigens (TSTAs) and tumor-associated transplantation antigens (TATAs)
- Tumor induced altered Immune response and immune-suppression.

7. Tumor Evasion mechanism (6 lectures + 2 tutorials)

- Changes in tumor cells
- Alteration in antigen presenting cells
- Dysfunction of host effector cells

8. Cancer Therapy (6 lectures + 2 tutorials)

- Chemotherapy
- Radiation therapy
- Surgery
- Cancer immuno-therapy
- Other treatment methods including targeted therapy

Text Books (if any):

1. "Molecular Biology of the Cell" by Alberts, Bruce; Johnson, Alexander; Lewis, Julian; Raff, Martin; Roberts, Keith; Walter, Peter
2. "Molecular Cell Biology" by Lodish, Harvey; Berk, Arnold; Zipursky, S. Lawrence; Matsudaira, Paul; Baltimore, David; Darnell, James E
3. "The Biology of Cancer" by Weinberg, Robert A

Suggested References:

Relevant articles from cancer journals.

Advanced Genetics (B754)

Course Title : Advanced Genetics
Course Code : B754
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : NIL
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Integrating knowledge of Basic genetics, molecular biology and genomics to understand advances in the field of Genetics.
- Stimulate research interest.

Course Contents:

1. Overview of Genetics and terminology (3 lectures + 1 tutorial)
2. Human Genome- Structure, mapping and sequencing (6 lectures + 2 tutorials)
3. Advanced Principles of Inheritance: Genetic variation and heterogeneity, Gene interaction, Polygenic inheritance, Penetrance and expressivity, Epigenetic Inheritance, Genetic Imprinting, Cytoplasmic Inheritance and Maternal Effects (9 lectures + 2 tutorials)
4. Gene Discovery approaches using Model Organisms: Mutant screens and selections, Tools for testing gene function, Mutagenesis and Transgenics (9 lectures + 3 tutorials)
5. Molecular diagnosis of human diseases: Cytogenetics and Molecular cytogenetics, Molecular genetics (6 lectures + 2 tutorials)
6. Identification of genetic component of diseases: Molecular basis of human diseases, Identifying genes for Mendelian traits, Linkage disequilibrium and haplotype analysis, Identifying genes for complex traits (6 lectures + 3 tutorials)
7. Gene therapy (3 lectures + 1 Tutorial)

Text Books (if any):

a)*Concepts of Genetics* (8th Edition) By William S. *Klug*, Michael R. *Cummings*Publisher: Prentice Hall
b)*Human Molecular Genetics* (2nd edition) by Peter Sudbery, published by Pearson/Prentice Hall
c)*Human Genetics* (2nd edition) by A. Gardener and T. Davies Publisher: Scion

Suggested References:
Human Genetics, Clinical Genetics, Nature Genetics, Nature Reviews Genetics

Immune regulation and Infection immunity (B755)

Course Title : Immune Regulation and Infection Immunity
Course Code : B755
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : NIL
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Comprehensive understanding on Immune regulation, immune deviation in bacterial, viral and parasitic infections
- Insights in to Translational aspects of Immunology such as vaccines, immunomodulatory agents in infectious as well as autoimmune diseases

Course Contents:

1. Introduction to Infectious Diseases and its worldwide scenario. (3 Lectures + 1 Tutorial)
2. Overview of Host cell immune response (3 Lectures + 1 Tutorial)
3. Outline of immuno- regulatory response and its role in infectious diseases (6 Lectures + 2 Tutorials)
4. Immuno-regulatory response to viral infection (6 Lectures + 2 Tutorials)
5. Immuno-regulatory response to bacterial infection (6 Lectures + 2 Tutorial)
6. Immuno-regulatory response to protozoan infection (6 Lectures + 2 Tutorial)
7. Immuno-regulatory response to helminth infection (6 Lectures + 2 Tutorial)
8. Immuno-therapeutic strategies targeting immuno-regulatory cells in Infectious diseases (6 Lectures + 2 Tutorials)

Suggested Books:

a) Kuby Immunology. Thomas J. Kindt, Richard A. Goldsby, Barbara Anne Osborne, Janis Kuby. W.H. Freeman, 2007
b) Infection and Immunity. Huw Davies, D. H. Davies. Taylor & Francis, 1999

<u>Suggested Journals</u>:

Infection Immunity, Journal of Experimental Medicine, Journal of Infectious Diseases, Immunology Immunotherapy, Nature Medicine, Nature Immunology, Journal of Immunology, Immunity, etc.

Macromolecular Crystallography (B756)

Course Title : **Macromolecular Crystallography**
Course Code : **B756**
Credits : **6**
Course Category : **Elective**
Course Prerequisite : **Nil**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:
Understand theory behind the X-ray diffraction to structure determination. Data collection strategy, processing, interpretation of data statistics, structure solution methods, refinement methods, interpretation of electron density map.
Course Contents (with both Lectures + Tutorials marked:

Introduction to X-ray crystallography, highlights from 54 years of macromolecular crystallography, future directions [1]
Basics of crystals, symmetry and crystal growth: Crystals, Crystal Systems, Crystal Lattice, Symmetry Elements, Point groups, Space groups, Unit cells, asymmetric units, Matrix representation of Symmetry, physical and energetic principles, Strategies and approaches for growing crystals (protein, DNA) [4 lectures + 2 tutorial]
X-ray sources and detectors: Sealed Tube, Rotating Anode, Synchrotron, Point detector, Area detectors, [3 lectures + 1 tutorial]
Theory of X-ray diffraction: Scattering by an Atom, Diffraction from a Crystal: one dimensional, two-dimensional, and three-dimensional array of atoms, Structure Factor, Reciprocal Lattice, Bragg's law, Ewald Sphere, Resolution [6 lectures + tutorial 2]
Theory of Structure factor, Fourier Syntheses and Electron density: The structure factor in exponential, and vector forms, Temperature factor, Fourier series, Fourier transform, Fourier synthesis, electron density equation, Fridel's law, Anomalous scattering [6 lectures + 2 tutorial]
Data collection: Rotation and oscillation theory, Diffractometer theory, Goniometer, Data collection Strategy, Partial and fully recorded reflections, Wide and fine slicing, Blind region, Total range of data collection, interpretation of diffraction images, Cryo data, Single/Multiple wavelength anomalous dispersion data collection [6, lectures + 2 tutorial]
Data Indexing, integration, scaling (Data reduction), and statistics: Indexing,Integration, Theory of Lorentz and Polarization corrections, Scaling, R-factors, I/sigma (I), completeness, X-ray data quality indicators, Space Group determination [6, lectures + 2 tutorial]
Electron density maps, Refinement and Model building: Difference Fourier map, locating heavy atoms, and anomalous scatter, locating water, ligand molecules, Refinement at atomic resolution: Refinement by Fourier syntheses, Series termination, Locating Hydrogen atoms, Optimization methods, Least-square refinement, full matrix solution,

Maximum likelihood, Target function for refinement, Bulk solvent, A prior knowledge, Restrains and Constrains, Non-crystallographic symmetry, Cross-validation, R-factors (Rwork & Rfree) Density modification, Good practice for refinement [10 lectures + 4 tutorial]

Text Books (if any):

X-ray structure determination, a practical guide edited by G. H. Stout and L. H. Jensen ISBN-10: 0471607118
Internal tables for crystallography Vol. F Crystallography of biological macromolecules
Internal tables for crystallography Vol. A Space Group Symmetry
Crystallization of Biological Macromolecules by Alexander MacPherson ISBN-13: 978-0879695279
An introduction to X-ray Crystallography M.M. Woolfson
Biomolecular Crystallography by Bernard Rupp ISBN-13: 978-0815340812
Internal tables for crystallography Vol. F Crystallography of biological macromolecules
Original research articles and reviews for each topic will be provided in the classes
Fundamentals of crystallography" by Giacovazzo,

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Quantitative Biology (B757)

Course Title : Quantitative Biology
Course Code : B757
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : Nil
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Introducing the concepts of mathematics in biology
- Understanding the quantitative aspects of biology
- How is statistics and mathematics required and applied in the field of biology
- Understanding how mathematical models of biology are developed
- Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of quantitative biology
- Understanding quantitative biology to do new and more insightful biology

Course Contents:

1. Recent Trends in Biology and Health Research (3 Lectures + 1 Tutorial)
    a. Modern tools of health research
    b. Existing and emerging health and biological problems
2. Modern Biotechnology (6 Lectures + 2 Tutorials)
    a. Recombinant technology and genetic engineering
    b. Application of biotechnology
3. Integrative and Systems Biology (10 Lectures + 2Tutorials)
    a. Comparative understanding of systems and integrative biology
    b. Concepts and high-throughput techniques of systems Biology
    c. Application of and advances in systems biology
4. Quantitative and Non-linear Biology (10 Lectures + 2Tutorials)
    a. Mathematical modelling and applications in Biology
    b. Lotka-Volterra Model
    c. B-Z reaction, population genetics
5. Statistics-Introduction (3 Lectures + 1 Tutorial)
    a. Simple and effect statistics
    b. Correlation and distribution
6. Univariate Analysis (6 Lectures + 2 Tutorials)
    a. Parametric and non-parametric analysis
    b. t-test, ANOVA, MANOVA
7. Multivariate Analysis (4 Lectures + 2 Tutorials)

    a. Classification and grouping
    b. Clustering, PCA, LDA, DCA
8. Sample size and power of calculation (3 Lectures + 1 Tutorial)

Recommended Books:-

a) Class notes, handouts

b) Systems Biology: A Textbook, Edda Klipp (Author), Wolfram Liebermeister (Author), Christoph Wierling (Author), Axel Kowald (Author), Hans Lehrach (Author), Ralf Herwig (Author)

c) Systems Biology: Properties of Reconstructed Networks by Bernhard O. Palsson, University of California, San Diego; ISBN: 9780521859035; DOI: 10.2277/0521859034

d) Statistics at the Bench: A Step-by-Step Handbook for Biologists by Martina Bremer

e) Nonlinear dynamics and chaos:with applications to physics, biology, chemistry, and engineering; Steven Henry Strogatz

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor

Ion Channels (B758)

Course Title : **Ion channels**
Course Code : **B758**
Credits : **6**
Course Category : **Elective**
Course Prerequisite : **Nil**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:
* Understanding the principles governing ion channel functions
* Biochemcial, biophysical, genetical basis of ion channel and its response
* Key concepts in maintenance of ion channel structure, function and ionic homeostasis of the cell
* Importance of ion channels in health and disease, pharmacology and applications
* Advanced knowledge of details of microscopy
* Bridging the gap between theory and research methodology

Course Contents (with both Lectures + Tutorials marked:

1. Introduction to different ion channels (3 Lectures +1 Tutorial)
(Difference between ion channels with pumps and carriers, ion channels in prokaryotes, Fungus, animal and plant systems, selective and non-selective ion channels)

2. Expression of different ion channels in different systems. (3 Lectures +1 Tutorial)
(Why channel expression are specific in certain tissues, Examples: neurons, sperm, bones, keratinocytes, immune cells, retina, pancreas, cardiac muscle, other specific tissues, Pharmacological advantages/disadvantages of expression, useful systems to study ion channels)

3. Importance of ion channels in evolution (3 Lectures +1 Tutorial)
(Evolution of different structural parts such as transmembrane regions, cytosolic domains, loop regions, ligand binding regions, voltage-sensor regions, selection pressure on the ion channels, ion channels and toxins: Pray predator relationship, ion channels and environmental cues, ion channels in reproduction)

4. Structural and functional uniqueness of ion channels (6 Lectures +2 Tutorials)
(Q10 values, thermodynamic properties behind channel opening and closing, conformational changes, ionic filter, voltage gating, ligand gating, voltage sensor, examples of high-resolution ion channel structures)

5. Organization in membranous environment, effect of lipid bilayer and specific lipids on ionic functions (3 Lectures +1 Tutorial)
(Need of specific lipid microenvironments for proper channel functions)

6. Different types of ion channels (6 Lectures +2 Tutorials)
(Different anion and cation channels, basics of Na+, K+, Cl-, Ca^{2+}, transport of other heavy metals)

7. Heteromeric and homomeric ion channels (3 Lectures +1 Tutorials)
(Organization of different polypeptides)

8. How natural and synthetic activators and inhibitors modulate ion channels. (3 Lectures + 1 Tutorials)
(Importance of different metabolites, Chemistry and pharmacology of different activators and inhibitors, effect on metabolism)

9. Measuring ionic conductivity by electrophysiology and imaging (3 Lectures + 1 Tutorial)
(Electrophysiological parameters and methods to analyze channel function, different types of channel recording, Cell biological parameters and methods to analyze channel function, metal imaging and different sensors)

10. Trafficking of ion channels (3 Lectures + 1 Tutorial)
(Different modes of trafficking of ion channels to ER to Golgi, Golgi to plasma membrane, to Lysosomes, Other organelles, prerequisites for such trafficking)

11. Channelopathy and human diseases, potential remedy (6 Lectures + 2 Tutorials)
(Genetic variations in ion channel sequences, information from recent genome sequencing data sets, penetrance effect of mutations)

Text Books (if any): Principles of biochemistry, Channels journal, other journals, distributed hand outs, notes, specific reviews and papers.

Suggested References: Important research articles and reviews as suggested in the class by the instructor

Concepts in Mechanobiology (B759)

Course Title : **Concepts in Mechanobiology**
Course Code : **B759**
Credits : **6 Credits**
Course Category : **Elective**
Course Prerequisites : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Outcome of the Course:

- Comprehend the concept that cells are complex micron-sized machines/ nano-machines.
- Understanding of the mechanical behavior of cell and tissues and the biological responses of these biological systems to mechanical stimuli.
- Gain knowledge on how cells generate and sustain mechanical forces within their environment, as part of their normal physiology.
- Ability to visualize that cells are active materials that can detect mechanical stimulation by the activation of mechanosensitive signaling pathways, and respond to physical cues through cytoskeletal re-organization and force generation
- Competence in reading and interpretation of primary literature in the area of mechanobiology and address research questions relating to cell processes using mechanobiological approaches.
- Enable students of disciplines other than biology to understand how principles of mechanics and engineering can be applied to biological systems and problems.

Course Contents:

Curriculum: (3 lectures [L] + 1 tutorial [T] per week)

Introduction
Mechanical framework for understanding biological systems
Cell mechanics in basic cellular and pathological processes.
[1 lecture]

Cell architecture
Cytoskeletal structure and dynamics
[2 lectures]
[Total = 3 lectures + 1 tutorial]

Cell mechanics
Basics of Mechanics

Viscoelasticity / basic rheology

[3 lectures + 1 tutorial]

Mechanics of cell membrane
Mechanics of cellular polymers
Controlling Cell and nuclear Morphology

[3 lectures + 1 tutorial]

Polymers Networks
Molecular motors
Tensegrity

[3 lectures + 1 tutorial]

Foams
Soft Glassy Material
Biphasic models of cells

[3 lectures + 1 tutorial]

[Total = 12 lectures + 4 tutorials]

Mechanosensing and Mechanotransduction
Mechanical Signals
Mechanosensing organelles and structures

[3 lectures + 1 tutorial]

Mechanics of receptor binding
Intracellular signaling
Mechano-chemical coupling

[3 lectures + 1 tutorial]

Cellular interactions with biomaterials
Mechanical regulation of cell fate

[3 lectures + 1 tutorial]
[Total = 9 lectures + 3 tutorials]

Mechanics of cell proliferation
Cytokinesis

[2 lectures]

Cancer cells and stem cells

[2 lectures]

Apoptosis

[2 lectures]
[Total = 6 lectures + 2 tutorials]

Mechanics of cell adhesion & migration
Adhesion proteins
Cytoskeletal structures & Forces

[3 lectures + 1 tutorial]

Molecular motors
Extracellular matrix mechanics

Mechanobiology in tissue engineering - Biomimetics and Cell-like Materials
[3 lectures + 1 tutorial]
[Total = 6 lectures + 2 tutorials]

Mechanical testing of cells
instrumentation tools used for mechanical characterization of cells – Microneedles, Micropipette Aspiration, Atomic Force Microscopy, Microrheology, Magnetic Twisting Cytometry, Optical Tweezers, Traction Force Microscopy, Nanofabrication – introduce to MEMS tools, Microfluidics & Lab-on-chip concepts.
[Total = 6 lectures + 2 tutorials]

Text Books (if any):

1. Jacobs, Huang, & Kwon. Introduction to Cell Mechanics and Mechanobiology. Garland Science, ISBN-10: 0815344252
2. Boal, Mechanics of the Cell. Cambridge University Press, ISBN-10: 0521796814; ISBN-13: 9780521130691
3. Ethier and Simmons, Introduction to Biomechanics: From Cells to Organisms. Cambridge University Press, ISBN: 0521841127
4. Mofrad & Kamm, Cytoskeletal Mechanics – Models and Measurements. Cambridge University Press, ISBN-10: 0521846374
5. Bray, Cell Movements. Garland Science, ISBN-10: 0815332823; ISBN-13: 9780815332824
6. Alberts et al., Molecular Biology of the Cell. Garland Science, ISBN-10: 0815332181
7. Discher and Wang, Methods in Cell Biology 83: Cell Mechanics. Academic Press. ISBN-10: 0123705002
8. Philip Nelson, Biological Physics, Energy, Information, Life. W.H. Freeman, ISBN-10: 0716798972; ISBN-13: 978-0716798972
9. Jonathon Howard, Mechanics of Motor Proteins and the Cytoskeleton. Sinauer Associates Inc. ISBN-10: 0878933344; ISBN-13: 978-0878933341

Suggested References:

Other relevant research articles and lecture material will be made available by the instructor during the course from time to time.

Molecular errors in disease pathogenesis (B760)

Course Title : Molecular errors in disease pathogenesis
Course Code : B760
Credits : 6 Credits
Course Category : Elective
Course Prerequisites : Basic knowledge of Biochemistry, Genetics, Molecular Biology and Cell biology. Having taken some of the biology core courses of SBS will be advantageous
Contact Hours (28/42/56) : 56 (including tutorials)

Outcome of the Course:

- Understanding the concepts of molecular pathogenesis.
- Basic understanding of the common pathologies of organ systems.
- Understanding of the recent advances in molecular explanation for such pathologies.

Course Contents:

1. General introduction to concepts of molecular pathogenesis (3 Lectures + 1 Tutorial)

2. Cardiovascular system (6 Lectures + 2 Tutorials)
    - Heart failure
    - Genetic cardiac diseases
    - Cholesterol metabolism and vascular diseases
    - Sudden cardiac death
    - Gender and cardiovascular system diseases

3. Respiratory system (3 Lectures + 1 Tutorial)
    - Novel pathways in pathogenesis of asthma
    - Cell signalling in asthma
    - Chronic Obstructive Pulmonary Disease
    - Lung matrix remodelling disorders

4. Infectious diseases (3 Lectures + 1 Tutorial)
    - Anti-malarial resistance
    - General vaccine strategies
    - Vaccine development against malaria
    - HIV, SARS, Dengue pathogenesis
    - Biofilms and chronic bacterial infections
    - Quorum sensing, its pharmacological inhibition and quorum sensing as an intervention target
    - Bacterial vaccines
    - Puzzles in sepsis pathogenesis

5. Oncology (3 Lectures + 1 Tutorial)
    - Oncogenes
    - Tumour suppressors
    - Specific example cancers
    - Receptor Tyrosine kinases in cancer
    - Cellular stress and cancer
    - Integrins, Cadherins, Catenins,
    - Polarity and cancer
    - Relationship between cellular senescence and cancer
    - Cancer vaccines

6. Neurological diseases (3 Lectures + 1 Tutorial)
    - Pathogenesis of neuro-degenerative disorders
    - Ageing
    - Mitochondrial dysfunction
    - Oxidative stress and neuro-degeneration
    - Genetics of psychiatric disorders eg. Schizophrenia

7. Genetics (3Lectures + 1Tutorial)
    - Complex genetic diseases
    - Gene therapy
    - Human embryonic stem cell applications, associated issues and debates

8. Ageing and Regeneration (6 Lectures + 2 Tutorials)
    - Pathophysiology of tissue ageing
    - Cellular reprogramming
    - Regeneration of □ cells

9. Haematology (3 Lectures + 1 Tutorial)

- Genomics and proteomics of blood cells in disease
- Platelets, inflammation and atherosclerosis, thromboses
- Issues associated with cord blood banking

10. Endocrinology (3 Lectures + 1 Tutorial)
    - Diabetes mellitus pathogenesis
    - Cell biology and signalling
    - Islet transplantation
    - Gestational diabetes
    - Metabolic syndrome.

11. Musculoskeletal system (3 Lectures + 1 Tutorial)
- Osteoporosis
- Menopause and bone metabolism
- Muscle dystrophies
- Stem cells in muscle degeneration

12. Summary discussions (3 Lectures + 1 Tutorial)
- Analyses and review of future perspectives in the field of molecular pathogenesis

Text Books (if any):

a) Introduction to Molecular Medicine, by Dennis W. Ross (ISBN 0-387-95372-8)
b) Principles of Molecular Medicine, by M. S. Runge and C. Patterson
c) Robbins and Cotran Pathologic basis of disease

Suggested References:

Instructor notes, additional reading suggestions and relevant URLs will be provided to the students during the course of the classes. Instructor will be available for individual meetings when required.

Plant Developmental Biology (B761)

Course Title : **Plant Developmental Biology**
Course Code : **B761**
Credits : **6 Credits**
Course Category : **Elective**
Course Prerequisites : **Nil**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Learning molecular genetics approaches to understand plant development.
- Understanding the interaction of biotic and abiotic component is major focus.
- Designing experimental strategies understanding plant development.

Course Contents:

1. Plant Development overview (1 Lecture)
2. Hormones influencing plant organogenesis and signaling (7-8 Lectures + 5 Tutorials)
3. Light and plant development and photomorphogenesis (10 Lectures + 2 Tutorials)
4. Leaf and flower development (10 Lectures + 2 Tutorials)
5. Circadian clock and plant development (7-8 Lectures + 2 Tutorials)
6. Epigenetics, siRNA world and plant development (8 Lecture + 2 Tutorials)

Recommended Books:

a) Plant Physiology Taiz and Zeiger: 5th Ed, 2010, Sinauer Associates Inc. Publishers

b) Plant Biology by Alison M. Smith et al., 2010, Garland Science, Taylor and Francis Gp. "Research articles"

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

UPCOMING COURSES

Translational Control in Biology (B762)

Course Title	**: Translational Control in Biology**
Course Code	**: B762**
Credits	**: 6 Credits**
Course Category	**: Elective**
Course Prerequisites	**: Nil**
Contact Hours (28/42/56)	**: 56**

Outcome of the Course:

This course is design to understand the recent advancements in the fundamentals of protein translation and its control. Translation is a fundamental step in the central dogma of molecular biology. The regulation of translation is key to all basic cellular processes. Metabolic pathways, signaling, developmental decisions are tightly linked with the regulation of translation. Any defects associated with this process and its repercussion in cancer, metabolic disorders and human diseases will be covered.

Course contents:

1) Recent advances in the general translation (structure-function and genetics). (6 lectures + 2 tutorial)
2) IRES elements and control of viral translation. (3 lectures)
3) IRES elements in cellular translation control. (3 lectures + 1 tutorial)
4) Cis-acting element and trans-activing factors in translation regulation (3 lectures + 1 tutorial)
5) Role of microRNA in translation control. (3 lectures)
6) Signaling in translation. (3 lectures + 1 tutorial)
7) Role of eIF2α kinase in translational control. (3 lectures + 1 tutorial)
8) Translational control in cancer development. (3 lectures + 1 tutorial)
9) Translational control during apoptosis. (3 lectures)
10) Translational control in metabolic disorder. (3 lectures + 1 tutorial)
11) Translational control in synaptic plasticity, memory and learning. (3 lectures)
12) Translational control in development. (3 lectures)
13) mRNA localization and turnover. (3 lectures + 1 tutorial)
14) Mitochondrial translation and human diseases. (3 lectures + 1 tutorial)

Recommended reading:

1) Translational control in Biology and Medicine (Mathews, Sonenberg, Hershey, CSHL press)
2) Translational control in gene expression (Sonenberg, Hershey, Mathews, CSHL press)
3) Class notes and research articles

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor

Macroevolutionary principles and patterns (B763)

Discipline	**: Biological Sciences**
Course Level	**: Ph.D**
Course Title	**: Macroevolutionary principles and patterns**
Course Code	**: B763**
Credits	**: 6**
Course Category	**: Elective**
Course Prerequisite	**: Evolutionary Biology, Molecular Biology**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by	**: Dr. Aniruddha Datta Roy** **Assistant professor, SBS, NISER**
Alternative faculty	**: Dr. Ramanujam Srinivasan,** **Reader – F, SBS, NISER**

Outcome of the Course:

- Understanding macroevolutionary principles with detailed module on tree building
- Working on real data using the latest phylogenetic approaches
- Understanding principles of biogeography and pattern created by dispersal and vicariance events

Course Contents (with both Lectures + Tutorials marked):

1. Evolution of life on Earth (3 lectures + 1 Tutorials)
2. Geological Eras and the five mass extinction events (3 lectures + 1 Tutorials)
3. Schools of systematics (3 lectures + 1 Tutorials)
4. Species concepts (3 lectures + 2 Tutorials)
5. Patterns of change in evolution (3 lectures + 2 Tutorials)
6. Phylogenetics and tree building (7 lectures + 6 Tutorials)
7. Adaptive radiations (3 lectures + 2 Tutorials)
8. Co-evolution (2 lectures)
9. Convergent evolution (3 lectures + 1 Tutorials)
10. Applications of phylogenetics (2 lectures + 1 Tutorial)
11. Introduction to biogeography (2 lectures)
12. Biogeographical patterns (3 lectures + 2 Tutorials)

Text Books (if any):

1. Lemey, P., Salemi, M. and Vandamme, A.M. eds., 2009. *The phylogenetic handbook: a practical approach to phylogenetic analysis and hypothesis testing*. Cambridge University Press.
2. Lomolino, M.V., Riddle, B.R., Whittaker, R.J. and Brown, J.H., 2010. Biogeography (Sinauer, Sunderland, MA).
3. Reece, J.B., Urry, L.A., Cain, M.L., Wasserman, S.A., Minorsky, P.V. and Jackson, R.B., 2014. *Campbell Biology* (No. s 1309). Boston: Pearson.
4. Stearns, S.C. and Hoekstra, R.F., 2000. *Evolution, an introduction*. Oxford University Press.

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor.

END OF DOCUMENT

Harish-Chandra Research Institute

SYLLABUS FOR

Ph.D. in Mathematical Science (Program Code: MATH04)

About the Ph. D. Programme

The Ph. D. Programme in mathematics at HRI consists of a rigorous course work and projects spanning the the first three semesters, followed by research work leading to a Ph.D. degree. The students are taught basic as well as advanced courses in mathematics during this period. They also get to work on a project in which they normally continue to work towards their Ph. D. Degree. A thesis advisor will be assigned to a student, only after successful completion of the course work - which also requires passing the Oral General Comprehensive Exam (OGCE), conducted after the completion of the course work.

Course Structure

The instructional part of the doctoral program consists of pedagogical lectures followed by a project during the span of first three semesters. There will be seven core courses in the first year of the programme, along with two seminar courses.

Semester I	Semester II
Algebra I	Algebra II
Analysis I	Analysis II
Topology I	Topology II
Differentiable Manifolds	Project I

In the third semseter, the student has to take a project course in one of the advanced topics given as electives below. The special topic will be chosen by the instructor and the text books will be announced well in advance.

Electives: A student can choose one from:

- Topics in Algebra
- Topics in Analysis
- Topics in Number Theory

- Topics in Algebraic Geometry
- Topics in Differential Geometry

  Credits information: Core Course: 6 credits, Seminar Course: 4 credits, Project course: 12 credits. Total 60 credits course work, in three semsters.

Curriculum and detailed course content

Semester I

08MATH04-001-C Algebra I

Group Theory: the JordanHolder Theorem; solvable groups; symmetric and alternating groups; nilpotent groups; groups acting on sets; the Sylow Theorems; free groups.

Rings and ModulesNoetherian and Artinian conditions; the Hilbert Basis Theorem; principal ideal domains; unique factorization domains; inductive and projective limits of rings and modules; bilinear maps and forms; the tensor product.

Field Theory: the Steinitz Theorem on algebraic closures; algebraic extensions; finite fields; Galois theory and applications.

Textbooks:

1. D. S. Dummit, and R. M. Foote, Abstract algebra, Third edition. John Wiley & Sons, Inc., Hoboken, NJ, 2004.
2. N. Jacobson, Basic algebra I, Second edition, W. H. Freeman and Company, New York, 1985.
3. N. Jacobson, Basic algebra II, Second edition, W. H. Freeman and Company, New York, 1989.
4. S. Lang, Algebra, Revised third edition, Graduate Texts in Mathematics, 211. Springer-Verlag, New York, 2002.

08MATH04-002-C Analysis I

Calculus: Summary of calculus of several real variables; the Stone-Weierstrass Theorem; Ascoli's Theorem.

Measure theory: Measure spaces; convergence theorems; product measure and Fubini's Theorem; Borel measures on locally compact spaces, and the Riesz Representation Theorem; the Lebesgue measure; regularity properties of Borel measures; complex measures, differentiation and decomposition of measures; the Radon-Nikodym Theorem.

Functional analysis: Topological vector spaces; Banach spaces; Hilbert spaces; the Hahn-Banach Theorem; the Open Mapping Theorem; The Banach-Steinhaus Theorem; bounded linear maps; linear functionals and dual spaces; L^p spaces; Hölder's inequality, Minkowski's inequality.

Textbooks:

1. S. Lang, Real and functional analysis, Third edition, Graduate Texts in Mathe- matics, 142. Springer-Verlag, New York, 1993.
2. H. L. Royden, Real analysis, Third edition, Macmillan Publishing Company, New York, 1988.
3. W. Rudin, Real and complex analysis, Third edition, McGraw-Hill Book Co., New York, 1987.
4. W. Rudin, Functional analysis, Second edition, International Series in Pure and Applied Mathematics, McGraw-Hill, Inc., New York, 1991.

08MATH04-003-C Topology I

Topological spaces: Topologies; bases; continuous maps; subspaces; quotient spaces; products; connectedness and compactness; proper maps.

Convergence: Nets; filters; limits of nets and filters; the relations between convergence and countability and separation axioms; relations with compactness and proper maps.

Topological groups: Topological groups; uniform structures; products of compact spaces; compactifications; actions; orbit spaces; proper actions; homogeneous spaces.

Metrisability: metrisability and paracompactness; complete metric spaces; function spaces.

Inductive and projective limits: Inductive and projective limits of topological spaces.

Homotopy theory: Homotopy; retraction and deformation; suspension; mapping cylinder; fundamental group; the Van Kampen Theorem; étale spaces; covering spaces; homotopy lifting property; relations with the fundamental group; lifting of maps; universal coverings; automorphisms of a covering; Galois coverings; the basic definitions regarding higher homotopy groups.

Textbooks:

1. N. Bourbaki, General topology, Chapters 1–4, Translated from the French. Reprint of the 1989 English translation. Elements of Mathematics (Berlin). Springer- Verlag, Berlin, 1998.
2. A. Hatcher, Algebraic topology, Cambridge University Press, Cambridge, 2002.
3. W. S. Massey, Algebraic topology: an introduction, Reprint of the 1967 edition. Graduate Texts in Mathematics, Vol. 56. Springer-Verlag, New York-Heidelberg, 1977.
4. E. H. Spanier, Algebraic topology, Corrected reprint of the 1966 original. Springer-Verlag, New York, 1995.

08MATH04-001-S Seminar Course I

A student can choose a topic of his interest, in consultation with a mathematics faculty member.

Semester II

08MATH04-004-C Algebra II

Multilinear algebra: tensor, symmetric, and exterior algebras; right ex- actness of tensoring, and flat and faithfully flat modules; left exactness of Hom, and injective and projective modules.

Commutative algebra: rings and modules of fractions; local rings; integral extensions; transcendence degree; Noether's Normalization Theorem; Hilbert's Nullstellensatz; discrete valuation rings; Dedekind domains; primary decomposition.

Linear algebra: modules over principal ideal domains; the minimal polynomial of an endomorphism; the Jordan canonical form; the characteristic polynomial of an endomorphism; the Cayley-Hamilton Theorem.

Textbooks:

1. D. S. Dummit, and R. M. Foote, Abstract algebra, Third edition. John Wiley & Sons, Inc., Hoboken, NJ, 2004.
2. N. Jacobson, Basic algebra I, Second edition, W. H. Freeman and Company, New York, 1985.
3. N. Jacobson, Basic algebra II, Second edition, W. H. Freeman and Company, New York, 1989.
4. S. Lang, Algebra, Revised third edition, Graduate Texts in Mathematics, 211. Springer-Verlag, New York, 2002.

08MATH04-005-C Analysis II

Distributions: The spaces D(U) and E(U) for an open subset U of R^n spacesn; basic operations on distributions; the support of a distribution; convolution; approximate identities; the Fourier transform on $L^p (R^n)$; the Schwartz space on R^n; the Inversion Theorem; Plancherel's Theorem; tempered distributions.

Functional analysis: Banach algebras; the Gelfand-Naimark Theorem; bounded op- erators on a Hilbert space; the Spectral Theorem for bounded normal operators ona Hilbert space; compact operators; Fredholm operators and the index.

Complex analysis: Basic properties of holomorphic functions; relations with the fundamental group and covering spaces; the Open Mapping Theorem; the Maximum Modulus Theorem; zeros of holomorphic functions; classification of singularities; meromorphic functions; the Weierstrass Factorization Theorem; brief account of the Riemann Mapping Theorem; the Little Picard Theorem.

Textbooks:

1. S. Lang, Real and functional analysis, Third edition, Graduate Texts in Mathematics, 142. Springer-Verlag, New York, 1993.
2. H. L. Royden, Real analysis, Third edition, Macmillan Publishing Company, New York, 1988.

3. W. Rudin, Real and complex analysis, Third edition, McGraw-Hill Book Co., New York, 1987
4. W. Rudin, Functional analysis, Second edition, International Series in Pure and Applied Mathematics, McGraw-Hill, Inc., New York, 1991

08MATH04-006-C Topology II

Simplicial topology: Simplicial complexes; triangulations; polyhedra; barycentric subdivision; the Simplicial Approximation Theorem with applications.

Homology: simplicial homology; singular homology; the Mayer-Vietoris sequence; The Jordan-Brouwer Separation Theorem; the Universal Coefficient Theorem; the Kunneth Formula; CW complexes; cellular homology and computations for projective spaces; the Lefschetz Fixed Point Theorem.

Cohomology: singular cohomology; the Universal Coefficient Theorem; the Kunneth Formula; cup and cap products; Poincare duality for a topological manifold.

Textbooks:

1. G. E. Bredon, Topology and geometry, Corrected third printing of the 1993 original, Graduate Texts in Mathematics, 139, Springer-Verlag, New York, 1997.
2. M. J. Greenberg, and J. R. Harper, Algebraic topology, A first course, Mathematics Lecture Note Series, 58. Benjamin/Cummings Publishing Co., Inc., Advanced Book Program, Reading, Mass., 1981.
3. A. Hatcher, Algebraic topology, Cambridge University Press, Cambridge, 2002.
4. E. H. Spanier, Algebraic topology, Corrected reprint of the 1966 original. Springer-Verlag, New York, 1995.

08MATH04-007-C Differential manifolds

Differentiable manifolds: basic notions; the effects of second countability and Hausdorffness; tangent and cotangent spaces; submanifolds; conse- quences of the Inverse Function Theorem; vector fields and their flows; the Frobenius Theorem; Sard's theorem.

Differential forms: recapitulation of multilinear algebra; tensors; differential forms; the de Rham complex and its behaviour under differentiable maps; the Lie derivative; differential ideals.

Lie groups: Lie groups; Lie algebras; homomorphisms; Lie subgroups; coverings of Lie groups; the exponential map; closed subgroups; the adjoint representation; homogeneous manifolds.

Integration on manifolds: orientation; the integral of differential forms on differentiable singular chains; integration of differential forms of top degree on an oriented differen- tiable manifold; the theorems of Stokes; the volume form on an oriented Riemannian manifold; the divergence theorem; integration on a Lie group.

de Rham cohomology: definition; real differentiable singular cohomology; statement of the de Rham theorem; the Poincar´e lemma.

Textbooks:

1. I. Madsen, and J. Tornehave, From calculus to cohomology: de Rham cohomology and characteristic classes, Cambridge University Press, Cambridge, 1997.
2. F. W. Warner, Foundations of differentiable manifolds and Lie groups, Corrected reprint of the 1971 edition, Graduate Texts in Mathematics, 94, Springer-Verlag, New York-Berlin, 1983.

08MATH04-002-S Seminar Course II

Student can choose a topic of interest in consultation with an HRI mathematics faculty member.

Semester III

By this time a student should have decided the area of specialisation. Based on the interest, a student can take a project in one of the following Topics: This may also involve lectures given by the prospective thesis advisor.

08MATH04-008-C Algebraic number theory

p-adic numbers, p-adic valuations, absolute values, completions, local fields, henselian fields, extensions of valuations, ramification, higher ramification groups.

Galoisian extensions, projective and inductive limits, abstract class field theory, the Herbrand quotient.

The local reciprocity law, the norm residue symbol, formal groups, cyclotomic extensions, compatibility with the ramification filtration.

Ideles and idele classes, ideles in extensions, global class field theory, power reciprocity laws.

Textbooks:

1. A. Fröhlich, and M. J. Taylor, Algebraic number theory, Cambridge Studies in Advanced Mathematics, 27, Cambridge University Press, Cambridge, 1993.
2. H. Hasse, Number theory, Translated from the third (1969) German edition, Reprint of the 1980 English edition, Classics in Mathematics, Springer-Verlag, Berlin, 2002.
3. J. Neukirch, Algebraic number theory, Translated from the 1992 German original, Grundlehren der Mathematischen Wissenschaften, 322. Springer-Verlag, Berlin, 1999
4. A. Weil, Basic number theory, Reprint of the second (1973) edition, Classics in Mathematics, Springer-Verlag, Berlin, 1995.

08MATH04-009-C Local fields

Discrete valuation rings and Dedekind domains, completions, discriminant and different, ramification groups, the norm, Artin representation, group cohomology, Galois cohomology, class formations, Brauer groups, local class field theory.

Textbooks:

1. J. W. S. Cassels, Local fields, London Mathematical Society Student Texts, 3, Cambridge University Press, Cambridge, 1986.
2. I. B. Fesenko, and S. V. Vostokov, Local fields and their extensions, Second edition, Translations of Mathematical Monographs, 121, American Mathematical Society, Providence, RI, 2002.
3. K. Iwasawa, Local class field theory, Oxford Science Publications, Oxford Mathematical Monographs, The Clarendon Press, Oxford University Press, New York, 1986.
4. J. P. Serre, Local fields. Translated from the French original, Graduate Texts in Mathematics, 67, Springer-Verlag, New York-Berlin, 1979.

08MATH04-010-C Fourier analysis

L^p spaces spaces, basic inequalities including Hö̇lder's, Chebyshev, and Minkowski, inequalities for integrals, weak Lp spaces, the Riesz-Thorin and Marcinkiewicz Interpolation Theorems.

Convolution, Young's inequality, the generalized inequality of Young, approximations to the identity, the Fourier transform, Hausdorf-Young inequality, the Riemann Lebesgue Lemma,

the Fourier Inversion Theorem, the Plancherel Theorem, summability theo- rems, including those of Cesaro and Fejer, Fourier inversion on the torus, the Riemann localisation principle.

Distributions, Sobolev spaces, Sobolev Embedding Theorem, Rellich's theorem, applications to basic linear PDE.

Textbooks:

1. G. B. Folland, Real analysis. Modern techniques and their applications, Second edition, Pure and Applied Mathematics (New York), A Wiley-Interscience Publication, John Wiley & Sons, Inc., New York, 1999.
2. W. Rudin, Functional analysis, Second edition, International Series in Pure and Applied Mathematics, McGraw-Hill, Inc., New York, 1991.

08MATH04-011-C Harmonic analysis

Maximal Function, the Riesz-Thorin Interpolation Theorem. Singular integrals, the Calderon-Zygmund Decomposition, Singular integral operators which commute with dilations, vector-valued analogues, Riesz transforms, Poisson in- tegrals, approximate identities, spherical harmonics.

The Littlewood-Paley g-function, multipliers, dyadic decomposition, the Hormander- Mihilin Multiplier Theorem, the Marcinkiewicz Multiplier Theorem.

Textbooks:

1. J. Duoandikoetxea, Fourier analysis, Translated and revised from the 1995 Spanish original, Graduate Studies in Mathematics, 29, American Mathematical Society, Providence, RI, 2001.
2. E. M. Stein, Singular integrals and differentiability properties of functions, Prince- ton Mathematical Series, No. 30, Princeton University Press, Princeton, N.J., 1970.

08MATH04-012-C Introduction to number theory

Divisibility, congruence, the Fundamental Theo- rem of Arithmetic, the Chinese Remainder Theorem.

Elementary proofs of the infinitude of primes in certain arithmetic progressions, the quadratic reciprocity law.

The Betrand postulate, the Euler and Abel summation formulas and applications, preparation for the Prime Number Theorem.

Combinatorial sieves including the Brun sieve and the Turan sieve, and their applications.

Rational approximations, the Dirichlet Theorem, the Liouviile Theorem, Siegel's Lemma, and their applications

Gaussian integers, sums of squares.

Textbooks:

1. D. M. Burton, Elementary number theory, Second edition, W. C. Brown Publish- ers, Dubuque, IA, 1989.
2. K. Chandrasekharan, Introduction to analytic number theory, Die Grundlehren der mathematischen Wissenschaften, Band 148, Springer-Verlag New York Inc., New York, 1968.
3. A. C. Cojocaru, and M. R. Murty, An introduction to sieve methods and their ap- plications, London Mathematical Society Student Texts, 66, Cambridge University Press, Cambridge, 2006.
4. G. H. Hardy, and E. M. Wright, An introduction to the theory of numbers, Sixth revised edition, Oxford University Press, Oxford, 2008.

08MATH04-013-C Analytic number theory

Arithmetical functions, Euler, Abel Summation formula and applications to summatory functions.

The Riemann Zeta function, and Dirichlet L-functions.

The Prime Number Theorem, and Dirichlet's Prime Number Theorem.

Sieve methods (Brun, Selberg, and Large), and their applications.

Fourier techniques and applications in number theory.

Textbooks:

1. K. Chandrasekharan, Introduction to analytic number theory, Die Grundlehren der mathematischen Wissenschaften, Band 148, Springer-Verlag New York Inc., New York, 1968
2. H. Iwaniec, and E. Kowalski, Analytic number theory, American Mathematical Society Colloquium Publications, 53, American Mathematical Society, Providence, RI, 2004.
3. H. Iwaniec, and E. Kowalski, Analytic number theory, American Mathematical Society Colloquium Publications, 53, American Mathematical Society, Providence, RI, 2004.

08MATH04-014-C Lie algebras

Linear Lie algebras, Lie algebras of derivations, homomorphisms of Lie algebras, representations of Lie algebras, solvable and nilpotent Lie algebras, Engel's Theorem, Lie's Theorem, the Jordan-Chevalley decomposition.

Cartan's criterion, the Killing form, criterion for semi-simplicity, inner derivations, the abstract Jordan decomposition, modules, the Casimir element, Weyl's Theorem, preservation of Jordan decomposition, Representations of sl(2, F), maximal toral subalgebras, and roots.

Orthogonality, integrality and rationality properties of roots, root systems, bases, Weyl chambers, the Weyl group, irreducible root systems, the Cartan matrix.

Coxeter graphs, Dynkin diagrams, the Classification Theorem, construction of root systems & automorphisms, the theory of weights, dominant weights, the Isomorphism Theorem, Cartan subalgebras, the universal enveloping algebra, the Poincare-Birkhoff- Witt Theorem.

Textbooks:

1. R. W. Carter, Lie algebras of finite and affine type, Cambridge Studies in Advanced Mathematics, 96, Cambridge University Press, Cambridge, 2005.
2. J. E. Humphreys, Introduction to Lie algebras and representation theory, Second printing, revised, Graduate Texts in Mathematics, 9, Springer-Verlag, New York-Berlin, 1978.
3. A. W. Knapp, Lie groups beyond an introduction, Second edition, Progress in Mathematics, 140, Birkh ̈auser Boston, Inc., Boston, MA, 2002.

08MATH04-015-C Representations of finite groups

Representations, irreducible and indecomposable representations, class functions, orthogonality relations for characters, character tables, Schur's lemma, unitary representations, duals and tensor products of representations, regular representations, canonical decompositions, examples, induced representations, Mackey's criterion, Frobenius reciprocity, group algebras, Maschke's theorem, applica- tions of the representation theory of finite groups. Artin's theorem, Brauer's theorem and applications.

Textbooks:

1. W. Fulton, and J. Harris, Representation theory. A first course, Graduate Texts in Mathematics, 129, Readings in Mathematics, Springer-Verlag, New York, 1991.
2. J-P. Serre, Linear representations of finite groups, Translated from the second French edition, Graduate Texts in Mathematics, 42, Springer-Verlag, New York- Heidelberg, 1977.

08MATH04-016-C Commutative algebra

Modules and tensor products, prime ideals, the Zariski topol- ogy, rings and modules of fractions, flatness, valuation theory, integral extensions, dis- crete valuation rings, Dedekind domains, Artinian and Noetherian rings and modules, the Hilbert basis theorem, primary decomposition, Noether normalization, Hilbert's Nullstellensatz, completions, the Krull dimension

Textbooks:

1. S. Bosch, Algebraic geometry and commutative algebra, Universitext, Springer, London, 2013.
2. D. Eisenbud, Commutative algebra. With a view toward algebraic geometry, Graduate Texts in Mathematics, 150, Springer-Verlag, New York, 1995.

08MATH04-017-C Algebraic varieties

Spaces with sheaves of functions, affine algebraic varieties over an algebraically closed field, the category of algebraic varieties, subvarieties, products, projective varieties, separation, normality, dimension, rational maps, tangent spaces, smoothness, completeness, finite morphisms, constructible sets, divisors, curves, and the Riemann-Roch theorem.

Textbooks:

1. G. R. Kempf, Algebraic varieties, London Mathematical Society Lecture Note Series, 172, Cambridge University Press, Cambridge, 19
2. D. Eisenbud, Commutative algebra. With a view toward algebraic geometry, Graduate Texts in Mathematics, 150, Springer-Verlag, New York, 1995.
3. J. S. Milne, Algebraic geometry, http://www.jmilne.org/math/ .

08MATH04-001-E Other elective courses

Apart from the list above, there may be elective courses in special Topics in Algebra/Analysis/Topology/ Algebraic Geometry/Differential Geometry based on the interest of students. If a faculty member opts to give such a course, the syllabus and text books will be announced well in advance.

IMSc

SYLLABUS FOR

Ph.D. in MATHEMATICAL SCIENCES
(Program Code: MATH04)

COURSEWORK AND SYLLABI FOR THE PH.D. AND INTEGRATED PH.D. PROGRAMS IN MATHEMATICS AT IMSC

All courses in mathematics carry 8 credits except for the seminar course which carries 4 credits and the research methodology course which is a pass/fail course with no credits earned.

The Ph.D. program requires a total of 9 courses including the seminar course and the research methodology course (for a total of 60 credits).

The I.Ph.D. program requires 13 courses including the seminar course and the research methodology course along with a 28 credit master's thesis (for a total of 120 credits).

The courses are chosen from among the courses listed below along with other courses offered from time to time either at IMSc or at other institutes with which HBNI has an MoU such as CMI. Topics courses in mathematics may be repeated for credit and will be shown on the transcript with suffixes such as I, II, III etc.

10MATH04-001-C ALgEBrA I - 8 crEDiTs

Group theory

- Group actions: Orbits, stabilisers, transitivity
- Lagrange, Cauchy, Sylow theorems in the language of group actions
- Direct and semidirect products
- symmetric and alternating groups

Matrices, determinants and linear maps

- Linear maps and matrices, dual = transpose
- determinants
- Equality of row, column and determinantal rank over a commutative ring

Representations of a single endomorphism

- Minimal and characteristic polynomials, eigenvalues and eigenvectors
- Rational and Jordan canonical forms
- S-N decomposition

Bilinear forms and spectral theorems

- Preliminaries and quadratic maps
- Symmetric forms, orthogonal basis, Sylvester's theorem
- Hermitian forms, polarization, Cauchy-Schwarz inequality
- Spectral theorems, polar decomposition

Basic category theory

- Categories and functors
- Universal properties
- Sums, products and limits

Rings and modules over a PID

- Finitely generated abelian groups
- PID $\Rightarrow$ UFD, R UFD $\Rightarrow$ $R[X]$ UFD, Gauss' lemma

- Irreducibility criteria
- Modules over a PID

Tensor products

- Of vector spaces, modules over a ring, basic properties
- connection with Hom, of algebras
- tensor, symmetric and exterior algebras and connection with the determinant

10MATH04-002-C ALGEBRA II - 8 CREDITS

Group theory

- simple, solvable and nilpotent groups
- Jordan-Holder theorem

Galois theory

- Finite extensions, algebraic extensions, algebraic closure
- Splitting fields and normal extensions
- separable extensions
- Finite fields
- Inseparable extensions
- Galois extensions
- Examples and applications
- Cyclotomic fields
- Independence of characters, norm and trace
- Cyclic extensions
- Solvable and radical extensions

Instructor's choice from among the following suggested topics or others.

Semisimplicity

- Schur's lemma and semisimple modules
- Jacobson density theorem, DCT
- Structure of semisimple rings
- Structure of simple rings

Representations of ftnite groups

- Maschke's theorem
- Characters
- Class functions
- Orthogonality relations

Commutative algebra and Dedekind domains

- Prime, maximal ideals, Zariski topology, CRT
- Localization and its properties
- Integral extensions
- Dedekind domains - characterizations
- Unique factorisation - failure and restoration

10MATH04-003-C ANALysis I - 8 crEDiTs

Measure Theory

- Measurable spaces, Caratheodory's theorem and construction of measures, Lebesgue measure, Riesz representation theorem for compact metric spaces
- Measurable mappings, various convergence concepts like almost sure, convergence in measure.
- Integration, MCT, DCT.
- Product measures, Fubini's theorem.
- Radon-Nikodym theorem, Lebesgue decomposition theorem.
- L^p spaces: Basic theory, Holder's inequality, Minkowsky inequality, completeness, their duality.
- (*) Analysis on R^n; convolutions; approximate identity; approximation theorems; Fourier transform; Fourier inversion formula; Plancherel theorem.

Note: Topics marked with asterisk are optional.

10MATH04-004-C ANALysis II - 8 crEDiTs

Elementary functional analysis

- Topological vector spaces; Banach spaces; Hilbert spaces.
- bounded linear transformation;linear functionals and dual spaces.
- Hahn Banach theorem and it's geometric meaning.
- Category theoem and it's applications like open mapping theorem, uniform boundedness principle, closed graph theorem.
- Weak and Weak-* topologies, Banach-Alaoglu's theorem.

Instructor's choice from among the following suggested topics or others.

Distribution Theory

- The spaces $D(\Omega)$, $E(\Omega)$, for Ω open in IR^n.
- $S(\mathsf{R}^n)$ and their duals, convolution, Fourier transform.
- Paley-Wiener theorems; fundamental solutions of constant coefficient partial differential operators.

Banach Algebras and Spectral Theory

- Banach algebras, spectrum of a Banach algebra element, Holomorphic functional calculus, Gelfand theory of commutative Banach algebras.
- Hilbert space operators, C*-algebras of operators, commutative C*-algebras.
- Spectral theorem for bounded self-adjoint and normal operators. formulation).
- Spectral theorem for compact operators,(*) application to Peter-Weyl theorem.

Note: Topics marked with asterisk are optional.

10MATH04-005-C Topology I - 8 credits

Point-set topology

- Quotient topology including the construction of standard topological spaces such as surfaces and real and complex projective spaces as quotient spaces
- The notion of attachment of a cell to a topological space
- Group actions and orbit spaces
- Topologies on function spaces
- Baire category theorem
- Arzelà-Ascoli theorem

Fundamental groups and covering spaces

- Fundamental groups, covering spaces and their relationship
- Free groups, free products of groups
- Seifert-van Kampen theorem - examples and applications

Introduction to homology

- Definition of homology groups
- Homotopy invariance of homology groups
- The first homology group as the abelianization of the fundamental group
- Review of homological algebra necessary to introduce the Mayer-Vietoris sequence
- Mayer-Vietoris sequence and its applications in computing homology groups of surfaces, complex projective spaces, real projective spaces etc.

Applications of fundamental groups and homology groups

Instructors choice among the following topics or other topics at this level.

- Jordan curve theorem
- Winding number of a closed curve
- Brouwer's fixed point theorem
- Fundamental theorem of algebra
- Nielsen-Schreier theorem

10MATH04-006-C Topology II - 8 credits

Instructors choice among the following topics. It is suggested that one topic from the first two and basic notions of differential topology be covered in addition to some of the advanced topics.

Homology theory

- Quick review of homology theory
- Relative homology and the associated long exact sequence
- Excision theorem and its applications
- Characterisation of homology theory by the Eilenberg-Steenrod axioms
- Homology with coefficients

Cohomology theory and introduction to homotopy groups

- Basic notions of cohomology
- Universal coefficient theorem
- Künneth formula
- Cup product and the cohomology ring, Borsuk-Ulam theorem

Basic notions of differential topology

- Differentiable manifolds, tangent bundle, vector fields, flows
- Differential forms and de Rham cohomology
- Integration on manifolds
- Stokes theorem
- Poincaré duality using differential forms.

Advanced topics

- Higher homotopy groups and the Hurewicz theorem
- H-spaces, suspensions, fibre bundles
- Cap product and various forms of duality with integral coefficients
- Bott periodicity theorem
- Topics in differential geometry such as:
  - Smooth vector bundles
  - Notions of connection, curvature and parallel transport
  - Definition of Riemannian manifold
  - Gauss-Bonnet formula
  - Notion of geodesic and Hopf-Rinow theorem
- Obstruction theory and introduction to characteristic classes:
- Topics in Morse theory such as:
  - Definition and genericity of Morse functions
  - Lemma of Morse
  - Cell structure associated to a Morse function and Morse homology
  - Morse-Smale-Witten complex

10MATH04-007-C Complex Analysis - 8 credits

- Analytic function, Cauchy-Riemann equations, power series, exponential and logarithmic function
- Cauchy theorem on a disc, Integral formula, power series and Laurent series expansion Product development, Weierstrass theorem, Homotopy version of Cauchy's theorem, Liouville's theorem, residue theorem, Argument principle
- Maximum modulus principle, Schwarz lemma, Phragmen-Lindelof method
- Conformal mapping, Mobius transformation, Automorphisms of the disc and upper half plane, Riemann mapping theorem
- Harmonic functions, Dirichlet problem, Mean value property
- Analytic continuation, Monodromy theorem
- (optional) Introduction to Hyperbolic geometry
- (optional) Elliptic functions, Gamma and Zeta functions

10MATH04-008-C Credit seminar - 4 credits

The topic of the seminar will be chosen by the student in consultation with an assigned faculty member. The student will read recent research papers as assigned by the faculty member, and present the results in a formal seminar.

10MATH04-009-C Research Methodology - Pass/Fail

An introduction to the methods and techniques of academic research through a project and presentations - both oral and written.

The following courses are advanced level research courses whose content will be decided by the instructor based on current research and the requirements of the individual students.

10MATH04-001-E Topics in analytic number theory - 8 credits

Course content varies according to instructor's choice. Possibilities for topics are: introduction to arithmetic functions, convolution and Mobius inversion for-mula, basic asymptotic formulas for arithmetic functions, characters and Fourier analysis on finite abelian groups, theory of Dirichlet series, primes in arithmetic progression, Riemann zeta function, Poisson summation and functional equation, The prime number theorem, error term in prime number theorem, its oscillation and the Riemann hypothesis, equivalent formulations of Riemann hypothesis, zero-free regions, explicit formula and Siegel's theorem, introduction to sieve methods, Brun and Selberg sieve, large sieve and the Bombieri-Vinogradov theorem and Vinogradov's three prime Theorem.

10MATH04-002-E Topics in algebraic number theory - 8 credits

Course content varies according to instructor's choice. Possibilities for topics are: Dedekind domains, ramification, different and discriminants, decomposition and inertia groups, quadratic fields and genus theory, classification of primitive quadratic characters, Gauss sums and quadratic reciprocity, geometry of numbers, finiteness of class number and explicit computations, regulators and Dirichlet's unit theorem, cyclotomic fields and inverse Galois problem for abelian number fields, Artin symbol and splitting in cyclotomic fields, Dedekind zeta function, the analytic class number formula and introduction to the Chebotarev density theorem

10MATH04-003-E Topics in commutative algebra - 8 credits

Course content varies according to instructor's choice. One possibility is a course covering the second half of Matsumura's text including topics such as: regular sequences, Koszul complex, Cohen-Macaulay rings, Gorenstein rings, regular rings, UFDs, complete intersections, local flatness criterion, generic freeness, derivations and differentials, separability, I-smoothness, Cohen's structure theorems and applications of complete local rings.

10MATH04-004-E Topics in modular forms - 8 credits

Course content varies according to instructor's choice. Possibilities include: Introduction to $SL_2(\mathbb{R})$ and its action on the Poincare upper half-plane $\mathcal{H}$, discrete subgroups Γ of $SL_2(\mathbb{R})$ and their cusps, the modular group $SL_2(\mathbb{Z})$, Topology, measure theory and complex structure on $\mathcal{H}/\Gamma$ and its compactification, Modular functions, modular forms and cusp forms on $SL_2(\mathbb{Z})$, examples : Eisenstein Series and the delta Function, finite dimensionality of space of modular forms, the Miller basis and the $\mathbb{Z}$-structure on the space of modular forms, growth of Fourier coefficients of cusp forms, introduction to Ramanujan's conjectures, theory of Hecke operators and Petersson inner-product on the space of cusp forms, application to Ramanujan's conjectures, the L-function of modular forms, congruence subgroups, modular forms and cusp forms on congruence subgroups, spectral theory of automorphic forms, introduction to Galois representations and Deligne's theorem, Lehmer's conjecture and the Atkin-Serre Conjecture.

10MATH04-005-E Topics in elliptic curves - 8 credits

Course content varies according to instructor's choice. Possibilities for material to be covered include selected topics from Elliptic functions by Lang, The arithmetic of Elliptic curves by Silverman, Elliptic curves by Milne or Elliptic curves by Husemoller. Another possibility would be to prove Mazur's theorem which is a well-known and important result covering elliptic curves and abelian varieties, and the moduli of elliptic curves.

10MATH04-006-E Topics in algebraic curves - 8 credits

Course content varies according to instructor's choice. Possibilities for material to be covered include selected topics from An invitation to arithmetic geometry by Lorenzini, Algebraic Curves by Fulton or lectures notes of Joseph Oesterle. Topics such as the basics of algebraic varieties over the complex numbers (with focus on dimension 1), singularities of curves (what are they and when is a curve nonsingular), desingularization of curves by normalization, the relationship between nonsingular algebraic curves and complex manifolds of dimension 1, nonsingular projective algebraic curves and function fields, the Riemann-Roch theorem, and also some of its applications.

10MATH04-007-E Topics in diophantine geometry - 8 credits

Course content varies according to instructor's choice. Some possibilities are: introduction to Global fields, absolute values on global fields, theory of heights, rational points on conics. local-global principle and application to quadratic forms, affine and projective varieties, morphisms and rational maps, explicit arithmetic on function fields and their zeta-functions, divisors on curves, The Riemann-Roch theorem, elliptic curves over global fields, endomorphism rings of Elliptic curves, CM and non-CM curves, ehe Mordell-Weil group and rank of an elliptic curve and local-global principle on elliptic curves and the Tate-Shaferevich group.

10MATH04-008-E Topics in transcendental number theory - 8 credits

Course content varies according to instructor's choice. Possibilities are: Liouville's theorem and Liouville Numbers, elements of rational approximation, transcendence of e and π, irrationality of $\zeta(3)$, introduction to algebraic independence, Lindemann-Weierstrass theorem, Schanuel's conjecture and Ax's theorem for formal power series, the Schneider-Lang Theorem, Hilbert's seventh problem and the Gelfond-Schneider theorem, Baker's Theorem and applications, six exponential theorem, introduction to heights and Roth's Theorem, the p-adic Baker theorem (by Brumer) and introduction to Leopoldt's conjecture and the p-adic subspace theorem and applications.

10MATH04-009-E Topics in algebraic groups - 8 credits

Course content varies according to instructor's choice. One possibility is to cover the basic theory of linear algebraic groups over an algebraically closed field up to the classification of the reductive groups by means of root data, developing the necessary background from algebraic geometry as and when needed. Thus covering preliminaries from algebraic geometry, linear algebraic groups: definition and first properties, commutative algebraic groups, derivations, differentials, and Lie algebras, topological properties of morphisms applied to this context, Parabolic subgroups, Borel subgroups, and solvable subgroups, Weyl group, roots, and root datum and reductive groups and their classification: isomorphism and existence theorems.

10MATH04-010-E Topics in infinite dimensional Lie algebras - 8 credits

Course content varies according to instructor's choice. Some possibilities are: generalized Cartan matrices and their associated Lie algebras, symmetrizability, the invariant bilinear form, the Weyl group, classification of indecomposable GCMs, finite, affine and indefinite types, affine Kac-Moody algebras, roots, the affine Weyl group, realizations of untwisted and twisted affine Kac-Moody algebras in terms of loop algebras, representation theory: integrable representations, category $\mathcal{O}$, proof of the Weyl-Kac character formula, highest weight integrable representations, weights, representations of affine Kac-Moody algebras.

10MATH04-011-E Topics in functional analysis - 8 credits

Course content varies according to instructor's choice. Some possibilities are: analytic Fredholm theory, compact and Fredholm operators, Atkinson's theorem, Gelfand duality, properties of the analytic index, Toeplitz operators on Hardy spaces, Pseudo-differential operators and Elliptic regularity, Fourier transforms and Sobolev spaces on R^n, Symbol calculus and Pseudo-differential operators, Ellipticity and Pseudo-differential operators on smooth manifolds, construction of parametrices, Elliptic regularity theorem, Ellipticity and Fredholm property of Dirac operators on closed manifolds.

10MATH04-012-E Topics in non-commutative geometry - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Vector bundles, K-theory for topological spaces, Serre Swan theorem, K_0 and $K_1$for a C*-algebra, homotopy invariance, split exactness, half-exactness, stability of K-theory, inductive limits and K-theory, Bott periodicity, Six term exact sequences, computations with them, Pimsner-Voiculescu exact sequence, Thom isomorphism, Hilbert C*-modules, KK groups, Geometric index theory, Vector bundles, connections and curvature on Riemannian manifolds, structure equations of Cartan, invariant forms and characteristic classes in de Rham cohomology, Chern-Gauss-Bonnet theorem and idea of proof, topological index and statement of the Atiyah-Singer index theorem

10MATH04-013-E Topics in Lie groups - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Introduction to Lie algebras, definitions, examples, abelian, nilpotent, solvable lie algebras, semisimple lie algebras, representation of Lie algebras, structure of general Lie algebras over characteristic zero field : statement of the Levi decomposition, statement of Ado's theorem, Introduction to real differentiable manifolds, and various standard objects associated with it, statement of the Frobenius theorem on integrability, definition of real Lie groups, examples, associated Lie algebra, the exponential map and its properties, closed subgroup theorem, continuous homomorphisms, definition of Lie subgroups and examples, association of lie subgroups and lie subalgebras, covering Lie groups, simply connected lie groups and association with real Lie algebras, the adjoint representation, the manifold structure of the left or right coset space with respect to a closed subgroup and the (subgroup)-principal bundle structure of the Lie group with respect to the projection to the coset space, Construction of left invariant Haar measure using left invariant differential forms, formula for modular function, compact Lie groups, Peter-Weyl theorem, embedding compact groups in linear Lie groups, Weyl group, conjugacy of maximal tori in connected compact Lie groups, Centralizers of tori, basic structure of semisimple Lie groups, existence of compact real forms of complex semi-simple Lie algebras, Cartan decomposition both at the Lie algebra and Lie group level, Iwasawa decomposition.

10MATH04-014-E Topics in algebraic geometry - 8 credits

Course content varies according to instructor's choice. One possibility is an introduction to the language of schemes, properties of morphisms, and sheaf cohomology. So that the students gain an understanding of the basic notions and techniques of modern algebraic geometry.

10MATH04-015-E Topics in differential geometry - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Definition of smooth manifolds, atlas, examples, tangent spaces, inverse and implicit functon theorems for manifolds, vector fields, flow, completeness of the flow function, integrability and Frobenius theorem, differential forms, pullback by functions, exterior derivative, orientations, manifolds with boundary, Stokes theorem, DeRham cohomology, computations using Mayer Vietoris, Riemannian metrics and geodesics.

10MATH04-016-E Topics in partial differential equations - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Examples of partial differential equations, Strategies for studying PDE., Well posed problem, Brief introduction to classical solutions, weak solution and regularity, Transport equation, Laplace's equation, Heat equation and wave equation, Problems associated to these equations, notion of fundamental solution etc., Non-linear first order PDE, Hamilton Jacobi equations, calculus of variations, Hamilton's ode, Legendre transforms, etc., Theory of linear partial differential equations: Sobolev spaces, weak derivative, Sobolev inequalities, Elliptic equations, Weak solutions, the existence of weak solutions, regularity, maximum principles, eigenvalues and eigenfunctions of elliptic operators, compactness, etc.

10MATH04-017-E Topics in mathematical physics - 8 credits

Course content varies according to instructor's choice. One possibility is to cover classical and quantum mechanics covering topics such as: review of Galilean group, mechanical system with one degree of freedom, mechanical system consisting of motion of a point in three dimensional space and motion of system of n points, review of calculus of variation, Lagrange's equation, Hamilton's equations, Liouville's theorem, Symplectic structures on phase spaces and Noether's theorem, D'Alembert's principle, Symplectic manifolds, Hamiltonian mechanics on symplectic manifolds, moment map, postulates of quantum mechanics, mathematical aspects of Schrödinger's equation, review of Lie group, Lie algebra and their representations with main focus on groups like $U(1)$, $SO(3)$, $SU(2)$, Spin groups in 3 and 4 dimensions, Spin $\frac{1}{2}$ particle in magnetic field, review of Fourier transforms, position and momentum space, Dirac notation, Heisenberg's uncertainty principle, Hydrogen atom, quantization, canonical quantization, The Groenewold-van Hove no-go theorem, canonical quantization in n–dimensions, quantization and symmetries.

10MATH04-018-E Topics in algebra - 8 credits

Course content varies according to instructor's choice. One possibility is a course in commutative algebra covering prime ideals and maximal ideals, nilradical and jacobson radical, prime avoidance and the Chinese remainder theorem, extension and contraction of ideals, modules, submodules and quotient modules, direct sum and direct product, finitely generated modules and Nakayama lemma, exact sequences, tensor products, restriction and extension of scalars, exactness properties of the tensor product, algebras, tensor product of algebras, localization, local properties, extended and contracted ideals in rings of fractions, primary decomposition, integral extensions, lying over, going-up theorems, integrally closed domains and the going-down theorem, valuation rings, Noetherian and Artinian modules, Noetherian rings, Hilbert basis theorem, primary decomposition in Noetherian rings, Artinian rings and their structure, discrete valuation rings and Dedekind domains, fractional ideals, completions, filtrations, topologies, and completions, graded rings and modules, associated graded ring, dimension theory, Hilbert functions, dimension theory of Noetherian local rings, regular local rings, transcendental dimension, relation to algebraic varieties and algebraic geometry.

10MATH04-019-E Topics in operator algebras - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Banach algebras, spectrum, spectral radius formula, C*-algebras, Gelfand Naimark theorem, continuous functional calculus, GNS construction, positivity, measurable functional calculus, von Neumann algebras, Kaplansky density theorem, double commutant theorem, finite-dimensional C*-algebras, representation theory of the C*-algebra of compact operators, Toeplitz algebra, Coburn's theorem, group C*-algebras, crossed products, amenability, groupoid C*-algebras.

10MATH04-020-E Topics in representation theory - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Lie algebras: definition and basic properties, ideals, subalgebras, homomorphisms, nilpotent and solvable Lie algebras, Lie's and Engel's theorems, semisimple Lie algebras, the Killing form, Cartan's criterion, abstract Jordan decomposition, classification of finite dimensional semisimple Lie algebras, Dynkin diagrams, the Weyl group, isomorphism and conjugacy theorems, representations, Verma modules, category $\mathcal{O}$, irreducible highest weight modules, complete reducibility, Weyl character formula, Freudenthal weight multiplicity formula, Kostant and Steinberg formulas.

10MATH04-021-E Topics in algebraic combinatorics - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Partially ordered sets and Mobius inversion, generating functions, permutations and statistics, Robinson-Schensted correpondence, partitions, Young's lattice, hook-length formula, Representation theory of symmetric groups, similarity classes of matrices and orthogonal polynomials

10MATH04-022-E Topics in topology - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Definitions and basic construction of homotopy groups, Whitehead's theorem, Hurewicz's theorem, stable homotopy groups, fibrations and obstruction theory, Bott's periodicity theorem, H-cobordism theorem, construction and applications of characteristic classes.

10MATH04-023-E Topics in symplectic geometry - 8 credits

Course content varies according to instructor's choice. Possibilities include: Motivations of sympletic Geometry from Hamiltonian mechanics, neighbourhood theorems, compatible almost complex structure, and the contractibility of the space of almost complex structures, integrability of almost complex structures, Newlander-Nirenberg theorem, Hamiltonian circle actions on symplectic manifolds, moment maps, Fubini-Studi form on projective space, Kähler forms as Hessians of plurisubharmonic function on complex manifolds, introduction to pseudoholomorphic curves, outline of proof of Gromov's non-squeezing theorem.

10MATH04-024-E Programming for mathematicians - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Basic python syntax, Iterables and generators, Object oriented programming, introduction to Sage, the Numpy library, the Networkx library, graphics with Sage and Matplotlib and a Programming project.

Course Curriculum

Doctoral program in School of Mathematical Sciences

Applicable from the Academic Year

2018-19

SYLLABUS FOR

Ph.D. in Mathematical Science (Program Code: MATH04)

NATIONAL INSTITUTE OF SCIENCE EDUCATION AND

RESEARCH BHUBANESWAR

SCHOOL OF MATHEMATICAL SCIENCES

COURSE STRUCTURE FOR DOCTORAL PROGRAM

School of mathematical sciences at NISER is engaged in research in diverse areas that includes, academic disciplines that are primarily mathematical in nature but may not be universally considered subfields of mathematics proper. To maintain this diversity, school provides two possible curriculum to a student. A student has to select one curriculum out of these two at the beginning of his/her doctoral program and is expected to finish it within one year. These curriculum are:

1. Mathematics - I: For students interested in algebra, analysis, cryptol- ogy, discrete mathematics, geometry, number theory, probability and topology.

2. Mathematics - II: For students interested in statistics.

Both curriculum will have 6 compulsory courses, 2 elective courses and 2 self study courses. In each of the two semesters a student will take 3 compulsory courses, 1 elective course and 1 self study course. Detailed list of courses in both the curriculum is provided in next section.

An instruction based course, consisting of three lectures and one tutorial, will be worth 6 credits. A self study course will be done under the supervision of a faculty member on an advanced topic in broad research area of interest to student. It will be worth 6 credits. Therefore total credits earned by a student in first year will be $6 \times 8 + 6 \times 2 = 60$.

Having completed the course work successfully, a student will appear for Oral General Comprehensive Examination (OGCE) conducted by the monitoring committee. OGCE will be based on all the 8 courses that a student has taken and will be conducted before the registration of third semester. The process of choosing Ph.D. advisor starts only after the successful completion of OGCE and it has to be done within a month from the date of completion of comprehensive examination.

A doctoral committee is then constituted by the Dean Academic as per HBNI guidelines once a guide and topic has been decided. If the doctoral committee so desires, the student can take more courses related to the topic of research. The doctoral committee should meet at least once in year to monitor the progress of a student. The student has to give one seminar every year before the doctoral committee. Guide, who is the convener of doctoral committee, should send the annual progress report of student to the dean academic every year before registration of odd/even semester depending upon the joining date of the student and a copy may be sent to PGCS convener for further reference.

COURSES IN CURRICULUM

Courses in Mathematics - I

Course No.	Credits	Course Name	Semester
M601	6	Algebra I	1
M603	6	Analysis I	1
M659	6	Topology and Complex Analysis	1
M***	6	Elective I	1
M***	6	Self study course I	1
M602	6	Algebra II	2
M604	6	Analysis II	2
M632	6	Advanced Probability	2
M***	6	Elective II	2
M***	6	Self study course II	2

Courses in Mathematics - II

Course No.	Credits	Course Name	Semester
M615	6	Introduction to Stochastic Processes	1
M641	6	Statistical Inference I	1
M644	6	Regression Analysis	1
M***	6	Elective I	1
M***	6	Self study course I	1
M632	6	Advanced Probability	2
M645	6	Time Series Analysis	2
M767	6	Statistical Inference II	2
M***	6	Elective II	2
M***	6	Self study course II	2

LIST OF ELECTIVE COURSES

Course No.	Credits	Course Name
M605	6	Functional Analysis
M606	6	Representations of Finite Groups
M607	6	Commutative Algebra
M608	6	Algebraic Topology
M611	6	Advanced Complex Analysis
M612	6	Advanced Functional Analysis
M613	6	Advanced Linear Algebra
M614	6	Partial Differential Equations
M616	6	Algebraic Geometry
M617	6	Algebraic Graph Theory
M618	6	Algebraic Number Theory
M620	6	Algorithm
M623	6	Finite Fields
M624	6	Information and Coding Theory
M625	6	Mathematical Logic
M626	6	Measure Theory
M627	6	Nonlinear Analysis
M628	6	Operator Theory
M630	6	Abstract Harmonic Analysis
M631	6	Advanced Number Theory
M633	6	Algebraic Combinatorics
M634	6	Foundations of Cryptography
M635	6	Incidence Geometry
M636	6	Lie Algebras
M637	6	Optimization Theory
M638	6	Advanced Partial Differential Equations
M639	6	Random Graphs
M640	6	Randomized Algorithms and Probabilistic Methods
M642	6	Multivariate Statistical Analysis
M643	6	Introduction to Manifolds
M652	6	Complex Analysis
M653	6	Differential Equations
M654	6	Discrete Mathematics
M655	6	Graph Theory
M656	6	Introduction to Number Theory
M657	6	Probability Theory-I
M658	6	Probability Theory-II

LIST OF ELECTIVE COURSES CONTD.

Course No.	Credits	Course Name
M751	6	Algebraic Computation
M752	6	Analytic Number Theory
M753	6	Classical Groups
M754	6	Ergodic Theory
M755	6	Harmonic Analysis
M756	6	Lie Groups and Lie Algebras-I
M757	6	Operator Algebras
M758	6	Representations of Linear Lie Groups
M759	6	Harmonic Analysis on Compact Groups
M760	6	Modular Forms of One Variable
M761	6	Elliptic Curves
M762	6	Brownian Motion and Stochastic Calculus
M763	6	Differentiable Manifolds and Lie Groups
M764	6	Lie Groups and Lie Algebras-II
M765	6	Mathematical Foundations for Finance

DETAILED SYLLABUS

(M601): (Algebra-I), Credits - 6
(3 Lectures + 1 Tutorial)

Group Theory: Dihedral groups, Permutation groups, Group actions, Sy- low' s theorems, Simplicity of the alternating groups, Direct and semidirect products, Solvable groups, Nilpotent groups, Jordan Holder Theorem, free groups.
Ring Theory: Properties of Ideals, Chinese remainder theorem, Field of fractions, Euclidean domains, Principal ideal domains, Unique factorization domains, Polynomial Rings, Irreducibility criteria, Matrix rings.
Module Theory: Examples, quotient modules, isomorphism theorems, Gen- eration of modules, free modules, tensor products of modules, Exact se- quences - Projective, Injective and Flat modules.

Reference reading materials:

1. D. S. Dummit and R. M. Foote, Abstract Algebra. John Wiley & Sons, 2004.
2. T. W. Hungerford, Algebra, Graduate Texts in Mathematics, 73, Springer, 1980.
3. M. Artin, Algebra, Prentice Hall, 1991.

(M602): (Algebra-II), Credits - 6
(3 Lectures + 1 Tutorial)

Linear Algebra: Matrix of a Linear transformation, dual vector spaces, de- terminants, Tensor algebras, Symmetric algebras, Exterior algebras, Modules over PIDs: Basic theory, Structure theorem for finitely generated abelian groups, Rational and Jordan canonical forms.
Field Theory: Algebraic extensions, Splitting fields, Algebraic closures, Sep- arable and Inseparable extensions, Cyclotomic polynomials and extensions, Galois extensions, Fundamental Theorem of Galois theory, Finite fields, Composite extensions, Simple extensions, Cyclotomic extensions and Abelian extensions over rational field, Galois groups of polynomials, Fundamental theorem of algebra, Solvable and Radical extensions, Computation of Ga- lois groups over rational field.

Reference reading materials:

1. D. S. Dummit and R. M. Foote, Abstract Algebra. John Wiley & Sons, 2004.

2. T. W. Hungerford, Algebra, Graduate Texts in Mathematics, 73, Springer, 1980.
3. M. Artin, Algebra, Prentice Hall, 1991.

(M603): (Analysis-I), Credits - 6
(3 Lectures + 1 Tutorial)

Spaces of functions: Continuous functions on locally compact spaces, Stone- Weierstrass theorems, Ascoli-Arzela Theorem. Review of Measure theory: Sigma-algebras, measures, construction and properties of the Lebesgue measure, non-measurable sets, measurable functions and their properties. Inte- gration: Lebesgue Integration, various limit theorems, comparison with the

Riemann Integral, Functions of bounded variation and absolute continu- ity. Measure spaces: Signed-measures, Radon-Nikodym theorem, Product spaces, Fubini' s thoerem (without proof) and its applications. Lp-spaces: Holder and Minkowski inequalities, completeness, Convolutions, Approxi- mation by smooth functions. Fourier analysis: Fourier Transform, Inverse Fourier transform, Plancherel Theorem for Real numbers.

Reference reading materials:

1. D. S. Bridges, Foundations of Real and Abstract Analysis, GTM series, Springer Verlag 1997.
2. G. B. Foland, Real Analysis: Modern Techniques and Their Applications (2nd ed.), Wiley-Interscience/John Wiley Sons, Inc., 1999.
3. P. R. Halmos, Measure Theory, Springer-Verlag, 1974.
4. H. L. Royden, Real Analysis, Macmillan 1988.
5. W. Rudin, Real and Complex Analysis, TMH Edition, Second Edition, New-York, 1962.

(M604): (Analysis-II), Credits - 6

(3 Lectures + 1 Tutorial)

Banach spaces: Review of Banach spaces, Hahn-Banach Theorem and its applications, Baire Category theorem and its applications like Closed graph theorem, Open mapping theorem. Topological Vector spaces: Weak and weak* topologies, locally convex topological vector spaces. Hilbert spaces: Review of Hilbert spaces and operator Theory, Compact operators, Schauder' s theorem on the spectral theory of compact operators. Banach algebras: Ele- mentary properties, Resolvent and spectrum, Spectral radius formula, Ideals and homomorphisms, Gelfand transforms, Gelfand theorem for commutative Banach algebras.

Reference reading materials:

1. D. S. Bridges, Foundations of Real and Abstract Analysis, GTM series, Springer Verlag 1997.
2. G. B. Foland, Real Analysis: Modern Techniques and Their Applications (2nd ed.), Wiley-Interscience/John Wiley Sons, Inc., 1999.
3. G. K. Pederson, Analysis NOW, GTM series, Springer-Verlag, 1991.
4. W. Rudin, Real and Complex Analysis, TMH Edition, Second Edition, New-York, 1962.
5. W. Rudin, Functional Analysis, TMH Edition, 1974.

6. K. Yosida, Functional Analysis, Springer-Verlag 1968.

(M615): (Introduction to Stochastic Processes), Credits - 6
(3 Lectures + 1 Tutorial)

Discrete Markov chains with countable state space; Classification of states: recurrences, transience, periodicity. Stationary distributions, reversible chains, Several illustrations including the Gambler's Ruin problem, queuing chains, birth and death chains etc. Poisson process, continuous time Markov chain with countable state space, continuous time birth and death chains.

Reference reading materials:

1. P.G.Hoel,S.C.Port,C.J.Stone, "IntroductiontoStochastic Processes" ,Houghton Mifflin Co., 1972.
2. R. Durrett, "Essentials of Stochastic Processes" , Springer Texts in Statistics, Springer,
2012.
3. G. R. Grimmett, D. R. Stirzaker, "Probability and Random Processes" , Oxford University Press, 2001.
4. S. M. Ross, "Stochastic Processes" , Wiley Series in Probability and Statistics:
Probability and Statistics, John Wiley & Sons, 1996

(M622): (Cryptology), Credits - 6
(3 Lectures + 1 Tutorial)

Overview: Cryptography and cryptanalysis, some simple cryptosystems (e.g., shift, substitution, affine, knapsack) and their cryptanalysis, classification of cryptosystems, classification of attacks; Information Theoretic Ideas: Per- fect secrecy, entropy; Secret key cryptosystem: stream cipher, LFSR based stream ciphers, cryptanalysis of stream cipher (e.g., correlation attack, alge- braic attacks), block cipher, DES, linear and differential cryptanalysis, AES; Public-key cryptosystem: Implementation and cryptanalysis of RSA, El- Gamal public-key cryptosystem, Discrete logarithm problem, elliptic curve cryptography; Data integrity and authentication: Hash functions, message authentication code, digital signature scheme, ElGamal signature scheme; Secret sharing: Shamir' s threshold scheme, general access structure and se- cret sharing.

Reference reading materials:

1. D. R. Stinson, "Cryptography: Theory And Practice" , Chapman & Hall/CRC, 2006.
2. A. J. Menezes, P. C. van Oorschot, S. A. Vanstone, "Handbook of Applied Cryp-
tography" , CRC Press, 1997.

(M629): (Theory of Computation), Credits - 6
(3 Lectures + 1 Tutorial)

Automata and Language Theory: Finite automata, regular expression, pump- ing lemma, context free grammar, context free languages, Chomsky normal form, push down automata, pumping lemma for CFL; Computability: Tur- ing machines, Churh-Turing thesis, decidability, halting problem, reducibil- ity, recursion theorem; Complexity: Time complexity of Turing machines, Classes P and NP, NP completeness, other time classes, the time hierarchy.

Reference reading materials:

1. J. E. Hopcroft, R. Motwani, J. D. Ullman, "Introduction to Automata Theory, Languages, and Computation", Addison-Wesley, 2006.
2. H. Lewis, C. H. Papadimitriou, "Elements of the Theory of Computation", Prentice-Hall, 1997.
3. M. Sipser, "Introduction to the Theory of Computation", PWS Publishing, 1997.

(M632): (Advanced Probability), Credits - 6

(3 Lectures + 1 Tutorial)

Probability spaces, Random Variables, Independence, Zero-One Laws, Ex- pectation, Product spaces and Fubini's theorem, Convergence concepts, Law of large numbers, Kolmogorov three-series theorem, Levy-Cramer Continu- ity theorem, CLT for i.i.d. components, Infinite Products of probability mea- sures, Kolmogorov’ s Consistency theorem, Conditional expectation, Discrete parameter martingales with applications.

Reference reading materials:

1. A. Gut, “Probability: A Graduate Course”, Springer Texts in Statistics, Springer, 2013.
2. K. L. Chung, “A Course in Probability Theory”, Academic Press, 2001.
3. S. I. Resnick, “A Probability Path”, Birkhäuser, 1999.
4. P. Billingsley, “Probability and Measure”, Wiley Series in Probability and Statis- tics, John Wiley & Sons, 2012.
5. J. Jacod, P. Protter, “Probability Essentials”, Universitext, Springer-Verlag, 2003.

(M641): (Statistical Inference I), Credits - 6

(3 Lectures + 1 Tutorial)

Review: joint and conditional distributions, order statistics, group family, exponential family. Introduction to parametric inference, sufficiency princi- ple and data reduction, factorization theorem, minimal sufficient statistics, Fisher information, ancillary statistics, complete statistics, Basu’ s theorem. Unbiasedness, best unbiased and linear unbiased estimator, Rao-Blackwell theorem, Lehmann- Scheffe theorem and UMVUE, Cramer-Rao lower bound and UMVUE, multi-parameter cases. Location and scale invariance, princi- ple of equivarience. Methods of estimation: method of moments, likelihood principle and maximum likelihood estimation, properties of MLE: invari- ance, consistency, asymptotic normality. Hypothesis testing: error prob- abilities and power, most powerful tests, Neyman-Pearson lemma and its applications, p-value, uniformly most powerful (UMP) test via Neyman- Pearson lemma, UMP test via monotone likelihood ratio property, exis- tence and nonexistence of UMP test for two sided alternative, unbiased and UMP unbiased tests. Likelihood (generalized) ratio tests and its properties, invariance and most powerful invariant tests. Introduction to confidence interval estimation, methods of fining confidence intervals: pivotal quantity, inversion of a test, examples such as confidence interval for mean, variance, difference in means, optimal interval estimators, uniformly most accurate confidence bound, large sample confidence intervals.

Reference reading materials:

1. E. L. Lehmann and G. Casella, “Theory of Point Estimation”, 2nd edition, Springer, New York, 1998.
2. E. L. Lehmann and J. P. Romano, “Testing Statistical Hypothesis”, 3rd edition, Springer, 2005.
3. N. Mukhopadhyay, “Probability and Statistical Inference”, Marcel Dekker, New York. 2000.
4. G. Casella and R. L. Berger, “Statistical Inference”, 2nd edition, Cengage Learning, 2001.
5. A. M. Mood, F. A. Graybill and D. C. Boes, “Introduction to the theory of Statis- tics”, 3rd edition, McGraw Hill, 1974.

(M659): (Topology and Complex Analysis), Credits - 6

(3 Lectures + 1 Tutorial)

• **Topology:** Topological spaces, Continuous maps between topological spaces, product topology, Quotient spaces, Connectedness, Compactness, Winding Numbers of Closed Curves, Brouwer Fixed Point Theorem (state- ment only), Borsuk-Ulam Theorem (Statement Only).

• **Complex Analysis :** Complex line integrals, Goursat' s theorem; Local existence of primitives and Cauchy' s theorem in a disc , Cauchy' s integral formula , Applications of Cauchy' s integral, Singularities and their classi- fications, zeros, poles and residue theorem. Applications of residue theo- rem. Argument principle and applications. Maximum Modulus principle, Schwarz lemma. Biholomorphic between between complex plane, Disc to itself, Statement of Riemann Mapping theorem

Reference reading materials:

1. Armstrong, *Basic Topology,* Springer, 1983
2. Munkres, *Topology,* Pearson Education, 2005.
3. Greene and Krantz, *Function Theory of One Complex Variable,* gsm 40, University Press, 2006
4. Stein and Shakarchi, *Complex Analysis (Princeton Lectures in Analysis, No. 2)*, Princeton University Press, 2003.
5. Gamelin, *Complex Analysis (Undergraduate Texts in Mathematics),* Springer, 2003.
6. Rudin, *Real and Complex Analysis*, McGraw-Hill, New York, 1966.

(M660): (Advanced Topology), Credits - 6
(3 Lectures + 1 Tutorial)

•**Homotopy Theory:** Fundamental groups and its functorial properties, examples, Van- Kampen Theorem,

•**Covering spaces :** Covering spaces, Computation of fundamental groups using cover- ings. The classification of covering spaces. Deck transforma- tions.

•**Simply connected spaces:** Simply connected spaces-Universal covering spaces of locally simply connected and pathwise connected spaces. - Uni- versal covering group of connected subgroups of General Linear groups.

•**Homology groups :** Affine spaces, simplexes and chains - Homology groups - Properties of Homology groups. - Chain Complexes, Relation Be- tween one dimensional Homotopy and Homology groups. - (As in sections 8 - 12 of Part II of Greenberg and Harper.)

Reference reading materials:

1. Armstrong, Basic Topology, Springer, 1983
2. Greenberg & Harper, Algebraic Topology: A First Course, Addition Wesley, 1984.
3. Munkres, Topology, Pearson Education, 2005. 1974

(M661): (Combinatorics and Graph Theory), Credits - 6
(3 Lectures + 1 Tutorial)

Pigeonhole principle, Counting principles, Binomial coefficients, Principles of inclusion and exclusion, recurrence relations, generating functions, Cata- lan numbers, Stirling numbers, Partition numbers, Schroder numbers.[25 lectures]

Graphs, subgraphs, graph isomorphisms, Hamilton cycles, Euler tours, di- rected graphs, matching, Tutte’ s theorem, Menger’ s theorem, planar graphs, Kuratowski’ s theorem, graph colourings, network flows, max-flow min-cut theorem, Ramsey theory for graphs, Matrices associated with graphs: Inci- dence matrix, Adjacency matrix, Laplacian matrix.[25 lectures]

Reference reading materials:

1. R. A. Brualdi, Introductory Combinatorics, Pearson Prentice Hall, 2010.
2. J. H. van Lint, R. M. Wilson, A Course in Combinatorics, Cambridge University Press, 2001.
3. R. P. Stanley, Enumerative Combinatorics Vol. 1, Cambridge Studies in Advanced Mathematics, 49, Cambridge University Press, 2012.
4. R. Diestel, Graph Theory, Graduate Texts in Mathematics, 173, Springer, 2010.
5. B. Bollobas, Modern Graph Theory, Graduate Texts in Mathematics, 184, Springer- Verlag, 1998.
6. J. A. Bondy, U. S. R. Murty, Graph Theory, Graduate Texts in Mathematics, 244, Springer, 2008.

(M766): (Designs and Codes), Credits - 6

(3 Lectures + 1 Tutorial)

Incidence structures, affine planes, translation plane, projective planes, con- ics and ovals, blocking sets. Introduction to Balanced Incomplete Block De- signs (BIBD), Symmetric BIBDs, Difference sets, Hadamard matrices and designs, Resolvable BIBDs, Latin squares. Basic concepts of Linear Codes, Hamming codes, Golay codes, Reed-Muller codes, Bounds on the size of codes, Cyclic codes, BCH codes, Reed-Solomon codes.

Reference reading materials:

1. G. Eric Moorhouse, “Incidence Geometry”, 2007 (available online).
2. Douglas R. Stinson, “Combinatorial Designs”, Springer-Verlag, New York, 2004.
3. W. Cary Huffman, V. Pless, “Fundamentals of Error-correcting Codes”, Cambridge Uinversity Press, Cambridge, 2003.

(M767): (Statistical Inference II), Credits -6

(3 Lectures + 1 Tutorial) *Prerequisites: M641 or equivalent*

General decision problem, loss and risk function, minimax estimation, min- imaxity and admissibility in exponential family. Introduction to Bayesian estimation, Bayes rule as average risk optimality, prior and posterior, conju- gate families, generalized Bayes rules. Bayesian intervals and construction of credible sets, Bayesian hypothesis testing. Empirical and nonparametric empirical Bayes analysis, admissibility of Bayes and generalized Bayes rules, discussion on Bayes versus non-Bayes approaches. Large sample theory: re- view of modes of convergences, Slutsky' s theorem, Berry-Essen bound, delta method, CLT for iid and non iid cases, multivariate extensions. Asymptotic level α tests, asymptotic equivalence, comparison of tests: relative efficiency, asymptotic comparison of estimators, efficient estimators and tests, local asymptotic optimality. Bootstrap sampling: estimation and testing.

Reference reading materials:

1. E. L. Lehmann and G. Casella, “Theory of Point Estimation”, 2nd edition, Springer, New York, 1998.
2. E. L. Lehmann, “Elements of Large-Sample Theory”, Springer-Verlag, 1999.
3. E. L. Lehmann and J. P. Romano, “Testing Statistical Hypothesis”, 3rd edition, Springer, 2005.
4. James O Berger, “Statistical Decision Theory and Bayesian Analysis”, 2nd edition, Springer, New York, 1985.

Syllabus of Elective Courses

(M606): (Representations of Finite Groups), Credits - 6
(3 Lectures + 1 Tutorial)

Group representations, Maschke' s theorem and completely reducibility, Char- acters, Inner product of Characters, Orthogonality relations, Burnside' s the- orem, induced characters, Frobenius reciprocity, induced representations, Mackey' s Irreducibility Criterion, Character table of some well-known groups, Representation theory of the symmetric group: partitions and tableaux, con- structing the irreducible representations.

Text Book:

1. G. James, M. Liebeck, "Representations and Characters of Groups", Cambridge University Press, 2010.

Reference reading materials:

1. J. L. Alperin, R. B. Bell, "Groups and Representations", Graduate Texts in Math- ematics 162, Springer, 1995.
2. B. Steinberg, "Representation Theory of Finite Groups", Universitext, Springer, 2012.
3. J-P. Serre, "Linear Representations of Finite Groups", Graduate Texts in Mathe- matics 42, Springer-Verlag, 1977.
4. B. Simon, "Representations of Finite and Compact Groups", Graduate Studies in Mathematics 10, American Mathematical Society, 2009.

(M607): (Commutative Algebra), Credits - 6
(3 Lectures + 1 Tutorial)

Commutative rings, ideals, operations on ideals, prime and maximal ideals, nilradicals, Jacobson radicals, extension and contraction of ideals, Mod- ules, free modules, projective modules, exact sequences, tensor product of modules, Restriction and extension of scalars, localization and local rings, extended and contracted ideals in rings of fractions, Noetherian modules, Artinian modules, Primary decompositions and associate primes, Integral extensions, Valuation rings, Discrete valuation rings, Dedekind domains, Fractional ideals, Completion, Dimension theory.

Text Book:

1. M. F. Atiyah, I. G. Macdonald, "Introduction to Commutative

Algebra" , Addison- Wesley Publishing Co., 1969.

Reference reading materials:

1. R. Y. Sharp, "Steps in Commutative Algebra" , London Mathematical Society Stu- dent Texts, 51. Cambridge University Press, 2000.
2. D. S. Dummit, R. M. Foote, "Abstract Algebra" , Wiley-India edition, 2013.

(M608): (Algebraic Topology), Credits - 6
(3 Lectures + 1 Tutorial)

Homotopy Theory: Simply Connected Spaces, Covering Spaces, Univer- sal Covering Spaces, Deck Transformations, Path lifting lemma, Homotopy lifting lemma, Group Actions, Properly discontinuous action, free groups, free product with amalgamation, Seifert-Van Kampen Theorem, Borsuk- Ulam Theorem for sphere, Jordan Separation Theorem. Homology Theory: Simplexes, Simplicial Complexes, Triangulation of spaces, Simplicial Chain Complexes, Simplicial Homology, Singular Chain Complexes, Cycles and Boundary, Singular Homology, Relative Homology, Short Exact Sequences, Long Exact Sequences, Mayer-Vietoris sequence, Excision Theorem, Invari- ance of Domain.

Text Books:

1. J. R. Munkres, "Topology", Prentice-Hall of India, 2013.
2. A. Hatcher, "Algebraic Topology", Cambridge University Press, 2009.

Reference reading materials:

1. G. E. Bredon, "Topology and Geometry", Graduates Texts in Mathematics 139, Springer, 2009.

(M611): (Advanced Complex Analysis), Credits - 6

(3 Lectures + 1 Tutorial)

Review of basic Complex Analysis: Cauchy-Riemann equations, Cauchy's theorem and estimates, power series expansions, maximum modulus prin- ciple, Classification of singularities and calculus of residues. Space of con- tinuous functions, Arzela's theorem, Spaces of analytic functions, Spaces of meromorphic functions, Riemann mapping theorem, Weierstrass Factoriza- tion theorem, Runge's theorem, Simple connectedness, Mittag-Leffler's the- orem, Analytic continuation, Schwarz reflection principle, Mondromy the- orem, Jensen's formula, Genus and order of an entire function, Hadamard factorization theorem, Little Picard theorem, Great Picard theorem, Har- monic functions.

Reference reading materials:

1. L. V. Ahlfors, "Complex Analysis", Tata McGraw-Hill, 2013.
2. J. B. Conway, "Functions of One Complex Variable II", Graduate Texts in Math- ematics 159, Springer-Verlag, 1996.
3. W. Rudin, "Real and Complex Analysis", Tata McGraw-Hill, 2013.
4. R. Remmert, "Theory of Complex Functions", Graduate Texts in Mathematics 122, Springer, 2008.

(M612): (Advanced Functional Analysis), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M605 or equivalent*

Definition and examples of topological vector spaces (TVS) and locally con- vex spaces (LCS); Linear operators; Hahn-Banach Theorems for TVS/ LCS (analytic and geometric forms); Uniform boundedness principle; Open map- ping theorem; Closed graph thoerem; Weak and weak* vector topologies; Bipolar theorem; dual of LCS spaces; Krein-Milman theorem for TVS; Krien-Smulyan theorem for Banach spaces; Inductive and projective limit of LCS.

Reference reading materials:

1. W. Rudin, “Functional Analysis”, Tata McGraw-Hill, 2007.
2. A. P. Robertson, W. Robertson, “Topological Vector Spaces”, Cambridge Tracts in Mathematics 53, Cambridge University Press, 1980.

3. J. B. Conway, “A Course in Functional Analysis”, Graduates Texts in Mathematics 96, Springer, 2006.

(M613): (Advanced Linear Algebra), Credits - 6
(3 Lectures + 1 Tutorial)

Rational and Jordan canonical forms, Inner product spaces, Unitary and Normal operators, Forms on inner product spaces, Spectral theorems, Bilin- ear forms, Matrix decomposition theorems, Courant- Fischer minimax and related theorems, Nonnegative matrices, Perron-Frobenius theory, General- ized inverse, Matrix Norm, Perturbation of eigenvalues.

Reference reading materials:

1. R. A. Horn, C. R. Johnson, “Matrix Analysis”, Cambridge University Press, 2010.
2. K. Hoffman, R. Kunze, “Linear Algebra”, Prentice-Hall of India, 2012.
3. S. Roman, “Advanced Linear Algebra”, Graduate Texts in Mathematics 135, Springer, 2008.

(M614): (Partial Differential Equations), Credits - 6
(3 Lectures + 1 Tutorial)

Classification of Partial Differential Equations, Cauchy Problem, Cauchy- Kowalevski Theorem, Lagrange-Green identity, The uniquness theorem of Holmgren, Transport equation: Initial value problem, nonhomogeneous prob- lem. Laplace equation: Fundamental solution, Mean Value formula, proper- ties of Harmonic functions, Green’s function, Energy methods, Harnack’s inequality. Heat Equation: Fundamental solution, Mean value formula, properties of solutions. Wave equation: Solution by spherical means, Non- homogeneous problem, properties of solutions.

Reference reading materials:

1. L. C. Evans, “Partial Differential Equations”, Graduate Studies in Mathematics 19, American Mathematical Society, 2010.
2. F. John, “Partial Differential Equations”, Springer International Edition, 2009.
3. G. B. Folland, “Introduction to Partial Differential Equations”, Princeton Univer- sity Press, 1995.
4. S. Kesavan, “Topics in Functional Analysis and Applications”, John Wiley & Sons, 1989.

(M616): (Algebraic Geometry), Credits - 6
(3 Lectures + 1 Tutorial)

Prime ideals and primary decompositions, Ideals in polynomial rings, Hilbert Basis theorem, Noether normalisation lemma, Hilbert’ s Nullstellensatz, Affine and Projective varieties, Zariski Topology, Rational functions and mor- phisms, Elementary dimension theory, Smoothness, Curves, Divisors on curves, Bezout’ s theorem, Riemann-Roch for curves, Line bundles on Pro- jective spaces.

Reference reading materials:

1. K. Hulek, “Elementary Algebraic Geometry”, Student Mathematical Library 20, American Mathematical Society, 2003.
2. I. R. Shafarevich, “Basic Algebraic Geometry 1: Varieties in Projective Space”, Springer, 2013.

3. J. Harris, “Algebraic geometry”, Graduate Texts in Mathematics 133, Springer- Verlag, 1995.
4. M. Reid, “Undergraduate Algebraic Geometry”, London Mathematical Society Stu- dent Texts 12, Cambridge University Press, 1988.
5. K. E. Smith et. al., "An Invitation to Algebraic Geometry", Universitext, Springer- Verlag, 2000.
6. R. Hartshorne, “Algebraic Geometry”, Graduate Texts in Mathematics 52, Springer- Verlag, 1977.

(M617): (Algebraic Graph Theory), Credits - 6

(3 Lectures + 1 Tutorial)

Adjacency matrix of a graph and its eigenvalues, Spectral radius of graphs, Regular graphs and Line graphs, Strongly regular graphs, Cycles and Cuts, Laplacian matrix of a graph, Algebraic connectivity, Laplacian spectral ra- dius of graphs, Distance matrix of a graph, General properties of graph automorphisms, Transitive and Arc-tranisitve graphs, Symmetric graphs.

Reference reading materials:

1. N. Biggs, “Algebraic Graph Theory”, Cambridge University Press, 1993.
2. C. Godsil, G. Royle, “Algebraic Graph Theory”, Graduate Texts in Mathematics 207, Springer-Verlag, 2001.
3. R. B. Bapat, “Graphs and Matrices”, Universitext, Springer, Hindustan Book Agency, New Delhi, 2010.

(M618): (Algebraic Number Theory), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M607*

Number Fields and Number rings, prime decomposition in number rings, Dedekind domains, Ideal class group, Galois theory applied to prime decom- position, Gauss reciprocity law, Cyclotomic fields and their ring of integers, finiteness of ideal class group, Dirichlet unit theorem, valuations and com- pletions of number fields, Dedekind zeta function and distribution of ideal in a number ring.

Reference reading materials:

1. D. A. Marcus, “Number Fields”, Universitext, Springer-Verlag, 1977.
2. G. J. Janusz, “Algebraic Number Fields”, Graduate Studies in Mathematics 7, American Mathematical Society, 1996.
3. S. Alaca, K. S. Williams, “Introductory Algebraic Number Theory”, Cambridge University Press, 2004.
4. S. Lang, “Algebraic Number Theory”, Graduate Texts in Mathematics 110, Springer- Verlag, 1994.
5. A. Frohlich, M. J. Taylor, “Algebraic Number Theory”, Cambridge

Studies in Ad- vanced Mathematics 27, Cambridge University Press, 1993.
6. J. Neukirch, "Algebraic Number Theory", Springer-Verlag, 1999.

(M620): (Algorithm), Credits - 6

(3 Lectures + 1 Tutorial)

Algorithm analysis: asymptotic notation, probabilistic analysis; Data Struc- ture: stack, queues, linked list, hash table, binary search tree, red-black tree; Sorting: heap sort, quick sort, sorting in linear time; Algorithm de- sign: divide and conquer, greedy algorithms, dynamic programming; Al- gebraic algorithms: Winograd’s and Strassen’s matrix multiplication algo- rithm, evaluation of polynomials, DFT, FFT, efficient FFT implementation; Graph algorithms: breadth-first and depth-first search, minimum spanning trees, single-source shortest paths, all-pair shortest paths, maximum flow; NP-completeness and approximation algorithms.

Reference reading materials:

1. A. V. Aho, J. E. Hopcroft, J. D. Ullman, “The Design and Analysis of Computer Algorithms”, Addison-Wesley Publishing Co., 1975.
2. T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, “Introduction to Algorithms”, MIT Press, Cambridge, 2009.
3. E. Horowitz, S. Sahni, “Fundamental of Computer Algorithms”, Galgotia Publica- tion, 1987.
4. D. E. Knuth, “The Art of Computer Programming Vol. 1, Vol. 2, Vol 3”, Addison- Wesley Publishing Co., 1997, 1998, 1998.

(M623): (Finite Fields), Credits - 6

(3 Lectures + 1 Tutorial)

Structure of finite fields: characterization, roots of irreducible polynomials, traces, norms and bases, roots of unity, cyclotomic polynomial, represen- tation of elements of finite fields, Wedderburn’s theorem; Polynomials over finite field: order of polynomials, primitive polynomials, construction of irre- ducible polynomials, binomials and trinomials, factorization of polynomials over small and large finite fields, calculation of roots of polynomials; Linear recurring sequences: LFSR, characteristic polynomial, minimal polynomial, characterization of linear recurring sequences, Berlekamp-Massey algorithm; Applications of finite fields: Applications in cryptography, coding theory, fi- nite geometry, combinatorics.

Reference reading materials:

1. R. Lidl, H. Neiderreiter, “Finite Fields”, Cambridge university press, 2000.
2. G. L. Mullen, C. Mummert, “Finite Fields and Applications”, American Mathe- matical Society, 2007.
3. A. J. Menezes et. al., “Applications of Finite Fields”, Kluwer Academic Publishers, 1993.
4. Z-X. Wan, “Finite Fields and Galois Rings”, World Scientific Publishing Co., 2012.

(M624): (Information and Coding Theory), Credits - 6

(3 Lectures + 1 Tutorial)

Information Theory: Entropy, Huffman coding, Shannon-Fano coding, en- tropy of Markov process, channel and mutual information, channel capacity; Error correcting codes: Maximum likelihood decoding, nearest neighbour decoding, linear codes, generator matrix and parity-check matrix, Ham- ming bound, Gilbert-Varshamov bound, binary Hamming codes, Plotkin bound, nonlinear codes, Reed-Muller codes, Cyclic codes, BCH codes, Reed- Solomon codes, Algebraic codes.

Reference reading materials:

1. R. W. Hamming, "Coding and Information Theory", Prentice-Hall, 1986.

2. N. J. A. Sloane, F. J. MacWilliams, "Theory of Error Correcting Codes", North- Holland Mathematical Library 16, North-Holland, 2007.
3. S. Ling, C. Xing, "Coding Theory: A First Course", Cambridge University Press, 2004.
4. V. Pless, "Introduction to the Theory of Error-Correcting Codes", Wiley-Interscience Publication, John Wiley & Sons, 1998.
5. S. Lin, "An Introduction to Error-Correcting Codes", Prentice-Hall, 1970.

(M625): (Mathematical Logic), Credits - 6

(3 Lectures + 1 Tutorial)

Propositional Logic, Tautologies and Theorems of propositional Logic, Tau- tology Theorem. First Order Logic: First order languages and their struc- tures, Proofs in a first order theory, Model of a first order theory, validity theorems, Metatheorems of a first order theory, e. g., theorems on constants, equivalence theorem, deduction and variant theorems etc. Completeness theorem, Compactness theorem, Extensions by definition of first order the- ories, Interpretations theorem, Recursive functions, Arithmatization of first order theories, Godels first Incompleteness theorem, Rudiments of model theory including Lowenheim-Skolem theorem and categoricity.

Reference reading materials:

1. J. R. Shoenfield, "Mathematical logic", Addison-Wesley Publishing Co., 1967.
2. E. Mendelson, "Introduction to Mathematical Logic", Chapman & Hall, 1997.

(M626): (Measure Theory), Credits - 6

(3 Lectures + 1 Tutorial)

$\sigma-$algebras of sets, measurable sets and measures, extension of measures, construction of Lebesgue measure, integration, convergence theorems, Radon- Nikodym theorem, product measures, Fubini's theorem, differentiation of integrals, absolutely continuous functions, L_p-spaces, Riesz representation theorem for the space $C[0,1]$.

Reference reading materials:

1. G. De Barra, "Measure theory and integration".
2. J. Nevue, "Mathematical foundations of the calculus of probability", Holden-Day, Inc., 1965.
3. I. K. Rana, "An introduction to measure and integration", Narosa Publishing House.
4. P. Billingsley, "Probability and measure", John Wiley & Sons, Inc., 1995.
5. W. Rudin, "Real and complex analysis", McGraw-Hill Book Co., 1987.

6. K. R. Parthasarathy, "Introduction to probability and measure" , The Macmillan Co. of India, Ltd., 1977.

(M627): (Nonlinear Analysis), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M605 or equivalent*

Calculus in Banach spaces, inverse and multiplicit function theorems, fixed point theorems of Brouwer, Schauder and Tychonoff, fixed point theorems for nonexpansive and set-valued maps, predegree results, compact vector fields, homotopy, homotopy extension, invariance theorems and applications.

Reference reading materials:

1. S. Kesavan, "Nonlinear Functional Analysis", Texts and Readings in Mathematics 28, Hindustan Book Agency, 2004.

(M628): (Operator Theory), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M605 or equivalent*

Compact operators on Hilbert Spaces. (a) Fredholm Theory (b) Index, C*- algebras - noncommutative states and representations, Gelfand-Neumark representation theorem, Von-Neumann Algebras; Projections, Double Com- mutant theorem, L^∞ functionalCalculus, Toeplitz operators.

Reference reading materials:

1. W. Arveson, "An invitation to C*-algebras", Graduate Texts in Mathematics, No.
   39. Springer-Verlag, 1976.
2. N. Dunford and J. T. Schwartz, "Linear operators. Part II: Spectral theory. Self adjoint operators in Hilbert space", Interscience Publishers John Wiley i& Sons 1963.
3. R. V. Kadison and J. R. Ringrose, "Fundamentals of the theory of operator alge- bras. Vol. I. Elementary theory", Pure and Applied Mathematics, 100, Academic Press, Inc., 1983.
4. V. S. Sunder, "An invitation to von Neumann algebras", Universitext, Springer- Verlag, 1987.

(M630): (Abstract Harmonic Analysis), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M605*

Topological Groups: Basic properties of topological groups, subgroups, quo- tient groups. Examples of various matrix groups. Connected groups. Haar measure: Discussion of Haar measure without proof on R, T, Z and simple matrix groups, Convolution, the Banach algebra $L^1(tt)$ and convolution with special emphasis on L^1(R), L^1(T) and L^1(Z). Basic Representation Theory: Unitary representation of groups, Examples and General properties, The representations of Group and Group algebras, $C*$-algebra of a group, GNS construction, Positive definite functions, Schur's Lemma. Abelian Groups: Fourier transform and its properties, Approximate identities in $L^1(tt)$, Clas- sical Kernels on R, The Fourier inversion Theorem, Plancherel theorem on R, Plancherel measure on R, T, Z. Dual Group of an Abelian Group: The Dual group of a locally compact abelian group, Computation of dual groups for R, T, Z, Pontryagin's Duality theorem.

Reference reading materials:

1. G. B. Folland, "A Course in Abstract Harmonic Analysis", CRC Press, 2000.

2. H. Helson, “Harmonic Analysis”, Texts and Readings in Mathematics, Hindustan Book Agency, 2010.
3. Y. Katznelson, “An Introduction to Harmonic Analysis”, Cambridge University Press, 2004.
4. L. H. Loomis, “An Introduction to Abstract Harmonic Analysis”, Dover Publica- tion, 2011.
5. E. Hewitt, K. A. Ross, “Abstract Harmonic Analysis Vol. I”, Springer-Verlag, 1979.
6. W. Rudin, “Real and Complex Analysis”, Tata McGraw-Hill, 2013.

(M631): (Advanced Number Theory), Credits - 6

(3 Lectures + 1 Tutorial)

Review of Finite fields, Gauss Sums and Jacobi Sums, Cubic and biquadratic reciprocity, Polynomial equations over finite fields, Theorems of Chevally and Warning, Quadratic forms over prime fields. Ring of p-adic integers, Field of p-adic numbers, completion, p-adic equations, Hensel's lemma, Hilbert symbol, Quadratic forms with p-adic coefficients. Dirichlet series: Abscissa of convergence and absolute convergence, Riemann Zeta function and Dirichlet L-functions. Dirichlet's theorem on primes in arithmetic progression. Functional equation and Euler product for L-functions. Modular Forms and the Modular Group, Eisenstein series, Zeros and poles of mod- ular functions, Dimensions of the spaces of modular forms, The j-invariant L-function associated to modular forms, Ramanujan τ function.

Reference reading materials:

1. J.-P. Serre, "A Course in Arithmetic", Graduate Texts in Mathematics 7, Springer- Verlag, 1973.
2. K. Ireland, M. Rosen, "A Classical Introduction to Modern Number Theory", Grad- uate Texts in Mathematics 84, Springer-Verlag, 1990.
3. H. Hasse, "Number Theory", Classics in Mathematics, Springer-Verlag, 2002.
4. W. Narkiewicz, "Elementary and Analytic Theory of Algebraic Numbers", Springer Monographs in Mathematics, Springer-Verlag, 2004.
5. F. Q. Gouvêa, "p-adic Numbers", Universitext, Springer-Verlag, 1997.

(M633): (Algebraic Combinatorics), Credits - 6

(3 Lectures + 1 Tutorial)

Catalan Matrices and Orthogonal Polynomials, Catalan Numbers and Lat- tice Paths, Combinatorial Interpretation of Catalan Numbers, Symmetric Polynomials and Functions, Schur Functions, Jacobi-Trudi identity, RSK Al- gorithm, Standard Tableaux, Young diagrams and q-binomial coefficients, Plane Partitions, Group actions on boolean algebras, Enumeration under group action, Walks in graphs, Cubes and the Radon transform, Sperner property, Matrix-Tree Theorem.

Reference reading materials:

1. R. P. Stanley, "Algebraic Combinatorics", Undergraduate Texts in Mathematics, Springer, 2013.
2. M. Aigner, "A Course in Enumeration", Graduate Texts in Mathematics 238, Springer, 2007.

3. R. P. Stanley, “Enumerative Combinatorics Vol. 2”, Cambridge Studies in Ad- vanced Mathematics 62, Cambridge University Press, 1999.

(M634): (Foundations of Cryptography), Credits - 6
(3 Lectures + 1 Tutorial)

Introduction to cryptography and computational model, computational diffi- culty, pseudorandom generators, zero-knowledge proofs, encryption schemes, digital signature and message authentication schemes, cryptographic proto- col.

Reference reading materials:

1. O. Goldreich, “Foundations of Cryptography - Vol. I and Vol. II”, Cambridge University Press, 2001, 2004.
2. S. Goldwasser, Mihir Bellare, "Lecture Notes on Cryptography", 2008, available online from http://cseweb.ucsd.edu/ mihir/papers/gb.html

(M635): (Incidence Geometry), Credits - 6

(3 Lectures + 1 Tutorial)

Definitions and Exampleas, projective planes, affine planes, projective spaces, affine spaces, collineations of projective and affine spaces, fundamental the- orem of projective and affine spaces, polar spaces, generalized quadrangles, quadrics and quadratic sets.

Reference reading materials:

1. J. Ueberberg, "Foundations of Incidence Geometry", Springer Monographs in Math- ematics, Springer, 2011.
2. L. M. Batten, "Combinatorics of Finite Geometries", Cambridge University Press, 1997.
3. E. E. Shult, "Points and Lines", Universitext, Springer, 2011.
4. L. M. Batten, A. Beutelspacher, "The Theory of Finite Linear Spaces: Combina- torics of points and lines", Cambridge University Press, 1993.
5. G. E. Moorhouse, "Incidence Geometry", 2007, available online from http://www.uwyo.edu/moorhouse/handouts/incidence geometry.pdf

(M636): (Lie Algebras), Credits - 6

(3 Lectures + 1 Tutorial)

Definitions and Examples, Derivations, Ideals, Homomorphisms, Nilpotent Lie Algebras and Engel's theorem, Solvable Lie Algebras and Lie's theo- rem, Jordan decomposition and Cartan's criterion, Semisimple Lie algebras, Casimir operator and Weyl's theorem, Representations of $sl(2, F)$, Root space decomposition, Abstract root systems, Weyl group and Weyl cham- bers, Classification of irreducible root systems, Abstract theory of weights, Isomorphism and conjugacy theorems, Universal enveloping algebras and PBW theorem, Representation theory of semi-simple Lie algebras, Verma modules and Weyl character formula.

Reference reading materials:

1. J. E. Humphreys, "Introduction to Lie Algebras and Representation Theory", Graduate Texts in Mathematics 9, Springer-Verlag, 1978.
2. K. Erdmann, M. J. Wildon, "Introduction to Lie Algebras", Springer Undergradu- ate Mathematics Series, Springer-Verlag, 2006.
3. J.-P. Serre, "Complex Semisimple Lie Algebras", Springer Monographs in Mathe- matics, Springer-Verlag, 2001.
4. N. Jacobson, "Lie Algebras", Dover Publications, 1979.

(M637): (Optimization Theory), Credits - 6
(3 Lectures + 1 Tutorial)

Linear programming problem and its formulation, convex sets and their properties, Graphical method, Simplex method, Duality in linear program- ming, Revised simplex method, Integer programming, Transportation prob- lems, Assignment problems, Games and strategies, Two-person (non) zero- sum games, Introduction to non-linear programming and techniques.

Reference reading materials:

1. J. K. Strayer, "Linear Programming and its Applications", Undergraduate Texts in Mathematics, Springer-Verlag, 1989.

2. P. R. Thie, G. E. Keough, “An Introduction to Linear Programming and Game Theory”, John Wiley & Sons, 2008.
3. L. Brickman, “Mathematical Introduction to Linear Programming and Game The- ory”, Undergraduate Texts in Mathematics, Springer-Verlag, 1989.
4. D. G. Luenberger, Y. Ye, “Linear and Nonlinear Programming”, International Se- ries in Operations Research & Management Science 116, Springer, 2008.

(M638): (Advanced Partial Differential Equations), Credits - 6
(3 Lectures + 1 Tutorial) *Prerequisites: M605, M614 or equivalent*

Distribution Theory, Sobolev Spaces, Embedding theorems, Trace theorem. Dirichlet, Neumann and Oblique derivative problem, Weak formulation, Lax–Milgram, Maximum Principles– Weak and Strong Maximum Princi- ples, Hopf Maximum Principle, Alexandroff-Bakelmann-Pucci Estimate.

Reference reading materials:

1. L. C. Evans, “Partial Differential Equations”, Graduate Studies in Mathematics 19, American Mathematical Society, 2010.
2. H. Brezis, “Functional Analysis, Sobolev Spaces and Partial Differential Equa- tions”, Universitext, Springer, 2011.
3. R. A. Adams, J. J. F. Fournier, “Sobolev Spces”, Pure and Applied Mathematics 140, Elsevier/Academic Press, 2003.
4. S. Kesavan, “Topics in Functional Analysis and Applications”, John Wiley & Sons, 1989.
5. M. Renardy, R. C. Rogers, “An Introduction to Partial Differential Equations”, Springer, 2008.

(M639): (Random Graphs), Credits - 6
(3 Lectures + 1 Tutorial)

Models of random graphs and of random graph processes; illustrative ex- amples; random regular graphs, configuration model; appearance of the giant component small subgraphs; long paths and Hamiltonicity; coloring problems; eigenvalues of random graphs and their algorithmic applications; pseudo-random graphs.

Reference reading materials:

1. N. Alon, J. H. Spencer, “The Probabilistic Method”, John Wiley & Sons, 2008
2. B. Bollobas, “Random Graphs”, Cambridge Studies in Advanced Mathematics 73, Cambridge University Press, 2001.
3. S. Janson, T. Luczak, A. Rucinski, “Random Graphs”, Wiley-Interscience, 2000.
4. R. Durrett, “Random Graph Dynamics”, Cambridge University Press, 2010.
5. J. H. Spencer, “The Strange Logic of Random Graphs”, Springer-Verlag, 2001.

(M640): (Randomized Algorithms and Probabilistic Methods), Credits - 6
(3 Lectures + 1 Tutorial)

Inequalities of Markov and Chebyshev (median algorithm), first and sec- ond moment method (balanced allocation), inequalities of Chernoff (per- mutation routing) and Azuma (chromatic number), rapidly mixing Markov chains (random walk in hypercubes, card shuffling), probabilistic generating functions (random walk in d-dimensional lattice)

Reference reading materials:

1. R. Motwani, P. Raghavan, "Randomized Algorithms", Cambridge University Press, 2004.
2. M. Mitzenmacher, E. Upfal, "Probability and Computing: Randomized algorithms and probabilistic analysis", Cambridge University Press, 2005.

(M642): (Multivariate Statistical Analysis), Credits - 6

(3 Lectures + 1 Tutorial)

Review of matrix algebra (optional), data matrix, summary statistics, graph- ical representations. Distribution of random vectors, moments and charac- teristic functions, transformations, some multivariate distributions: multi- variate normal, multinomial, Dirichlet distribution, limit theorems. Multi- variate normal distribution: properties, geometry, characteristics function, moments, distributions of linear combinations, conditional distribution and multiple correlation. Estimation of mean and variance of multivariate nor- mal, theoretical properties, James-Stein estimator (optional), distribution of sample mean and variance, the Wishart distribution, large sample behavior of sample mean and variance, assessing normality. Inference about mean vector: testing for normal mean, Hotelling T^2 and likelihood ratio test, con- fidence regions and simultaneous comparisons of component means, paired comparisons and a repeated measures design, comparing mean vectors from two populations, MANOVA. Techniques of dimension reduction, principle component analysis: definition of principle components and their estimation, introductory factor analysis, multidimensional scaling. Classification prob- lem: linear and quadratic discriminant analysis, logistic regression, support vector machine. Cluster analysis: non-hierarchical and hierarchical methods of clustering.

Reference reading materials:

1. K. V. Mardia, J. T. Kent and J. M. Bibby, "Multivariate Analysis", Academic Press, 1980.
2. T. W. Anderson, "An introduction to Multivariate Statistical Analysis", Wiley, 2003.
3. C. Chatfield and A. J. Collins, "Introduction to Multivariate Analysis", Chapman & Hall, 1980.
4. R. A. Johnson and D. W. Wichern, "Applied Multivariate Statistical Analysis", 6th edition, Pearson, 2007.
5. Brian Everitt and Torsten Hothorn, "An Introduction to Applied Multivariate Analysis with R", Springer, 2011.
6. M. L. Eaton, "Multivariate Statistics", John Wiley, 1983.

(M643): (Introduction to Manifolds), Credits - 6
(3 Lectures + 1 Tutorial)

Differentiable manifolds and maps: Definition and examples, Inverse and implicit function theorem, Submanifolds, immersions and submersions. The tangent and cotangent bundle: Vector bundles, (co)tangent bundle as a vector bundle, Vector fields, flows, Lie derivative. Differential forms and Integration: Exterior differential, closed and exact forms, Poincaré lemma, Integration on manifolds, Stokes theorem, De Rham cohomology.

Reference reading materials:

1. Michael Spivak, "A comprehensive introduction to differential geometry", Vol. 1, 3rd edition, 1999.

2. Frank Warner, “Foundations of differentiable manifolds and Lie groups”, Springer- Verlag, 2nd edition, 1983.
3. John Lee, “Introduction to smooth manifolds”, Springer Verlag, 2nd edition, 2013.
4. Louis Auslander and Robert E. MacKenzie, “Introduction to differentiable mani- folds”, Dover, 2nd edition, 2009.

(M644): (Regression Analysis), Credits - 6

(3 Lectures + 1 Tutorial)

Introduction to simple linear regression, least square estimation and hypoth- esis testing of model parameters, prediction, interval estimation in simple linear regression, Coefficient of determination, estimation by maximum like- lihood, multiple linear regression, matrix representation of the regression model, estimation and testing of model parameters and prediction, model adequacy checking- residual analysis, PRESS statistics, outlier detection, lack of fit test, serial correlation and Durbin-Watson test, transformation and weighting to correct model inadequacies-variance-stabilizing transfor- mation, generalized and weighted least squares, diagnostics for influential observations, Cooks D test, multicollinearity- sources and effects, diagnosis and treatment for multicollinearity, ridge regression and LASSO, bootstrap estimation, dummy variable model, variable selection and model building- stepwise methods, polynomial regression and interaction regression models, nonlinear regression, generalized linear models-logistic regression and Pois- son regression.

Reference reading materials:

1. Douglas C. Montgomery, Elizabeth A. Peck, G. Geoffrey Vining, Introduction to Linear Regression Analysis, 5th Edition, Wiley, 2012.
2. N. R. Draper and H. Smith (1998), Applied Regression Analysis, 3rd Edition, New York: Wiley.
3. Michael H. Kutner, Chris J. Nachtsheim, and John Neter, Applied Linear Statistical Models, McGraw-Hill/Irwin; 5th edition, 2004.
4. Seber, G. A. F. and Lee, A. J., Linear Regression Analysis, John Wiley and Sons, 2nd Edition, 2003.
5. N. H. Bingham, John M. Fry, Regression: Linear Models in Statistics, Springer Undergraduate Mathematics Series, 2010.

(M645): (Time Series Analysis), Credits - 6

(3 Lectures + 1 Tutorial)

Examples and objectives of time series, stationary time series and autocor- relation function, estimation and elimination of trend and seasonal compo- nents, testing for noise sequence, moving average process, autoregressive pro- cesses and ARMA processes, estimation of autocorrelation function, meth- ods of forecasting-Durbin-Levinson algorithm and Innovations algorithm, the Wold decomposition, ARMA models-the auto-covariance and partial auto-covariance function, forecasting ARMA processes, spectral analysis- spectral densities, periodogram, modeling with ARMA processes, Yule-Walker estimation, maximum likelihood estimation, diagnostic checking, non-stationary time series-ARIMA models, identification techniques, forecasting ARIMA models, seasonal ARIMA models, multivariate time series, ARCH and GARCH models.

Reference reading materials:

1. Peter J. Brockwell and Richard A. Davis, Introduction to Time Series and Fore- casting, Springer Texts in Statistics, 2010.
2. Chris. Chatfield, The analysis of time series: An introduction, 6th edition, Chap- man & Hall/CRC, 2004.
3. Michael H. Kutner, Chris J. Nachtsheim, and John Neter, Applied Linear Statistical Models, McGraw-Hill/Irwin; 5th edition, 2004.
4. J. D. Cryer and K.-S. Chan, Time series analysis with applications in R, 2nd edition, Springer, 2008.
5. R. H. Shumway and D. S. Stoffer, Time series analysis and its applications with R examples, 3rd edition, Springer, 2011.

(M652): (Complex Analysis), Credits - 6
(3 Lectures + 1 Tutorial)

Cauchy-Riemann equations, Cauchy’ s theorem and estimates, Zeros, Poles and Singularities, The open mapping theorem, The argument principle, Maximum modulus principle, Schwarz lemma, Residues and the residue cal- culus.Normal families, Arzela’ s theorem, Product developments, functions with prescribed zeroes and poles, Hadamard’ s theorem, Conformal map- pings, Riemann mapping theorem, the linear fractional transformations.

Reference reading materials:

1. L. V. Ahlfors: Complex analysis (McGraw-Hill), 1978.
2. J. B. Conway: Functions of one complex variable II (Springer), 1995.
3. W. Rudin: Real and Complex Analysis (McGraw-Hill), 1987.
4. R. Remmert: Theory of Complex Functions, Springer 1998.

(M653): (Differential Equations), Credits - 6
(3 Lectures + 1 Tutorial)

Ordinary Differential Equations: Initial and boundary value problems, Ba- sic existence, Uniqueness theorems for a system of ODE, Gronwalls lemma, Continuous dependence on initial data, Linear systems with variable coef- ficients, Variation of parameter formula, Floquet theory, Systems of linear equations with constant coefficients, Stability of equilibrium positions.Partial Differential Equations: Single and systems of PDE, First order PDE, Semi- linear and nonlinear equations (Monges method), Four important linear PDE, Transport equations, Laplace equations, Fundamental solution, Mean value formulas, Greens functions, Energy methods, Heat equation, funda- mental solution, Mean value formula, Energy methods, Wave equations, So- lutions by spherical mean, Energy method, Maximum principle for elliptic and parabolic equations with applications.

Reference reading materials:

1. V. I. Arnold, Ordinary Differential Equations , Prentice Hall of India.
2. Brauer and Nohel, Qualitative Theory of Differential Equations, Dover Publica- tions.
3. Coddington and Levinson, Ordinary Differential Equations, Tata Mcgraw-Hill.
4. Fritz John, Partial Differential Equation, Narosa Publications.
5. M. Renardy and R. C. Rogers, An Introduction to Partial Differential Equations, Springer International Edition.
6. L. C. Evans, Partial Differential Equations, AMS Graduate Studies in Mathematics, Vol 19.

(M654): (Discrete Mathematics), Credits - 6
(3 Lectures + 1 Tutorial)

Combinatorics:Counting principles, Generating functions, Recurrence rela- tion, Polyas enumeration theory, partially ordered sets.
Graph Theory:Graphs, Trees, Blocks, Connectivity, Eulerian and Hamilto- nian graphs, Planer graphs, Graph colouring.
Design Theory: Block Designs, Balanced incomplete block design, Differ- ence sets and Automorphism, Latin squares, Hadamard matrices, Projective planes, Generalized quadrangles.
Algorithm:Algorithm, Asymptotic analysis, Complexity hierarchy, NP-complete problems.

Reference reading materials:

1. F. Roberts and B. Tesman: Applied Combinatorics. Pearson Education, 2005.
2. M. Aigner, A course in Enumeration, Springer.
3. R. P. Stanley, Enumerative Combinatorics, Cambridge University Press.
4. F. Harary, Graph Theory, Narosa Publishing House.
5. G.A. Bondy and U.S.R. Murty: Graph Theory. Springer, 2008.
6. W. D. Wallis, Introduction to Combinatorial Designs, Chapman & Hall/CRC
7. D. R. Stinson and D. Stinson, Combinatorial Designs: Construction and Analysis, Springer.
8. Thomas Cormen, Charles Leiserson, Ronald Rivest: Introduction to Algorithms. PHI, 1998.

(M655): (Graph Theory), Credits - 6
(3 Lectures + 1 Tutorial)

Basic definitions, Eulerian and Hamiltonian graphs, Planarity, Colourabil- ity, Four colour problem, Matching and Halls marriage theorem, Max-flow Min-cut theorem, Ramsey theory, Line graphs, Enumeration, Digraphs. Ma- troids, Groups and Graphs, Matrices and graphs, Eigenvalues of graphs, The Laplacian of a graph, Strongly regular graphs.

Reference reading materials:

1. D. B. West, Introduction to Graph Theory, Prentice Hall of India.
2. F. Harary, Graph Theory, Narosa Publishing House.
3. B. Bollobas, Extremal Graph Theory , Dover Publications.
4. R. Diestel, Graph Theory, Springer International Edition.
5. G. A. Bondy and U. S. R. Murty, Graph Theory, Springer
6. C. Godsil and G. Royle, Algebraic Graph Theory, Springer International Edition.

(M656): (Introduction to Number Theory), Credits - 6
(3 Lectures + 1 Tutorial)

The Fundamental Theorem of Arithmetic, Distribution of prime numbers, Congruences, Chinese remainder theorem, Congruences with prime-power modulus, Fermat' s little theorem, Wilson' s theorem, Euler function and its applications, Group of units, Primitive roots, Quadratic residues and Quadratic reciprocity law, Arithmetic functions, Mobius Inversion formula, Dirichlet product, Sum of squares, Introduction to Zeta function and Dirich- let Series.

Reference reading materials:

1. G. H. Hardy & E. M. Wright: An Introduction to the Theory of Numbers (Oxford).
2. J. A. Jones and J. M. Jones: Elementary Number Theory (Springer).
3. I. Niven, H. S. Zuckerman & H. L. Montgomery: The Theory of Numbers (Wiley)
4. T. M. Apostol: Introduction to Analytic Number Theory (Springer)

(M657): (Probability Theory-I), Credits - 6

(3 Lectures + 1 Tutorial)

Review of Basic undergraduate probability: Random variables, Standard discrete and continuous distributions, Expectation, Variance, Conditional Probability.

Discrete time Markov chains: countable state space, classification of states Characteristic functions, modes of convergences, Borel-Cantelli Lemma, Cen- tral Limit Theorem, Law of Large numbers, Convergence Theorems in Markov Chains.

Reference reading materials:

1. W. Feller: Introduction to Probability Theory and ins Applications Vol.I & Vol. II (Wiley)
2. S. M. Ross: Introduction to Probability Models (AP)
3. Hoel, Port & Stone: Introduction to Stochastic Processes (HMC)
4. S. M. Ross: Stochastic Processes (Wiley)

(M658): (Probability Theory - II), Credits - 6

(3 Lectures + 1 Tutorial)

Martingale Theory: Radon-Nikoydm Theorem, Doob-Meyer decomposition. Weak convergence of probability measures, Brownian motion, Markov processes and Stationary processes.

Reference reading materials:

1. O. Kallenberg: Foundation of Modern Probability (Springer)
2. P. Billingsley: Convergence of probability measures.(John Wiley & Sons, Inc.)
3. D. Revuz & M. Yor: Continuous martingales and Brownian motion (Springer- Verlag)
4. S. M. Ross: Stochastic Processes (Wiley)
5. J. L. Doob: Stochastic Processes (Wiley)

(M751): (Algebraic Computation), Credits - 6

(3 Lectures + 1 Tutorial)

Linear algebra and lattices: Asymptotically fast matrix multiplication algo- rithms, linear algebra algorithms, normal forms over fields, Lattice reduc- tion; Solving system of non-linear equations: Gröbner basis, Buchberger's algorithms, Complexity of Gröbner basis computation; Algorithms on poly- nomials: GCD, Barlekamp-Massey algorithm, factorization of polynomials over finite field, factorization of polynomials over Z and Q; Algorithms for algebraic number theory: Representation and operations on algebraic num- bers, trace, norm, characteristic polynomial, discriminant, integral bases, polynomial reduction, computing maximal order, algorithms for quadratic fields; Elliptic curves: Implementation of elliptic curve, algorithms for ellip- tic curves.

Reference reading materials:

1. A. V. Aho, J. E. Hopcroft, J. D. Ullman, "The Design and Analysis of Computer Algorithms", Addison-Wesley Publishing Co., 1975.
2. H. Cohen, "A Course in Computational Algebraic Number Theory", Graduate Texts in Mathematics 138, Springer-Verlag, 1993.
3. D. Cox, J. Little, D. O' shea, "Ideals, Varieties and Algorithms: An introduction to computational algebraic geometry and commutative algebra", Undergraduate Texts in Mathematics, Springer-verlag, 2007.

(M752): (Analytic Number Theory), Credits - 6
(3 Lectures + 1 Tutorial)

Arithmetic functions, Averages of arithmetical functions, Distribution of primes, finite abelian groups and characters, Gauss sums, Dirichlet series and Euler products, Reimann Zeta function, Dirichlet L-functions, Analytic proof of the prime number theorem, Dirichlet Theorem on primes in arith- metic progression.

Reference reading materials:

1. T. M. Apostol, "Introduction to Analytic Number Theory", Springer International Student Edition, 2000.
2. K. Chandrasekharan, "Introduction to Analytic Number Theory", Springer-Verlag, 1968.
3. H. Iwaniec, E. Kowalski, "Analytic Number Theory", American Mathematical So- ciety Colloquium Publications 53, American Mathematical Society, 2004.

(M753): (Classical Groups), Credits - 6
(3 Lectures + 1 Tutorial)

General and special linear groups, bilinear forms, Symplectic groups, sym- metric forms, quadratic forms, Orthogonal geometry, orthogonal groups, Clifford algebras, Hermitian forms, Unitary spaces, Unitary groups.

Reference reading materials:

1. L. C. Grove, "Classical Groups and Geometric Algebra", Graduate Studies in Math- ematics 39, American Mathematical Society, 2002.
2. E. Artin, "Geometric Algebra", John Wiley & sons, 1988.

(M754): (Ergodic Theory), Credits - 6
(3 Lectures + 1 Tutorial)

Measure preserving systems; examples: Hamiltonian dynamics and Liou- villes theorem, Bernoulli shifts, Markov shifts, Rotations of the circle, Ro- tations of the torus, Automorphisms of the Torus, Gauss transformations, Skew-product, Poincare Recurrence lemma: Induced transformation: Kaku- tani towers: Rokhlins lemma. Recurrence in Topological Dynamics, Birkhoffs Recurrence theorem, Ergodicity, Weak-mixing and strong-mixing and their characterizations, Ergodic Theorems of Birkhoff and Von Neumann. Con- sequences of the Ergodic theorem. Invariant measures on compact systems, Unique ergodicity and equidistribution. Weyls theorem, The Isomorphism problem; conjugacy, spectral equivalence, Transformations with discrete spectrum, Halmosvon Neumann theorem, Entropy. The Kolmogorov-Sinai theorem. Calculation of Entropy. The Shannon Mc-MillanBreiman Theo- rem, Flows. Birkhoffs ergodic Theorem and Wieners ergodic theorem for flows. Flows built under a function.

Reference reading materials:

1. Peter Walters, “An introduction to ergodic theory”, Graduate Texts in Mathemat- ics, 79. Springer-Verlag, 1982.
2. Patrick Billingsley, “Ergodic theory and information”, Robert E. Krieger Publishing Co., 1978.
3. M. G. Nadkarni, “Basic ergodic theory”, Texts and Readings in Mathematics, 6. Hindustan Book Agency, 1995.
4. H. Furstenberg, “Recurrence in ergodic theory and combinatorial number theory”, Princeton University Press, 1981.
5. K. Petersen, “Ergodic theory”, Cambridge Studies in Advanced Mathematics, 2. Cambridge University Press, 1989.

(M755): (Harmonic Analysis), Credits - 6

(3 Lectures + 1 Tutorial)

Fourier series and its convergences, Dirichlet kernel, Frejer kernel, Parse- val formula and its applications. Fourier transforms,the Schwartz space, Distribution and tempered distribution, Fourier Inversion and Plancherel theorem. Fourier analysis on L_p-spaces. Maximal functions and bounded- ness of Hilbert transform. Paley-Wiener Theorem for distribution. Poisson summation formula, Heisenberg uncertainty Principle, Wiener’s Tauberian theorem.

Reference reading materials:

1. Y. Katznelson, “An Introduction to Harmonic Analysis”, Cambridge University Press, 2004.
2. E. M. Stein, G. Weiss, “Introduction to Fourier Analysis on Euclidean Spaces”, Princeton Mathematical Series 32, Princeton University Press, 1971.
3. G. B. Folland, “Fourier Analysis and its Applications”, Pure and Applied Under- graduate Texts 4, America Mathematical Society, 2010.

(M756): (Lie Groups and Lie Algebras - I), Credits - 6

(3 Lectures + 1 Tutorial)

General Properties: Definition of Lie groups, subgroups, cosets, group ac- tions on manifolds, homogeneous spaces, classical groups. Exponential and logarithmic maps, Adjoint representation, Lie bracket, Lie algebras, subal- gebras, ideals, stabilizers, center Baker-Campbell-Hausdorff formula, Lie’s Theorems. Structure

Theory of Lie Algebras: Solvable and nilpotent Lie algebras (with Lie/Engel theorems), semisimple and reductive algebras, invariant bilinear forms, Killing form, Cartan criteria, Jordan decomposition. Complex semisimple Lie algebras, Toral subalgebras, Cartan subalgebras, Root decomposition and root systems. Weight decomposition, characters, highest weight representations, Verma modules, Classification of irreducible finite-dimensional representations, BGG resolution, Weyl character formula.

Reference reading materials:

1. D. Bump, “Lie Groups”, Graduate Texts in Mathematics 225, Springer, 2013.
2. J. Faraut, “Analysis on Lie Groups”, Cambridge Studies in Advanced Mathematics 110, Cambridge University Press, 2008.

3. B. C. Hall, "Lie Groups, Lie algebras and Representations", Graduate Texts in Mathematics 222, Springer-Verlag, 2003.
4. W. Fulton, J. Harris, "Representation Theory: A first course", Springer-Verlag, 1991.
5. J. E. Humphreys, "Introduction to Lie Algebras and Representation Theory", Graduate Texts in Mathematics 9, Springer-Verlag, 1978.
6. A. Kirillov, "Introduction to Lie Groups and Lie Algebras", Cambridge Studies in Advanced Mathematics 113, Cambridge University Press, 2008.
7. V. S. Varadharajan, "Lie Groups, Lie Algebras and their Representations", Springer- Verlag, 1984.

(M757): (Operator Algebras), Credits - 6
(3 Lectures + 1 Tutorial) *Prerequisites: M605 or equivalent*

Banach algebras/C*–algebras: Definition and examples; Spectrum of a Ba- nach algebra; Gelfand transform; Gelfand-Naimark theorem for commu- tative Banach algebras/ C*-algebras; Functional calculus for C*-algebras; Positive cone in a C*-algebra; Existance of an approximate identity in a C*-algebra; Ideals and Quotients of a C*-algebra; Positive linear functionals on a C*-algebra; GNS construction. Locally convex topologies on the alge- bras of bounded operators on a Hilbert space, von-Neumann' s bi-commutant theorem; Kaplansky' s density theorem. Ruan' s characterization of Operator Spaces (if time permites).

Reference reading materials:

1. R. V. Kadison, J. R. Ringrose, "Fundamentals of the Theory of Operator Algebras Vol. I", Graduate Studies in Mathematics 15, American Mathematical Society, 1997.
2. G. K. Pedersen, "C*–algebras and their Automorphism Groups", London Mathe- matical Society Monographs 14, Academic Press, 1979.
3. V. S. Sunder, "An Invitation to von Neumann Algebras", Universitext, Springer- Verlag, 1987.
4. M. Takesaki, "Theory of Operator Algebras Vol. I", Springer-Verlag, 2002.

(M758): (Representations of Linear Lie Groups), Credits - 6
(3 Lectures + 1 Tutorial)

Introduction to topological group, Haar measure on locally compact group, Representation theory of compact groups, Peter Weyl theorem, Linear Lie groups, Exponential map, Lie algebra, Invariant Differentail operators, Rep- resentation of the group and its Lie algebra. Fourier analysis on $SU(2)$ and

$SU(3)$. Representation theory of Heisenberg group . Representation of Eu- clidean motion group.

Reference reading materials:

1. J. E. Humphreys, "Introduction to Lie algebras and representation theory", Springer- Verlag, 1978.
2. S. C. Bagchi, S. Madan, A. Sitaram, U. B. Tiwari, "A first course on representation theory and linear Lie groups", University Press, 2000.
3. Mitsou Sugiura, "Unitary Representations and Harmonic Analysis", John Wiley & Sons, 1975.
4. Sundaram Thangavelu, "Harmonic Analysis on the Heisenberg Group", Birkhauser, 1998.
5. Sundaram Thangavelu, "An Introduction to the Uncertainty Principle", Birkhauser, 2003.

(M759): (Harmonic Analysis on Compact Groups), Credits - 6
(3 Lectures + 1 Tutorial) *Prerequisites: M605*

Review of General Theory: Locally compact groups, Computation of Haar measure on R, T, $SU(2)$, $SO(3)$ and some simple matrix groups, Convolu- tion, the Banach algebra $L^1(tt)$. Representation Theory: General properties of representations of a locally compact group, Complete reducibility, Basic operations on representations, Irreducible representations. Representations of Compact groups: Unitarilzibality of representations, Matrix coefficients, Schur' s orthogonality relations, Finite dimensionality of irreducible represen- tations of compact groups. Various forms of Peter-Weyl theorem, Fourier analysis on Compact groups, Character of a representation. Schur' s orthog- onality relations among characters. Weyl' s Chracter formula, Computing the Unitary dual of $SU(2)$, $SO(3)$; Fourier analysis on $SO(n)$.

Reference reading materials:

1. T. Brocker, T. Dieck, "Representations of Compact Lie Groups", Springer-Verlag, 1985.
2. J. L. Clerc, "Les Représentatios des Groupes Compacts, Analyse Harmonique" (J. L. Clerc et. al., ed.), C.I.M.P.A., 1982.
3. G. B. Folland, "A Course in Abstract Harmonic Analysis", CRC Press, 2000.
4. M. Sugiura, "Unitary Representations and Harmonic Analysis", John Wiley & Sons, 1975.
5. E. B. Vinberg, "Linear Representations of Groups", Birkhäuser/Springer, 2010.
6. A. Wawrzyńczyk, "Group Representations and Special Functions", PWN–Polish Scientific Publishers, 1984.

(M760): (Modular Forms of One Variable), Credits - 6
(3 Lectures + 1 Tutorial)

$SL_2(Z)$ and its congruence subgroups, Modular forms for $SL_2(Z)$, Modular forms for congruence subgroups, Modular forms and differential operators, Hecke theory, L-series, Theta functions and transformation formula.

Reference reading materials:

1. J.-P. Serre, "A Course in Arithmetic", Graduate Texts in Mathematics 7, Springer- Verlag, 1973.
2. N. Koblitz, "Introduction to Elliptic Curves and Modular Forms", Graduate Texts in Mathematics 97, Springer-Verlag, 1993.
3. J. H. Bruinier, G. van der Geer, G. Harder, D. Zagier, "The 1-2-3 of Modular Forms", Universitext, Springer-Verlag, 2008.
4. F. Diamond, J. Shurman, "A First Course in Modular Forms", Graduate Texts in Mathematics 228, Springer-Verlag, 2005.

5. S. Lang, "Introduction to Modular Forms", Springer-Verlag, 1995.
6. G. Shimura, "Introduction to the Arithmetic Theory of Automorphic Forms", Princeton University Press, 1994.

(M761): (Elliptic Curves), Credits - 6

(3 Lectures + 1 Tutorial)

Congruent numbers, Elliptic curves, Elliptic curves in Weierstrass form, Ad- dition law, Mordell–Weil Theorem, Points of finite order, Points over finite fields, Hasse-Weil L-function and its functional equation, Complex multipli- cation.

Reference reading materials:

1. J. H. Silverman, J. Tate, "Rational Points on Elliptic Curves", Undergraduate Texts in Mathematics, Springer-Verlag, 1992.
2. N. Koblitz, "Introduction to Elliptic Curves and Modular Forms", Graduate Texts in Mathematics 97, Springer-Verlag, 1993.
3. J. H. Silverman, "The Arithmetic of Elliptic Curves", Graduate Texts in Mathe- matics 106, Springer, 2009.
4. A. W. Knapp, "Elliptic Curves", Mathematical Notes 40, Princeton University Press, 1992.
5. J. H. Silverman, "Advanced Topics in the Arithmetic of Elliptic Curves", Graduate Texts in Mathematics 151, Springer-Verlag, 1994.

(M762): (Brownian Motion and Stochastic Calculus), Credits - 6
(3 Lectures + 1 Tutorial) *Prerequisites: M632 or equivalent*

Brownian Motion, Martingale, Stochastic integrals, extension of stochastic integrals, stochastic integrals for martingales, Itô's formula, Application of Itô's formula, stochastic differential equations.

Reference reading materials:

1. H. H. Kuo, "Introduction to Stochastic Integration", Springer, 2006.
2. J. M Steele, "Stochastic Calculus and Financial Applications", Springer-Verlag, 2001.
3. F. C. Klebaner, "Introduction to Stochastic Calculus with Applications", Imperial College, 2005.

(M763): (Differentiable Manifolds and Lie Groups), Credits - 6
(3 Lectures + 1 Tutorial)

Review of Several variable calculus: Directional derivatives, Inverse Function Theorem, Implicit function Theorem, Level sets in R^n, Taylor's theorem, Smooth function with compact support. Manifolds: Differentiable manifold, Partition of Unity, Tangent vectors, Derivative, Lie groups, Immersions and submersions, Submanifolds. Vector Fields: Left invariant vector fields of Lie groups, Lie algebra of a Lie group, Computing the Lie algebra of various classical Lie groups. Flows: Flows of a vector field, Taylor's formula, Com- plete vector fields. Exponential Map: Exponential map of a Lie group, One parameter subgroups, Frobenius theorem (without proof). Lie Groups and Lie Algebras: Properties of Exponential function, product formula, Cartan's Theorem, Adjoint representation, Uniqueness of differential structure on Lie groups. Homogeneous Spaces: Various examples and Properties. Coverings: Covering spaces, Simply connected Lie groups, Universal covering group of a connected Lie group. Finite dimensional representations of Lie groups and Lie algebras.

Reference reading materials:

1. D. Bump, "Lie Groups", Graduate Texts in Mathematics 225, Springer, 2013.
2. S. Helgason, "Differential Geometry, Lie Groups and Symmetric Spaces", Graduate Studies in Mathematics 34, American Mathematical Society, 2001.
3. S. Kumaresan, "A Course in Differential Geometry and Lie Groups", Texts and Readings in Mathematics 22, Hindustan Book agency, 2002.
4. F. W. Warner, "Foundations of Differentiable Manifolds and Lie Groups", Graduate Texts in Mathematics 94, Springer-Verlag, 1983.

(M764): (Lie Groups and Lie Algebras - II), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M756 or equivalent*

General theory of representations, operations on representations, irreducible representations, Schur' s lemma, Unitary representations and complete re- ducibility. Compact Lie groups, Haar measure on compact Lie groups, Schur' s Theorem, characters, Peter-Weyl theorem, universal enveloping alge- bra, Poincare-Birkoff-Witt theorem, Representations of Lie($SL(2, \mathbb{C})$). Ab- stract root systems, Weyl group, rank 2 root systems, Positive roots, simple roots, weight lattice, root lattice, Weyl chambers, simple reflections, Dynkin diagrams, classification of root systems, Classification of semisimple Lie al- gebras. Representations of Semisimple Lie algebras, weight decomposition, characters, highest weight representations, Verma modules, Classification of irreducible finite-dimensional representations, Weyl Character formula, The representation theory of $SU(3)$, Frobenius Reciprocity theorem, Spherical Harmonics.

Reference reading materials:

1. D. Bump, "Lie Groups", Graduate Texts in Mathematics 225, Springer, 2013.
2. J. Faraut, "Analysis on Lie Groups", Cambridge Studies in Advanced Mathematics 110, Cambridge University Press, 2008.
3. B. C. Hall, "Lie Groups, Lie algebras and Representations", Graduate Texts in Mathematics 222, Springer-Verlag, 2003.
4. W. Fulton, J. Harris, "Representation Theory: A first course", Springer-Verlag, 1991.
5. A. Kirillov, "Introduction to Lie Groups and Lie Algebras", Cambridge Studies in Advanced Mathematics 113, Cambridge University Press, 2008.
6. A. W. Knapp, "Lie Groups: Beyond an introduction", Birkäuser, 2002.
7. B. Simon, "Representations of Finite and Compact Groups", Graduate Studies in Mathematics 10, American Mathematical Society, 2009.

(M765): (Mathematical Foundations for Finance), Credits - 6

(3 Lectures + 1 Tutorial) *Prerequisites: M632 or equivalent*

Financial market models in finite discrete time, Absence of arbitrage and martingale measures, Valuation and hedging in complete markets, Basic facts about Brownian motion, Stochastic integration, Stochastic calculus: Itô's formula, Girsanov transformation, Itô's representation theorem, Black-Scholes formula

Reference reading materials:

1. J. Jacod, P. Protter, "Probability Essentials", Universitext, Springer-Verlag,

2003.
2. D. Lamberton, B. Lapeyre, “Introduction to Stochastic Calculus Applied to Fi- nance”, Chapman-Hall, 2008.
3. H. Follmer, A. Schied, “Stochastic Finance: An Introduction in Discrete Time”, de Gruyter, 2011.

IMSc

SYLLABUS FOR

Ph.D. in Computer Science (Program Code: MATH04)

Doctoral programmes in Theoretical Computer Science at IMSc

There are two streams leading to the Doctoral degree in TCS at IMSc: the Ph.D. programme and the Integrated Ph.D. programme.

The course credit requirement for the Ph.D. programme is 60 credits, fulfilled during two semesters of course work, typically comprising of 5 core courses, 3 elective courses, one credit seminar, and a research methodology course.

For the Integrated Ph.D. programme, the requirement is 120 credits, including a 32 credit Master's thesis. This typically involves three semesters of course work of 4 courses each, one credit seminar, a research methodology course, and a Master's thesis in the fourth semester.

TCS courses are generally of 7 credits each. The seminar is 4 credits. The research methodology course is a pass/fail course, with no credits earned.

The books suggested for reference are indicative rather than definitive: faculty teaching the course may follow other texts. Moreover, the references keep getting updated as newer and better books become available.

1 Core courses

10MATH04-001-C-CS Theory of computation (7 credits)

Finite automata Robustness of definition, right/left equivalences, non-regularity.

Properties Analysis and synthesis theorems, closure properties, Decision algorithms, Minimization, Syntactic monoid.

Trees, PDA Bottom up and top down tree automata, pushdown automata, algorithms on these.

Turing machines Basic constructions, Robustness, Universal TM, Church-Turing thesis.

Undecidability Undecidability of halting problem, Reductions.

Recursion Recursion theorem, definition of information.

Books for reference:

- J E Hopcroft, J D Ullman and R Motwani. Introduction to automata theory, languages and computation (3rd Ed. Pearson, 2013).
- M Sipser, Introduction to the theory of computation (PWS Publishing, 1997).

10MATH04-002-C-CS Algorithms (7 credits)

Definitions O, o, ω, Ω notations

Algorithmic Paradigms and Problems Divide and Conquer, Greedy, Dynamic Programming. Sorting, selection, searching and merging, master method for solving recurrence relations,

Data Structures and Applications to Graph Algorithms

- Queues and Stacks applied to BFS, DFS and applications.
- Variations of heaps applied to single source shortest paths and spanning tree algorithms
- Disjoint union-find applied to Kruskal's minimum spanning tree algorithm
- Balanced binary search trees (some sample of red-black trees, AVL, B-trees)

Network Flows MaxFlow and Mincut Algorithms.

Lower Bound Techniques Oracle, Adversary Techniques, Introduction to NP-completeness and coping strategies.

Books for reference:

1. T H Cormen, C E Leiserson, R L Rivest, C Stein. Introduction to algorithms, 3rd ed (MIT Press, 2001).
2. U Manber. Introduction to algorithms.
3. E Horowitz, S Sahni, S Rajasekaran. Fundamentals of computer algorithms (Galgotia, 1998).
4. Jon Kleinberg and Eva Tardos, Algorithm Design. 2005.

<u>10MATH04-003-C-CS</u> Discrete mathematics (7 credits)

Basic combinatorics Double counting, induction, subsets, partitions, permutations, Recurrence relations, generating functions, some formal power series.

Pigeon-hole principle Ramsey's theorem as generalization, Systems of Distinct Representatives, Hall's Theorem.

Compactness principle König's infinity lemma, applications to infinite graphs, Posets and lattices, Dilworth's theorem.

Inclusion exclusion principles Steiner triple systems, designs, Mobius inversion (including the poset form) and applications,.

Basic probability theory Distributions, Moments, Tail Inequalities, Martingales, Markov Chains, Probabilistic Method, Lovasz Local Lemma and applications.

Basic algebra Groups, rings, fields, applications of groups in combinatorics (Pólya's enumeration theorem), Applications to error-correcting codes.

Books for reference:

5. Peter Cameron. Combinatorics: topics, techniques, algorithms (CUP, 1998).
6. R.P. Stanley. Enumerative combinatorics (CUP, 1997), Volume 1.
7. C.L. Liu, Introduction to combinatorial mathematics (McGraw-Hill, 1968).
8. J.H. van Lint, R.M. Wilson. A course on combinatorics (CUP, 1992).

10MATH04-004-C-CS Logic (7 credits)

Propositional/zeroth order logic Syntax and semantics, Satisfaction in a structure, Consequence, Compactness, Deduction theorem, Natural deduction.

Basic theorems and extensions Compactness and Completeness theorems, Boolean algebras, Quantified boolean formulas.

First order logic Syntax and semantics, Truth checking, Completeness, Compactness and applications, Sequent calculus, Cut elimination, Monadic second order logic.

Modal logic Syntax and semantics, Correspondence theory, Decidability and complexity, Completeness of modal logics, Propositional dynamic logic.

Books for reference:

9. M Ben-Ari, Mathematical Logic for Computer Science, 2nd edition (Springer, 2001).
10. H-D Ebbinghaus, J Flum, W Thomas. Mathematical logic (Springer, 1994).

10MATH04-005-C-CS

Computational complexity (7 credits) **General results**

Space and time hierarchy theorems, diagonalization, speedup and compression theorems.

Complexity classes Many-one Reductions, completeness, Turing reductions, relativization, oracles. Decision, search, optimization, self-reducibility.

Space classes Halting, reachability, determinization, complementation.

Polynomial hierarchy Alternation, relativization.

Randomized computation Classes, resources, bounds.

Proofs and circuits Interactive Proof Systems, The Complexity of Boolean Functions, Uniform circuit families and branching programs, interactive proofs.

Extended models Counting classes, parsimonious reductions, isolation, counting vs alternation, overview of PCPs, connections to inapproximability.

Books for reference:

11. S Arora and B Barak. Computational Complexity: A Modern Approach (Cambridge Unviersity Press 2009).

12. C Papadimitriou. Computational complexity (Addison Wesley 1994).

13. J Balcazar, Diaz, Gabarro. Structural complexity I & II (Springer, 1990).

<u>10MATH04-006-C-CS</u> Credit Seminar (4 credits)

The topic of the seminar will be chosen by the student in consultation with an assigned faculty member. The student will read recent research papers as assigned by the faculty member, and present the results in a formal seminar.

2 Elective courses

The syllabi of elective courses which have been offered over the past several years follows. The composition of electives offered, as well as the syllabus for each elective, is decided each time by the Monitoring Committees according to the needs of individual students. Many take the form of seminar courses, or reading courses of assisted independent study.

10MATH04-001-E-CS Advanced Data Structures (7 credits)

Splay trees and related conjectures, link-cut trees, Perfect Hashing, Suffix Trees and Arrays and applications, Geometric data structures (interval trees, segment trees, ...), orthogonal range searching, van Emde Boas trees, Fusion trees, Dynamic Graph Algorithms, Space efficient data structures.

Books for reference:

- Multidimensional searching and Computational Geometry, Volume 3 of Data Structures and Algorithms, K. Mehlhorn, EATCS monograph, Springer 1984
- Sorting and searching, Volume 1 of Data Structures and Algorithms, K. Mehlhorn, EATCS monograph, Springer 1984
- Data Structures and Network Algorithms, R.E. Tarjan, SIAM 1983.
- Research papers and surveys

10MATH04-002-E-CS Algorithms for special classes of graphs (7 credits)

Core : Characterization, Polynomial Time Recognition and algorithms for some NP-hard problems on the following graph classes: Interval, Permutation, Chordal, Split, Permutation, Threshold, Perfect, Comparability, Superperfect

Advance : Minimal Triangulations, Minimal Separators, Potential Maximal Cliques based algorithms in designing polynomial time, parameterized algorithms and exact exponential time algorithms, geometric graphs.

Books for reference:

- Algorithmic graph theory and perfect graphs, Martin Charles Golumbic, Elsevier, 2004.
- Topics in Intersection Graph Theory, Terry A. McKee and F. R. McMorris, SIAM, 1999.
- Graph Classes: A Survey (Monographs on Discrete Mathematics and Applications), Andreas Brandstädt , Van Bang Le and Jeremy P. Spinrad, SIAM, 1987.
- Relevant papers.

10MATH04-003-E-CS Graph Theory (7 credits)

Core: Graphs, trees, forests, bipartite graphs, contractions, minors, directed graphs), König's theorem, Halls theorem, Tuttes theorem, Erdös-Pósa theorem on vertex disjoint cycles and feedback vertex set, Nash-Williams theorem, Gallai-Milgram theorem for path covering, Mengers theorem

Advance: Hadwiger's conjecture, Szemerédi's regularity lemma and its applications, a couple of ramsey theorems, Minors-Trees and WQO (graph minor theorem for tress, graphs of bounded treewidth, grid minor theorem, high level description of graph minor theorem

Books for reference:

- Reinhard Diestel, Graph Theory, Fourth edition, Springer, 2010.

10MATH04-004-E-CS Kernelization (7 credits)

Core: Definition of Kernel, Vertex Cover and Generlization, Crown Reduction, Expansion Lemma, Sunflower Lemma, Hypergraph Matching, Modular Decomposition, Inductive Priorities, Kernels on Planar Graphs, Machinery to show lower bound on the existence of polynomial kernels

Advance: Protrusions, Finite Integer Index, Representative Sets, Matroids, Lossy Kernels

Books for reference:

- Kernelization: Theory of Parameterized Preprocessing, Fedor V. Fomin, Daniel Lokshtanov, Saket Saurabh and Meirav Zehavi. To appear in Cambridge University Press, 2016.
- Relevant Papers.

10MATH04-005-E-CS Mathematical foundations of computer science (7 credits)

Probability: Events and Probability, Discrete Random Variables and Expectations, Moments and Deviations, Chernoff Bounds, Poisson Distribution, Probabilistic Method, Markov Chain and Random Walks, Monto Carlo Methods and Martingales

Linear Algebra: linear algebra background, orthogonality and rank arguments, eigenvalues and graph expansion, polynomial methods, exterior algebra based methods

Books for reference:

- Probability and Computing: Randomized Algorithms and Probabilistic Analysis by Michael Mitzenmacher and Eli Upfel, Cambridge University Press, 2005.
- Extremal Combinatorics, Second Edition, Stasys Jukna, Springer, 2011.
- Linear Algebra Methods in Combinatorics by Laszlo Babai and Peter Frankl.

10MATH04-006-E-CS Parameterized Complexity (7 credits)

Course Content: Kernelization, Bounded Search Trees, Iterative Compression, Randomized Methods in Parameterized algorithms, Finding cuts and separators, Treewidth, Fixed Parameter Intractability, Lower bounds for kernelization

Books for reference:

- Parameterized Complexity Theory, Jörg Flum and Martin Grohe, Springer, 2006.
- Invitation to fixed-parameter algorithms, Rolf Niedermeier, Oxford University Press, 2006.
- Fundamentals of parameterized complexity, Rodney G Downey and Michael R. Fellows, Springer, 2013.
- Parameterized algorithms, Marek Cygan, Fedor V. Fomin, Łukasz Kowalik, Daniel Lokshtanov, Dániel Marx, Marcin Pilipczuk, Michał Pilipczuk and Saket Saurabh, Springer, 2015.

10MATH04-007-E-CS Advanced Parameterized Complexity (7 credits)

Course Content: Advance Kernelization Algorithms, Algebraic techniques: sieves-convolutions-and-polynomials, Improving dynamic programming on tree decompositions, Matroids, Recursive Understanding, Bounded Treewidth Graph Isomorphism, Bisection Decomposition, Lossy Kernelization, Parameterized Complexity for problems solvable in polynomial time, Lower bounds based on the Exponential-Time Hypothesis

Books for reference:

- Parameterized Complexity Theory, Jörg Flum and Martin Grohe, Springer, 2006.
- Fundamentals of parameterized complexity, Rodney G Downey and Michael R. Fellows, Springer, 2013.
- Parameterized algorithms, Marek Cygan, Fedor V. Fomin, Łukasz Kowalik, Daniel Lokshtanov, Dániel Marx, Marcin Pilipczuk, Michał Pilipczuk and Saket Saurabh, Springer, 2015.
- Relevant Papers in the area.

10MATH04-008-E-CS Algorithmic Game Theory (7 credits)

Course Content: Introduction and examples, Mechanism design basics, Myerson's Lemma, Algorithmic mechanism design, Revenue-maximizing auctions, Simple near-optimal auctions, Multi-parameter mechanism design, Spectrum auctions, Mechanism design with payment constraints, Kidney exchange and stable matching, Selfish routing and the price of anarchy, Network over-provisioning and atomic selfish routing, Equilibria: definitions, examples, and existence, Robust price-of-anarchy bounds in smooth games, Best-case and strong Nash equilibria, Best-response dynamics, No-regret dynamics, Swap regret and the Minimax theorem, Pure Nash equilibria and PLS-completeness, Mixed Nash equilibria and PPAD-completeness.

Books for reference:

- Twenty Lectures on Algorithmic Game Theory, Tim Roughgarden, Cambridge University Press, 2016.
- Algorithmic game theory, Noam Nisan, Tim Roughgarden, Eva Tardos and Vijay Vazirani, Cambridge University Press, 2007.

10MATH04-009-E-CS Computational Social Choice Theory (7 credits)

Voting : Introduction to theory of Voting, (Weighted) Tournament Solutions, Dodgson's Rule and Young's Rule, Barriers to manipulation in voting, Control and bribery in voting, Rationalizations of voting rules, Voting in combinatorial domains, Incomplete information and communication in voting

Fair Allocation : Introduction to the theory of fair allocation, Fair allocation of indivisible goods, Cake cutting algorithms

Coalition Formation : Matching under preferences, Hedonic games, Weighted voting games

Additional Topics : Judgment aggregation, Axiomatic approach and the internet, Knockout tournaments

Books for reference:

- Handbook of Computational Social Choice, Felix Brandt, Vincent Conitzer, Ulle Endriss, Jérome Lang and Ariel D. Procaccia, Cambridge Univer- sity Press, 2016.
- Relevant papers in the area.

10MATH04-010-E-CS Algebraic Graph Theory (7 credits)

Course Content: Graphs, Groups, Transitive Groups, Generlized polygons and Morre graphs, Homomorphisms, Kneser graphs, Matrix theory, Interlacing, Strongly regular graphs, Line graphs and Eigenvalues, Laplacian of a graph, Cuts and Flows, Rank polynomial, Knots and Eulerian graphs

Books for reference:

- Spectra of Graphs, Andries E. Brouwer and Willem H. Haemers, Springer, 2012.
- Algebraic Graph Theory, Chris Godsil and Gordon Royle, Gordon, Graduate Texts in Mathematics 207, Springer, 2001.
- Algebraic Graph Theory (2nd ed.), Norman Biggs, Cambridge University Press, 1993.

10MATH04-011-E-CS Topological Graph Theory (7 credits)

Course Content: Basic graph terms, basics of topology, Jordan's curve theorem with a proof, Kuratowski's theorem, with a proof, The Four Colour Theorem with an outline of a proof, Planarity algorithms and complexity, Graphs embedded on higher surfaces, Graph minors, treewidth, and "forbidden" characterizations, The "Kuratowski" theorem for any surface, Graphs drawings with edge-crossings, The crossing number problem and its complexity, Crossing-critical graphs and their structure, Sparse graph classes and depth measures.

Books for reference:

- Graphs on Surfaces, Bojan Mohar and Carsten Thomassen , Johns Hopkins University Press, 2001.
- Graphs on Surfaces: Dualities, Polynomials, and Knots, oanna A. Ellis-Monaghan and Iain Moffatt, Springer, 2013.
- The Foundations of Topological Graph Theory, C. Paul Bonnington and Charles H. C. Little, Springer, 1995.

10MATH04-012-E-CS Machine Learning (7 credits)

Course Content: Prologue: A machine learning sampler, The ingredients of machine learning, Density Estimation, Optimization, Binary classification and related tasks, Beyond binary classification, Concept learning, Online Learning and Boosting, Conditional Densities, Kernels and Function Space, Tree models, Rule models, Linear models, Distance-based models, Probabilistic models, Features, Model ensembles, 12 Machine learning experiments

Books for reference:

- Introduction to Machine Learning, Alex Smola and S.V.N. Vishwanathan, Cambridge University Press, 2008.
- Machine Learning: The Art and Science of Algorithms that Make Sense of Data, Peter Flach, Cambridge University Press, 2012.

10MATH04-013-E-CS Algebraic Graph Algorithms (7 credits)

Course Content: Introduction to matrix multiplication, Equivalences with other linear algebraic operations, Four-Russians algorithms, Graph transitive closure is equivalent to Boolean matrix multiplication, Seidel's algorithm for All pair shortest paths (APSP), Zwick's algorithm for APSP, Yuster/Zwick's Distance oracle; APSP in node-weighted graphs, All pairs earliest arrivals, bottleneck paths and the dominance product, Successor and witness matrices; computing actual paths, Equivalences between APSP and other problems, Perfect matching: Rabin-Vazirani algorithm, Perfect matching: Harvey's algorithm, The Baur-Strassen theorem and graph algorithms, Algorithms for Matroid Intersection and Matroid Parity, Matrix multiplication algorithms, Coppersmith-Winograd and beyond

Books for reference:

- Relevant papers.

10MATH04-014-E-CS Algorithms for Genomics (7 credits)

Course Content: Introduction, Trees First, A deeper introduction to recombination and networks, exploiting recombination, first bounds, fundamental combinatorial structure and tools, Galled Trees, General AEG construction methods, Conditions to guarantee a fully decomposed MinARG, Tree and ARG-Based Haplotyping, Tree and ARG-Based Association Mapping

Suffix Trees and Applications

Books for reference:

- ReCombinatorics: The Algorithmics of Ancestral Recombination Graphs and Explicit Phylogenetic Networks, Dan Gusfeld, MIT Press, 2014.
- Algorithms on Strings, Trees and Sequences, Dan Gusfeld, Cambridge University Press, 1997.

10MATH04-015-E-CS Matroid Theory (7 credits)

Course Content: Graph Theory, Vector Spaces, Transversals, Definition of Matroids, Representability, Duality, Minors and Connectivity, Decomposition of Graphic Matroids, Signed Graphic Matroids, Higher Connectivity, Binary Matroids, Excluded minor theorems, Submodular functions and matroid union, Seymour's decomposition theorem

Books for reference:

- Topics in Matroid Theory, Leonidas S. Pitsoulis, Springer, 2014.
- Matroid Theory, James Oxley, Oxford University Press, 2011.

- Matroids: A geometric introduction, Gary Gordon and Jennifer McNulty, Cambridge University Press, 2012.

<u>10MATH04-016-E-CS</u> Probabilistic Method (7 credits)

Course Content: The basic method, Ramsey numbers, Dominating sets in graphs, Hypergraph 2-coloring, Sum-free subsets, Set pairs theorem, Linearity of expectation, Hamiltonian paths in tournaments and the conjecture of Szele, Minc Conjecture, The second moment method, Turan's proof of the Hardy Ramanujan theorem, distinct sums, random graphs and threshold functions, cliques in random graphs, Dependent Random Choice and its applications, The local lemma: the general lemma and its symmetric version, Straus' problem, directed cycles, Correlation inequalities: the four functions theorem and its applications, the FKG Inequality, Kleitman's Theorem, correlation between properties of random graphs, Martingales: the edge exposure and the vertex exposure martingales, Azuma's Inequality, Poisson approximation: The Janson Inequalities and their application for constructing Ramsey type graphs, Application in property testing

Books for reference:

- The Probabilistic Method, N. Alon and J. H. Spencer, Wiley, 1992. (Second Edition, 2000, Third Edition 2008).
- Relevant papers.

<u>10MATH04-017-E-CS</u> Exact Exponential Algorithms (7 credits)

Course Content: Branching, Dynamic Programming, Inclusion-Exclusion, Treewidth, Measure and Conquer, Subset Convolution, Local Search and SAT, Monotone Local Search, Split and List, Time-Space tradeoffs, Bandwidth, Subexponential time algorithms, ETH and SETH based on lower bounds

Books for reference:

- Exact Exponential Algorithms, Fedor V. Fomin and Dieter Kratsch, Springer, 2010.

- Relevant papers.

<u>10MATH04-018-E-CS</u> Randomized Algorithms (7 credits)

Tools and Techniques : Computation Model and Complexity classes, Probabilistic Recurrences, Game-Theoretic Techniques, Moments and Deviation, Tail Inequalities, Probabilistic Method, Markov Chain and Random Walks, Algebraic Techniques

Application : Data Structures, Geometric Algorithms and Linear Programming, Graph Algorithms, Approximate Counting, Online Algorithms, Number Theory and Algebra, Randomized Approximate Algorithms.

Books for reference:

- Randomized Algorithms, Rajeev Motwani and Prabhakar Raghavan, Cambridge University Press, 1995.
- Probability and Computing: Randomized Algorithms and Probabilistic Analysis by Michael Mitzenmacher and Eli Upfel, Cambridge University Press, 2005.
- Extremal Combinatorics, Second Edition, Stasys Jukna, Springer, 2011.
- Relevant papers.

<u>10MATH04-019-E-CS</u> Computational complexity - II (7 credits))

Course Content: Advanced topics in complexity theory — circuit lower bounds, hardness vs randomness, PCPs, etc.

References: S Arora and B Barak. Computational Complexity: A Modern Approach (Cambridge Unviersity Press 2009). Also, recent papers.

<u>10MATH04-020-E-CS</u> Algebraic Complexity Theory (7 credits)

Course Content: Algebraic computation models, reductions and completeness, complexity measures for polynomials, lower bounds, connections to polynomial identity testing,

References:

- Bürgisser, Clausen, Shokrollahi. Algebraic Complexity Theory (Springer 1997).
- Bürgisser. Completeness and Reductions in Algebraic Complexity Theory (Springer 2000).
- Shpilka and Yehudayoff. Arithmetic Circuits: A Survey of Recent Results and Open Questions (FTTCS, Now Publishers, 2010).

10MATH04-021-E-CS Analysis of Boolean functions (7 credits)

Course Content: The study of Boolean functions via their Fourier expansion and other analytic means. Applications to property testing, circuit complexity, learning theory, inapproximability, concrete complexity.

References: Ryan O' Donnell. Analysis of Boolean Functions (Cambridge University Press, 2012).

10MATH04-022-E-CS Circuit complexity (7 credits)

Course Content: Low level complexity questions: to understand how circuits compute, to develop mathematical machinery for the analysis of circuits, and to create a mathematical toolbox against our adversary – the circuit.

References:

- S Jukna. Boolean Function Complexity: Advances and Frontiers (Springer 2012).
- H. Vollmer. Introduction to Circuit Complexity: A Uniform Approach (Springer 1999).

10MATH04-023-E-CS Communication Complexity (7 credits)

Course Content: Models of communication complexity and inter-relationships; applications to streaming algorithms, games, circuit complexity; lower bound techniques.

References:

- Kushilevitz and Nisan. Communication Complexity (Cambridge University Press 1997).
- Tim Roughgarden. Communication Complexity (for Algorithm Designers) (FTTCS Vol 11, Now Publishers 2016).

10MATH04-024-E-CS Concrete Lower Bounds (7 credits)

Course Content: basic lower bounds techniques in various models: Boolean circuits (with various restrictions: formulas, branching programs, decision trees, monotone circuits, span programs, negation-limited circuits, bounded-depth circuits ...), communication complexity, proof complexity, algebraic complexity, extension complexity.

References:

- S Jukna. Boolean Function Complexity: Advances and Frontiers (Springer 2012).
- Tim Roughgarden. Communication Complexity (for Algorithm Designers) (FTTCS Vol 11, Now Publishers 2016).

10MATH04-025-E-CS Expanders, PCPs, and Derandomization (7 cred- its)

Course Content: Hardness amplification, derandomization, pseudo-randomness, probabilistically checkable proofs.

References: S Arora and B Barak. Computational Complexity: A Modern Approach (Cambridge Unviersity Press 2009).

10MATH04-026-E-CS Proof Complexity (7 credits)

Course Content: proof complexity and connections to SAT solving; resolution – size, width, space, pebbling; polynomial calculus, cutting planes, Frege proofs; proof systems for QBFs.

References: Survey papers –

- Paul Beame and Toniann Pitassi: Propositional Proof Complexity: Past, Present and Future. Bulleting of the EATCS Vol 65, 1998. Also on ECCC TR 1998-067.
- Nathan Segerlind: The Complexity of Propositional Proofs. Bulletin of Symbolic Logic 13(4): 417-481 (2007)
- Jakob Nordström: Pebble Games, Proof Complexity, and Time-Space Trade-offs. Logical methods in CS Vol 9, 2013.

10MATH04-027-E-CS Small Space Computation (7 credits)

Course Content: Space-bounded computation models - TMs, width-bounded circuits and branching programs, auxiliary PDA, streaming model; complexity classes, relations, and completeness; arithmetization.

References:

- S Arora and B Barak. Computational Complexity: A Modern Approach (Cambridge Unviersity Press 2009).
- H. Vollmer. Introduction to Circuit Complexity: A Uniform Approach (Springer 1999).
- Recent Papers.

10MATH04-028-E-CS Incidence Theorems and their Applications (7 cred- its)

Course Content: Arrangements of lines, points, and other geometric objects in space. Counting incidences. Kakeya-type problems. Sylvester-Gallai type problems.

References: Zeev Dvir. Incidence Theorems and their Applications (FTTCS Vol 6, Now Publishers, 2012).

10MATH04-029-E-CS Randomness and Computation (7 credits)

Course Content: Probabilistic computation and complexity classes, examples of randomized algorithms, Interactive Proofs with variants and examples, perfect security and its limitations, computational security, secure psuedorandom generators, one-way functions and one-way permutations, PCP theorem and hardness of approximation, derandomization using pseudorandom generators, Nisan-Wigderson construction, expanders and extractors.

Books for reference:

- Computational Complexity : A Modern Approach, Sanjeev Arora and Boaz Barak, Cambridge University Press, 2009.
- Computational Complexity, Christos Papadimitriou, Addison-Wesley, 1994.

- Published Literature.

10MATH04-030-E-CS Algorithmic Geometry of Numbers (7 credits)

Course Content: Basic definitions from Geometry of Numbers, Minkowski's convex body theorem, Minkowski's first and second inequality, Planar Lattice Reduction, Eisenbrand's algorithm for shortest vector using extended Euclidean algorithm, LLL reduced basis, the LLL algorithm, Exact algorithms for Shortest Vector Problem and the Closest Vector Problem (CVP), approximate algorithms for CVP, Dual Lattices and basic transference theorems, Fourier Analysis over Lattices and its applications.

References:

- Kannan's notes on Algorithmic Geometry of Numbers.
- Oded Regev's lecture notes on Lattices in Computer Science.
- Eisenbrand's survey: Integer Programming and Algorithmic Geometry of Numbers.
- Carl Ludwig Siegel's Lectures on the Geometry of Numbers.
- Chapters 8 and 9 of Yap's Fundamental Problems in Algorithmic Algebra.

10MATH04-031-E-CS Algorithms for solving polynomial equations (7 credits)

Course Content: Root Isolation for Univariate Polynomials, Resultants, Theory of Ideals, Gröbner basis, Elimination theory, Invariant Theory, Theory of Fewnomials, Sums of Squares, Tropical Algebraic Geometry.

References:

- Cox, Little, O'Shea: Ideals, Varieties and Algorithms; Sturmfels – Solving Polynomial Equations.
- Yap: Fundamental problems in Algorithmic Algebra; Sturmfels – Algorithms in Invariant Theory.
- Sturmfels: Grobner Basis and Convex Polytopes.

<u>10MATH04-032-E-CS</u> Computational geometry (7 credits)

Course Content: Convex hulls, Voronoi Diagram, Delaunay Triangulation, Polygon Triangulation, Point Location, Quadtrees, Orthogonal Range Searching, Line Segment Intersection, Incidence Geometry, Discrete geomtery, epsilon-nets, Set Traversals, Embedding Finite Metrics, Measure Concentration.

References:
- de Berg et al.: Computational Geometry; Matousek: Discrete Geometry.

<u>10MATH04-033-E-CS</u> Computational Topology (7 credits)

Course Content: Topological Spaces, Manifolds, Simplicial Complexes, Homology, Morse Theory, The Persistence algorithm, Topological simplification, Morse-Smale complex algorithm, Knot theory.

References:
- Edelsbrunner: Computational Topolgy; Zomordian: Computational Topology.
- Rote and Vegter: Computational Topology.

<u>10MATH04-034-E-CS</u> Convex Optimization (7 credits)

Course Content: Mathematical (nonlinear) programming, convex sets, convex functions, convex optimization problems, Duality, Applications to graph theory and statistics, Algorithms for unconstrained minimization, Algorithms for equality constrained minimization, interior point methods, multiplicative weights update method.

References:
- Boyd and Vandenberghe: Convex Optimization; Vishnoi: Fundamentals of Convex optimization.

<u>10MATH04-035-E-CS</u> Linear programming and combinatorial optimiza- tion (7 credits)

Course Content: Simplex method, Randomized algorithms, Polyhedral theory, Duality theory, Ellipsoid method, Primal-Dual methods, Interior point methods, Semidefinite programming, Combinatorial optimization problems, Extension complexity, Lovasz-Schrijver and Lasserre Hierarchies.

References:
- B. Gartner and J. Matousek: Understanding and using linear programming.
- Schrijver: Theory of Linear and Integer Programming.
- Recent Papers

<u>10MATH04-036-E-CS</u> Algebraic theory of automata (7 credits)

Course contents: Myhill-Nerode congruence, syntactic monoid, varieties, structure of D-classes, Schützenberger's theorem, Simon's theorem, concatenation hierarchies, monoid products, Krohn-Rhodes theorem, Omega-automata, omega-semigroups, Wilke algebras, Büchi's theorem, McNaughton's theorem.

Books for reference:

- J.-E. Pin. Varieties of formal languages (North Oxford, 1986).
- H. Straubing. Finite automata, formal logic and circuit complexity (Birkhauser, 1994).
- D. Perrin, J.-E. Pin. Infinite words (Elsevier, 2004).

<u>10MATH04-037-E-CS</u> Automata and concurrency (7 credits)

Course contents: Petri nets, boundedness, liveness, 1-safe nets, Mazurkiewicz traces, product systems, asynchronous automata, Zielonka's theorem, concurrent regular expressions.

Books for reference:

- D. D'Souza and Priti Shankar (eds), Modern applications of automata theory (IISc-World Scientific, 2012).

10MATH04-038-E-CS Concurrency theory (7 credits)

Course contents: Petri nets, basic situations, conflicts, free choice, S-invariants, T-invariants, Commoner's theorem, Hack's theorem, rank theorem, Communicating sequential processes, process calculi, pi-calculus.

Books for reference:

- J. Desel, J. Esparza. Free choice Petri nets (CUP, 1995).
- C.A.R. Hoare. Communicating sequential processes (Prentice-Hall, 1984).
- R. Milner. Communicating and mobile systems (CUP, 1999).
- M. Hennessy. A distributed pi-calculus (CUP, 2007).

10MATH04-039-E-CS Programming languages and correctness (7 cred- its)

Course contents: Reasoning about programs, assertions, invariants, predicate transformers, Semantics, fixed points, domains, operational semantics, structural induction, While programs, declarations, type checking, procedures, lazy and eager evaluation.

Books for reference:

- D Gries, The science of programming (Springer, 1984).
- J Loeckx and K Sieber, The foundations of program verification (Springer, 1987).

10MATH04-040-E-CS Programming language theory (7 credits)

Course contents: Denotational semantics, fixed points, domains, Structural operational semantics, While programs, declarations, types, procedures, lazy and eager evaluation, Lambda calculus, functional programming, Curry-Howard correspondence, type theory, polymorphism.

Books for reference:

- J Reynolds. Theories of programming languages (CUP, 1998).

10MATH04-041-E-CS Theory of computation: a second course (7cred- its)

Course contents: Regular expressions, star height, feedback number, matrices, semirings, Kleene algebras, inequations, completeness, formal power series, weighted automata, Kleene-Schützenberger theorem.

Books for reference:

- J R Büchi, Finite automata, their algebras and grammars, edited by D Siefkes (Springer, 1989).
- N Pippenger, Theories of computability (CUP, 1997).
- J Sakarovitch, Elements of automata theory (CUP, 2009).

10MATH04-042-E-CS Artificial intelligence (7 credits)

Course Content: Heuristic search, game playing, planning, logic for knowledge representation. Factor graphs and Bayesian networks. Markov decision processes and reinforcement learning, statistical learning. Constraint satisfaction problems.

References:

- Russell and Norvig. Artificial Intelligence: A Modern Approach.
- Koller and Friedman. Probabilistic Graphical Models.
- Sutton and Barto. Reinforcement Learning: An Introduction.
- Hastie, Tibshirani, and Friedman. The elements of statistical learning.
- Tsang. Foundations of constraint satisfaction.

10MATH04-043-E-CS Game theory (7 credits)

Course Content: Introduction to combinatorial games: nim games, sprague - grundy theorem. Extensive form games, backwards induction. Normal form games, iterated elimination of dominated strategies, Nash equilibrium. Brouwer fixed-point theorem, Nash's theorem, von Neumann's minmax theorem. Computation of equilibria, Linear Programming solutions, the complexity class FP. Introduction to co-operative game theory: core and nucleolus. Simple stochastic games and optimal values. Introduction to infinite games: lack of determinacy. Regular infinite games, memoryless determinacy, parity games and Zielonka's theorem. Imperfect information games, Bayesian equilibria.

References:

- Osborne and Rubinstein: A course in game theory.
- Rasmussen: Games and information.
- B Loewe: Lecture notes on infinite games.
- Graedel and Thomas: Lectures on automata, games and logic.

10MATH04-044-E-CS Automata and games (7 credits)

Course Content: Introduction to infinite games: lack of determinacy. Games on finite graphs, backwards induction for reachability. Regular infinite games, Büchi and Muller conditions, parity games. Decidability of logics on infinite words and trees, Rabin's theorem. Strategy improvement for parity games. Nash equilibria for games on graphs. Imperfect information games on graphs.

References:

- Graedel and Thomas: Lectures on automata, games and logic.
- Recent Papers.

10MATH04-045-E-CS Distributed algorithms (7 credits)

Course Content: Introduction to parallel algorithms: partial sums, Batcher merge. Leader election in asynchronous rings: upper and lower bounds. Distributed minimum spanning tree: message complexity. Constructing BFS tree, partition algorithm. Mutual exclusion in Read / Write registers. Fault tolerance: Fischer, Lynch and Paterson theorem. Byzantine agreement in synchronous systems: upper and lower bounds. Selfish agents: introduction to mechanism design.

References:
- Lynch: Distributed algorithms.
- Attiyah: Introduction to distributed algorithms.

10MATH04-046-E-CS Infinite discrete structures (7 credits)

Course Content: Basic set theory: ordinals and transfinite induction. Zorn's lemma and its applications. Well founded orderings.

Ramsey's theorem, infinite and finite versions; van der Waarden's theorem, Roth's theorem; idea of Szemeredi's theorem.

Partial orders: Well quasi orderings; Higman's Lemma, Kruskal's theorem; treewidth theorem. Applications to infinite state systems.

Complete partial orders: Knaster-Tarski theorem; Computing fixeedpoints, applications to program analysis.

References:
- Keith Devlin: The joy of sets, fundamentals of contemporary set theory.
- F Nielson and H R Nielson: Principles of program analysis.
- Schmidt and Schoebelen: Algorithmic theory of WQOs.

10MATH04-047-E-CS Mathematical Logic: a second course (7 credits)

Course Content: Basics of model theory: elementary classes, spectra; Compactness and applications; size of models; interpolation theorems.

Decision problem: Trakhtenbrot's theorem; sharpening undecidability; syntactic decidable fragments – prefix classes and finite variable logics.

Descriptive complexity: Fagin's theorem, LFP logics.

Modal μ-calculus, guarded logics, connection to games.

References:
- Ebbinghaus and Flum: Finite model theory.
- W Hodges: A shorter model theory.
- Recent Papers.

<u>10MATH04-048-E-CS</u> Logics of programs (7 credits)

Course Content: Propositional dynamic logic: completeness, decidability, extensions. Hennessy Milner logics, bisimulations. Process logics. Temporal logics: linear and branching time. Interval logics. Alternating temporal logic. Game logic. Game semantics of logic.

References:

- D Harel: Dynamic logic.
- R Goldblatt: Logics of time and computation.
- Recent Papers.

<u>10MATH04-049-E-CS</u> Verification (7 credits)

Course Content: Kripke structures, Linear time properties, Branching time, expressiveness. Model checking algorithms. Automata based algorithms. Binary decision diagrams, Symbolic model checking, SAT solvers. Craig interpolation, equivalences and abstractions.

References:

- Huth and Ryan: Logic in Computer Science: Modelling and reasoning about systems.
- Clarke, Gumberg and Peled: Model checking.
- Recent Papers.

<u>10MATH04-050-E-CS</u> Topics in Algorithms (7 credits)

Course Content: This is an advanced level research course. The content will be decided by the instructor based on current research and the requirements of the individual students.

References: Current research papers and advanced lecture notes, as specified by the instructor.

<u>10MATH04-051-E-CS</u> Topics in Complexity Theory (7 credits)

Course Content: This is an advanced level research course. The content will be decided by the instructor based on current research and the requirements of the individual students.

References: Current research papers and advanced lecture notes, as specified by the instructor.

10MATH04-052-E-CS Algebra and Computation (7 credits)

Course Content: Permutation group algorithms and Graph Isomorphism. Construction of finite fields. Polynomial factorization over finite fields. Solving linear Diophantane equations. Integer Lattices and the LLL algorithm for approximating the shortest vector in integer lattices. Factorization of univariate and multivariate polynomials over rationals.

References:

- Modern Computer Algebra. Joachim von zur Gathen and Juergen Gerhard. (Cambridge University Press New York, NY, USA, 2003).
- Lectures on polynomial-time computation in groups. Eugene Luks. (Technical Report NU-CCS-90-16, Northeastern University, 1990).

10MATH04-053-E-CS Algebra and Computation: a second course (7 credits)

Course Content: Algorithmic problems in number theory: discrete log, integer factorization, counting points on elliptic curves. The quantum computing model and efficient quantum algorithms for number-theoretic and group-theoretic problems.

References:

- Algorithmic number theory. Eric Bach and Jeff Shallit. (MIT Press, 1996).
- Quantum computation and quantum information. M.A. Nielsen and I.L. Chuang. (Cambridge Univ Press, 2000).

Course Curriculum

for

Ph.D. in Computer Science

Ph.D. MATHEMATICAL SCIENCES COMPUTER SCIENCE (PROGRAM CODE: MATH04)

NATIONAL INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

BHUBANESWAR

SCHOOL OF COMPUTER SCIENCES

Course structure for *PhD in Computer Science*

List 1: Core Courses

Course No.	Course Name	Credits (assigned by BoS)	Suggested credits
CS651	Modern Cryptology		8
CS652	Algorithmic Coding Theory		8
CS653	Complexity Theory		8
CS654	Linear Programming and Combinatorial Optimization		8
CS655	Distributed Network Algorithms		8
CS656	Cyber Forensics		8
CS657	Penetration Testing		8
CS658	Social and Information Network Analysis		8
CS659	Advanced Algorithms		8
CS660	Machine Learning		8
CS661	Randomized Algorithms and Probabilistic Analysis		8

List 2: Seminar Courses

Course No.	Course Name	Credits (assigned by BoS)	Suggested credits
CS791	Seminar Course-I		4
CS792	Seminar Course-II		4
CS793	Seminar Course-III		4

List 3: Pass/Fail Course

Course No.	Course Name	Credits (assigned by BoS)	Suggested credits
CS601	Research Methods		Pass/Fail

1. A student should meet 60 credit requirements as follows:
   (a) In the first semester, the student will do 3 courses from List 1, and CS791 Seminar Course-I.
   (b) In the second semester, the student will do 3 courses from List 1, and CS792 Seminar Course-II and CS793 Seminar Course-III.
   (c) The seminar courses can be on any advanced topic on Computer Science as suggested by the doctoral monitoring committee.
   (d) The performance in the courses will be assessed through assignments, student presentations, vivas, and /or written examinations. The contact hours for each course will be 4 hours per week.
2. A student has to compulsorily attend and pass a Research Methodology course. However no credit for the course will be counted.
3. Having completed the course work successfully, a student will appear for Oral General Comprehensive Examination (OGCE) conducted by the monitoring committee. OGCE will be based on all the courses that a student has taken and will be conducted before the registration of third semester. The process of choosing Ph.D. advisor starts only after the successful completion of OGCE and it has to be done within a month from the date of completion of comprehensive examination.
4. A doctoral committee is constituted by the Dean Academic as per HBNI guidelines after a guide and topic has been decided. The doctoral committee should meet at least once in a year to monitor the progress of a student. Guide, who is the convener of doctoral committee, will send the annual progress report of student to the Dean Academic every year before registration of odd/even semester depending upon the joining date of the student and a copy may be sent to PGCS for further reference.

Remarks

1. CS601 (Research Methods) course is in concurrance with H601 offered by the School of Humanities and Social Sciences.

DETAILED SYLLABUS

CS652: Algorithmic Coding Theory, Credits - 8

Course Outcome Students will be introduced to formalization of the notion of uncertainty of a random variable, Source coding for error-free reconstruction, channel coding and the fundamental theorem, introduction to some algebraic codes (Parity-check codes, Reed-Solomon codes).

Topics
Module 1: Entropy, Characterization and Properties. Application to Combinatorics. Mutual Information and KL Divergence.
Module 2: Source coding theorem, lossless compression of data, Lempel-Ziv Algorithm, Optimal lossless coding.
Module 3 Communication channels (binary symmetric, erasure) and channel capacity, channel coding theorem.
Module 3: Introduction to Error Correcting Codes. Hamming Codes and Hamming Bounds. BCH Codes, Maximum likelihood decoding and syndrome decoding; coding theory bounds.
Module 4: Reed-Solomon codes and the Berlekamp-Welch decoding algorithm with Analysis. List Decoding of Reed-Solomon Codes.
Module 5. Reed-Muller Code and Local decoding.
Module 6. (Optional) Algebraic Algorithm like Miller Rabin, Solvay-Strassen, Berlekamp Algorithm.

Reference

1. T. M. Cover and J. A. Thomas, "Elements of Information Theory" (Second Edition, Wiley).
2. S. Ling C. Xing, " Coding Theory: A First Course", Cambridge University Press.
3. J. Radhakrishnan, "Entropy and Counting", http://www.tcs.tifr.res.in/ jaikumar/Papers/EntropyAndCounting.pdf
4. V. Guruswami, A. Rudra and M. Sudan, "Essential Coding Theory (Draft of a new book)" available at http://www.cse.buffalo.edu/faculty/atri/courses/coding-theory/book/
5. F.J. MacWilliams and N.J.A. Sloane, The Theory of Error-Correcting Codes, North-Holland ML, 1983.

CS653: Complexity Theory, Credits - 8

Course Outcome Students would be able to

- Understand P vs NP arguments and corresponding proofs.
- Learn about interactive proofs and randomized computation

Topics
Module 1 : Introduction, P and NP - Review of Turing machines, universal Turing machines, and uncomputable functions, P vs. NP, NP vs. co-NP, and NP-completeness, EXP, NEXP
Module 2: Cook Levin's Theorem
Module 3 : Diagonalization, Space complexity (Savitch's Theorem, Immerman-Szelepchenyi Theorem, and Reyngold's Theorem.), Polynomial Hierarchy

Module 4 : Interactive Proofs - PCP theorem and its application to approximability, Queery Complexity, Communication Complexity
Module 5 : Circuit complexity and lower bounds
Module 6 : Hardness vs. Randomness - Randomized Computation, derandomization, Pseudo-random generators
Module 7 : Polynomial identity testing vs Lower bounds for arithmetic circuits

Reference

1. S. Arora and B. Barak, "Computational Complexity: A Modern Approach", Cambridge University Press.
2. O. Goldreich, "Computational Complexity: A conceptual perspective", Cambridge University Press.
3. J. Hopcroft, R. Motwani, J. D. Ullman. Introduction to Automata Theory, Languages, and Computation. Pearson Education.
4. C. H. Papadimitriou, Computational Complexity, Pearson Education.
5. P. Harsha, Graduate course on Computational Complexity, http://www.tcs.tifr.res.in/ prahladh/teaching/2013-14/complexity.

CS654: Linear Programming and Combinatorial Optimization, Credits - 8

Course Outcome Students will learn definition and properties of convex sets and functions, convex and affine hulls, recession cones and hyperplanes, constrained optimization, Duality, Minimax Theory
Topics
Module 1: Basic geoemetry and linear algebra related to Linear Programming. Simplex-method and Duality theorem (leading to Von Neumann's minmax principle) and complementary slackness.
Module 2: Ellipsoid algorithm. separation oracles.
Module 3: Semidefinite programming as an extension of linear programming.
Module 4: LP relaxation. Examples of problems where LP relaxation achieves optimum. Examples where LP/SDP relaxation achieves approximate solution. Integrality gaps.
Module 5: Rounding, probabilistic roundings, iterative rounding, primal dual methods.
Module 6 (Optional): Gale-Shapley algorithm, Connection of LP to Cooperative Game Theory core, nucleolus, combinatorial optimization games.

Reference

1. A. Schrijver, "Theory of Linear and Integer Programming", Wiley.
2. A. Schrijver, "Combinatorial Algorithm: Polyhedra and Efficiency, Volume A", Springer.
3. V. Vazirani, "Approximation Algorithm", Springer.
4. S. Chakraborty, M. Mitra, P. Sarkar, "A Course on Cooperative Game Theory", Cambridge University Press.
5. Matousek, Jiri, Gartner, Bernd, Understanding and Using Linear Programming, Springer.

CS659: Advanced Algorithms, Credits - 8

Course Outcome

- Augment their understanding of algorithms with hashing and online algorithms.
- Gain knowledge about parameterized algorithms and computational geometry.
- Learn to prove hardness and equivalences.

Topics
Module 1: Universal Hashing, Load Balancing, Locally Sensitive Hashing.
Module 2: String Algorithms
Module 3: Flow in Networks
Module 4: Online Algorithms
Module 5: Approximation Algorithms
Module 6: Fixed Parameter Algorithms. Parameterized Complexity, Kernelization, Vertex Cover, Connection to Approximation.
Module 7: Computational Geometry. Convex Hull, Line Segment Inersection, Sweep Lines, Voronoi Diagram.
Module 8: Graph Sparsification. Graph Spanners, Distance Oracles.
Module 9. Hardness and equivalences in P.

Reference

1. Berg, Mark de, Marc van Kreveld, Mark Overmars, and Otfried Schwarzkopf. Computational Geometry: Algorithms and Applications. New York, NY: Springer-Verlag, 2000..
2. Vijay Vazirani, Approximation Algorithms. Springer.
3. Lecture Notes and Research Papers.

CS660: Machine Learning, Credits - 8

Course Outcome Students would be able to

- Learn key concepts of machine learning.
- Understand and implement supervised, unsupervised learning algrithms as well as introduction to reinforcement learning.

Topics
Module 1: Introduction
Module 2: Supervised learning: Supervised learning setup. LMS , Logistic regression. Perceptron. Exponential family , Generative learning algorithms. Gaussian discriminant analysis. Naive Bayes, Support vector machines, Model selection and feature selection., Ensemble methods: Bagging, boosting, Evaluating and debugging learning algorithms.
Module 3: Learning theory: Bias/variance tradeoff. Union and Chernoff/Hoeffding bounds. VC dimension. Worst case (online) learning. Practical advice on how to use learning algorithms.
Module 4: Unsupervised learning: Clustering. K-means, EM. Mixture of Gaussians, Factor analysis, PCA (Principal components analysis), ICA (Independent components analysis).
Module 5: Reinforcement learning and control: MDPs. Bellman equations. , Value iteration and policy iteration, Linear quadratic regulation (LQR) LQG, Q-learning. Value function approximation., Policy search. Reinforce. POMDPs.

References

1. Richard Duda, Peter Hart and David Stork, Pattern Classification, 2nd ed. John Wiley & Sons.
2. Tom Mitchell, Machine Learning. McGraw-Hill,.
3. Richard Sutton and Andrew Barto, Reinforcement Learning: An introduction. MIT Press,

CS661: Randomized Algorithms and Probabilistic Analysis, Credits - 8

Course Outcome

- Understand probabilistic analysis and the manners in which it can be used in designing efficient algorithms.
- Study key concepts in Probability Theory and learning about various applications to well-known problems in Computer Science.

Topics
Module 1: Review of discrete probability spaces – Basic probability theory (Events, Expectation, Variance, Markov, Chebyshev, and moment inequalities), Simple randomized algorithms analysis (Randomized Quicksort, polynomial identity, min-cut algorithm, median algorithm), Naïve Bayesian classifier
Module 2: Basic concentration bounds – Chernoff and Hoeffding, Applications (Set balancing, network packet routing, etc.)
Module 3: The occupancy problem – Balls Into Bins, Hashing, Fingerprinting and random graphs
Module 4: The Probabilistic Method – MAX-SAT, conditional expectations, Lovazs Local Lemma, explicit constructions
Module 5: Martingales and concentration bounds
Module 6: Markov Chains and the Monte Carlo method, Rapidly mixing chains and the coupling method
Module 7: Foundations of Machine Learning – Sample Complexity, PAC learning, VC-dimension, Rademacher complexity

Reference

1. M. Mitzenmacher, E. Upfal, "Probability and Computing: Randomized algorithms and probabilistic analysis", Cambridge University Press, 2005 (2nd Edition July, 2017).
2. R. Motwani, P. Raghavan, "Randomized Algorithms", Cambridge University Press, 2004.
3. Dubhashi, Panconesi, "Concentration of Measure for the Analysis of Randomized Algorithms".
4. Alon, Spencer, "The Probabilistic Method".
5. Levin, Peres, Wilmer, "Markov Chains and Mixing Times".
6. William Feller. "An introduction to Probability Theory and Its Applications", Volumes I and II, John Wiley, New York, 1968.

CS651: Modern Cryptology, Credits - 8

Course Outcome

- Understanding basic concepts in Mathematical Cryptology
- Ability to design and analysis of security algorithms

Topics
Module 1: Introduction and Classical Cryptography, Perfect Secrecy, One Time Pad.
Module 2: Symmetric Key Encryption. Computational Security, Concrete vs Asymptotic Approach. Semantic Security. Pseudorandom generators and Stream ciphers, Pseudorandom Functions and Block Ciphers. Practical Constructions.
Module 3: Hash Functions and Message Authentication Codes. Notions of Security, Generic Attacks, Domain Extension techniques, CBC MAC, HMAC, PMAC, Idea of Authenticated Encryption.
Module 4: Review of Basic Number Theory. Hardness Assumptions. One-way functions, Trapdoor Permutations, RSA assumptions, Discrete Log and Diffie Hellman Assumptions, SIS and LWE Assumptions. Introduction to Elliptic Curves (Optional)
Module 5. Key Exchange Protocols and Key Management.
Module 6. Public Key Encryption, Semantic Security, El Gamal Encryption, Padded RSA PKCS#1 v1.5. Random Oracle Technique, OAEP.

Module 7. Digital Signatures, Hash and Sign paradigm, Schnorr Signature, Forking Lemma, DSA. SSL/TLS.
Module 8. (Optional) Idea of some of the following notions, Protocols and Zero Knowledge Proofs, Multiparty Computations and Oblivious Transfers, Secret Sharing. Algorithms for factoring and computing discrete logarithms, Linear and Differential Cryptanalysis, Crypto Currencies.

Reference

1. J. Katz and Y. Lindell, Introduction to Modern Cryptography. CRC, 2014.

CS655: Distributed Network Algorithms, Credits - 8

Course Outcome

- Understand basics of distributed network algorithms and systems.
- Gain knowledge on applications of distributed network algorithms to real-world networks and analysis of such algorithms.

Topics

Module 1: Foundations of distributed network algorithms - Broadcast, converge-cast, maximal independent set, coloring, leader election, spanning tree algorithms, shortest paths, and routing.
Module 2: Fundamental concepts in distributed algorithms - Symmetry breaking, locality, synchronizers
Module 3: Basics of distributed network systems - Communication, synchronization, fault-tolerance, and resource allocation
Module 4: Applications to real-world networks - Internet, peer-to-peer networks, wireless networks, sensor networks and dynamic networks
Module 5: Lower bounds using communication complexity, distributed computation of large-scale data, dynamic network algorithms.

References

1. D. Peleg, "Distributed Computing: A Locality-Sensitive Approach", SIAM 2000.
2. H. Attiya, J. Welch, "Distributed Computing: Fundamentals, Simulations and Advanced Topics", McGraw-Hill Publishing, 1998.
3. N. Lynch, "Distributed Algorithms", Morgan Kaufmann 1996.
4. G. Tel, "Introduction to Distributed Algorithms", Cambridge University Press 2000.
5. G. Pandurangan, "Distributed Network Algorithms, a monograph", Department of CS, University of Houston.

CS656: Cyber Forensics, Credits - 8

Course Outcome

- Understand the key concepts in computer forensics across domains of systems (Windows, linux and Mac) as well as Internet artifacts.
- Investigate mobile systems and get a brief idea on intellectual property and cyber laws.

Topics

Module 1: Introduction to Computer Forensics: computer crimes, evidence, extraction, preservation, etc..

Module 2: Overview of hardware and operating systems: structure of storage media/devices; windows/Macintosh/ Linux – registry, boot process, file systems, file metadata.
Module 3: Data and File System Analysis: identifying hidden data, Encryption/Decryption, Steganography, recovering deleted files.
Module 4: Windows Systems and Artifacts: uncovering attacks that evade detection by Event Viewer, Task Manager, and other Windows GUI tools, data acquisition, disk imaging, recovering swap files, temporary & cache files
Module 5: Linux Systems and Artifacts: File system layers, linux boot process and services, system organization and artifacts, logs and task scheduling
Module 6: Mac Artifacts: File system, system artifacts, user artifacts
Module 7: Internet Artifacts: Browser artifacts, mail artifacts
Module 8: File Analysis: Images, audio, video, archives and documents
Module 9: Automating analysis and extending capabilities: Graphical investigation environments, automating artifact extraction, timelines.
Module 10: Mobile Network Forensic: Introduction, Mobile Network Technology, Investigations, Collecting Evidence, Where to seek Digital Data for further Investigations, Interpretation of Digital Evidence on Mobile Network.
Module 11: Computer crime and Legal issues: Intellectual property, privacy issues, Criminal Justice system for forensic, audit/investigative situations and digital crime scene, investigative procedure/standards for extraction, preservation, and deposition of legal evidence in a court of law.

Reference

1. Cory Altheide , Harlan Carvey , Ray Davidson, "Digital Forensics with Open Source Tools", Syngress Publishing; 1 edition (April 28, 2011)
2. Albert J. Marcella Jr., Frederic Guillossou "Cyber Forensics: From Data to Digital Evidence", Wiley Publication
3. Marjie T. Britz, "Computer Forensics and Cyber Crime: An Introduction", (3rd Edition) 2013

CS657: Penetration Testing, Credits - 8
Course Outcome

- Understand the basics of penetration testing both passive and active.
- Able to test the system for exploits in system, network and web as well as run penetration test in vulnerable systems.

Topics
Module 1: Penetration Testing: What You Should Know, Getting Comfortable with Kali Linux
Module 2: The Essential Tools: Netcat, Ncat, Wireshark, Tcpdump
Module 3: Passive Information Gathering: Open Web information gathering, Email harvesting
Module 4: Active Information Gathering: DNS enumeration, port scanning, SMB enumeration, SNMP enumeration
Module 5: Vulnerability Scanning, Buffer Overflows, Win32 Buffer Overflow Exploitation, Linux Buffer Overflow Exploitation
Module 6: Working with Exploits, File Transfers, Privilege Escalation
Module 7: Client Side Attacks: Know Your Target, MS12-037- Internet Explorer 8 Fixed Col Span ID, Java Signed Applet Attack

Module 8: Web Application Attacks: Cross Site Scripting (XSS), File Inclusion Vulnerabilities, MySQL SQL Injection, Web Application Proxies
Module 9: Password Attacks: Preparing for Brute Force, Online Password Attacks, Password Hash Attacks
Module 10: Port Redirection and Tunneling: SSH Tunneling, Proxychains
Module 11: The Metasploit Framework: Metasploit Payloads, Building Your Own MSF Module, Post Exploitation with Metasploit, Bypassing Antivirus Software

Reference

1. Hacking Exposed 7: Network Security Secrets and Solutions, Stuart McClure, Joel Scambray, George Kurtz, © 2012, McGraw Hill, ISBN 978-0-07-178028-5.
2. Penetration Testing: A Hands-On Introduction to Hacking, Georgia Weidman, No Starch Press

CS658: Social and Information Network Analysis, Credits - 8

Course Outcome

- Learn the basics of social and information network and how to analyze them.
- Key concepts in information maximization and community detection in large graphs.

Topics
Module 1: Introduction and the Bowtie Structure of the Web
Module 2: Basic Network Properties and the Random Graph Model
Module 3: The Small World Phenomena, Decentralized search in small-world and P2P networks
Module 4: User Evaluations in Social Media
Module 5: Cascading Behavior: Decision Based Models of Cascades, Cascading Behavior: Probabilistic Models of Information Flow
Module 6: Influence Maximization, Outbreak Detection
Module 7: Power-laws and Preferential attachment
Module 8: Link Analysis: HITS and PageRank
Module 9: Strength of weak ties and Community structure in networks, Network community detection: Modularity optimization and Spectral Clustering, Overlapping communities in networks
Module 10: Link Prediction and Network Inference, Biological networks

Reference

1. Networks, Crowds, and Markets: Reasoning About a Highly Connected World by David Easley and Jon Kleinberg.
2. Networks: An introduction by Mark Newman.

PHYSICAL SCIENCES

Programme Code: PHYS04

Programme Outcome:

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower to take up research in frontier areas of physics
- Building human resource in carrying out R&D in physical and nuclear sciences
- Training of manpower in working in interdisciplinary subjects with physics as one of the subjects

List of Courses

Course Structure Under BARC:

Sr. No.	Old Course Code	New Course Code	Subject Title	Lectures	Credits	Marks
FOUNDATION COURSES						
1	PHYS04.1	01-PHYS04-501-F	Mathematical Methods	22	3	
2	PHYS04.2	01-PHYS04-502-F	Quantum Mechanics	22	3	
3	PHYS04.3	01-PHYS04-503-F	Classical mechanics & Statistical Mechanics	22	3	
4	PHYS04.4	01-PHYS04-504-F	Electrodynamics	22	3	
5	PHYS04.5	01-PHYS04-505-F	Accelerator Physics	22	3	
6	PHYS04.6	01-PHYS04-506-F	Computational and Numerical Methods	22	3	
7	PHYS04.7	01-PHYS04-507-F	Reactor Physics	15	2	
8	PHYS04.8	01-PHYS04-508-F	Health Physics	15	2	
9	PHYS04.9	01-PHYS04-509-F	Atomic & Molecular Physics	15	2	
			TOTAL	**177**	**24**	
CORE COURSES						
ADVANCED COURSES (THEORY)						
10	PHYS04.10	01-PHYS04-610-C	Advanced Nuclear and Astrophysics	30	4	
11	PHYS04.11	01-PHYS04-611-C	Advanced Condensed Matter Physics	30	4	
12	PHYS04.12	01-PHYS04-612-C	Advanced Laser and Plasma Physics	30	4	
Advanced Experimental Techniques						
13	PHYS04.13	01-PHYS04-613-C	Advanced Experimental Techniques in Nuclear & Astrophysics Advanced	15	2	
14	PHYS04.14	01-PHYS04-614-C	Experimental Techniques in Condensed Matter Physics	15	2	

15	PHYS04.15	01-PHYS04-615-C	Advanced Experimental Techniques in Laser Physics	15	2	
RESEARCH METHODOLOGY						
16	PHYS04.16	01-PHYS04-616-C	Research Methodology		0	
			CORE TOTAL		**18**	
Projects						
17	PHYS04.17	01-PHYS04-617-PR	Common projects at different divisions		8	
18	PHYS04.18	01-PHYS04-618-PR	Common projects at different divisions		10	
			CORE TOTAL		**18**	
			GRAND TOTAL		**60**	

FOUNDATION COURSES

PHYS04.1: Mathematical Methods (22 Lectures / 3 Credits) (01-PHYS04-501-F)

Course Outcomes:

- Understand and apply mathematical techniques for describing and deeper understanding of physical systems.

Course Details:

Linear vector spaces, Linear operators and matrices, Systems of linear equations. Eigen values and eigen vectors, Infinite-dimensional vector spaces: Hilbert space & Hermitian operators. Linear ordinary differential equations, Special functions. Linear partial differential equations in physics, Separation of variables method of solution. Complex variable theory; Analytic functions. Taylor and Laurent expansions, Classification of singularities, Analytic continuation, Contour integration, Method of steepest descent. Integral equations and Green functions, Ideas about nonlinear equations, Approximation methods: WKB approximation, Fourier and Laplace transforms.

References:

1. Mathematical Methods for Physics and Engineering: A Comprehensive Guide, *K. F. Riley, M. P. Hobson, S. J. Bence*
2. Complex Variables: Introductions and Applications, *M. J. Ablowitz and A. S. Focas*
3. Lectures on Advanced Mathematical Methods for Physicists, *S. Mukhi & N. Mukunda*
4. Mathematical Methods for Physicists, *J Mathews and R L Walker*
5. Mathematical Methods for Physicist, *G. Arfken, H. Weber and F.E. Harris*

PHYS04.2: Quantum Mechanics (22 Lectures / 3 Credits) (01-PHYS04-502-F)

Course Outcomes:

- Understand and apply principles of Quantum mechanics for understanding the physical systems in quantum realm.

Course Details:

Review of basic concepts in Quantum Mechanics. Quantum mechanics in one dimension, Particle in a box, Tunneling through finite potential barrier, Harmonic oscillators. Approximation methods in quantum mechanics: W. K. B. and variational methods and their applications. Time independent perturbation theory (for non-degenerate and degenerate cases) and its application to helium atom, Stark and Zeeman effects, Time dependent perturbation theory and Fermi golden rule, its applications to beta decay theory and principle of detailed balance. Collision theory: Born series and approximations, Partial wave analysis, Need for complex potentials, Analytic properties of S-matrix and dispersion theory. Schrodinger, Heisenberg and interaction pictures: Propagator in quantum mechanics. Measurements in Quantum Mechanics, entanglement and uncertainty relations, EPR paradox, Hidden variables and Bell's inequality, spin correlation experiments & applications. Relativistic quantum mechanics: Klein-Gordon and Dirac equations and their solutions, Gamma matrices, Non relativistic limit of Dirac equation; continuous and discrete symmetries and conservation laws in quantum mechanics, Bilinear covariants, Charge conjugation. Lagrangian formulation: Symmetries of Lagrangian density, Noether's theorem, Energy-momentum tensor $T_{\mu\nu}$ – its origin & physical meaning of different components. Path integral formulation of quantum theory: applications.

References:

1. Quantum Mechanics, *Leonard I. Schiff*
2. Quantum Mechanics, *Eugen Merzbacher*

3. Quantum Mechanics, *A. S. Davydov*
4. Principles of Quantum Mechanics, *R. Shankar*
5. Relativistic Quantum Mechanics, *James D. Bjorken and Sidney D. Drell*
6. (i) Quantum Mechanics: Non- Relativistic Theory & (ii) Classical Theory of Fields, *L.D. Landau and E.M. Lifshitz*
7. Quantum Mechanics and Path Integrals, *P. Feynman and A.R. Hibbs*

PHYS04.3: Classical mechanics & Statistical Mechanics (22 Lectures / 3 Credits) (01-PHYS04-503-F)

Course Outcomes:

- Understand and apply principles of physics for understanding the scientific phenomenon in classical domain. Understand and apply statistical methods for describing the classical and quantum particles in various physical systems and processes.

Course Details:

Classical mechanics: Hamilton's equations, Phase space, Principle of least action and Hamilton's principle, Canonical transformations, Contact transformations, Examples of canonical transformations, Poisson brackets and its identities, Liouville's theorem , Poincaré- Cartan integral and differential invariant, Symplectic structure of phase space, Jacobi theorem, Hamilton Jacobi equation, Action-angle variables, Adiabatic invariants, Small oscillations, Canonical perturbation theory, Secular perturbation theory, Nonlinear resonance, Applications in plasma physics, Kolmogorov-Arnold-Moser theorem, Application to understanding of Kirkwood gaps, Saturn's rings, Birkhoff-Poincaré theorem, Chaos in discrete dynamical systems.

Statistical mechanics: Distribution functions, Liouville's equation, Fokker-Planck Equation; Gibbsian statistical ensembles: Microcanonical, Canonical and Grand Canonical ensembles. Gibbs' theorem: Information entropy: Fluctuations: Passage to the classical limit of quantum statistics: Bose Einstein statistics, Fermi-Dirac statistics, properties of Bose and Fermi gases at low temperatures, Bose condensation; Ising Model: Theory of phase transition and critical phenomena- Critical exponents and universality: Statistical mechanics of finite system: Transport theory – BBGKY hierarchy to Boltzmann equation.

References:

1. Mathematical Methodsof Classical Mechanics, V. I. Arnold.
2. Classical Mechanics, T.W.B. Kibble & F. H. Berkshire
3. Fundamentals of Statistical and Thermal Physics, *F. Reif*
4. Non-equilibrium Statistical Thermodynamics, *D. N. Zubarev*
5. Introduction to Phase Transition and Critical Phenomena, *H. E. Stanley*
6. Equilibrium and Non-equilibrium Statistical Mechanics, *R. Balescu*
7. Statistical Mechanics, *K. Huang (John Wiley & Sons, 2nd Ed.)*
8. Statistical Mechanics, *R. K. Pathria, (Pergamon Press).*
9. Fundamentals of Statistical Mechanics, *B. B. Laud, (New Age International Edition).*
10. Statistical Mechanics (Parts I and II), *L. D. Landau and E. M. Lifshitz.*
11. Statistical Mechanics (Frontiers in Physics), *R. P. Feynman*

PHYS04.4: Electrodynamics (22 Lectures / 3 Credits) (01-PHYS04-504-F)

Course Outcomes:

- Gain knowledge in understanding the principles and dynamic phenomena of electromagnetism that occur in the case of time-varying sources (local charges and currents). Equips the students with the necessary mathematical knowledge for a detailed and accurate description of these phenomena and for solving related problems.

Course Details:

Maxwell equations, Macroscopic electromagnetism, Conservation laws: Maxwell's displacement current, Vector and scalar potentials, Gauge transformations, Lorentz gauge and Coulomb gauge, Green's theorem for the wave equation, Poynting's theorem and conservation of energy and momentum, Boundary value problems and numerical techniques, Plane electromagnetic wave and wave propagation, Wave guides and resonant cavities: Plane waves in a non-conducting medium, Linear and circular polarization, Fields at the surface and within conductor, Cylindrical cavities and wave-guides, Modes in a rectangular waveguide,

Energy flow and attenuation in a wave-guide. Radiating systems, Multipole fields and radiation: Fields and radiation of a localized oscillating source, Electric dipole field and radiation, Multipole expansion and electromagnetic fields, Properties of multipole fields, Energy and angular momentum of multipole radiation, Sources of multipole radiation: Multipole moments. Relativistic electrodynamics: The special theory of relativity, The Lorentz transformation and basic kinematic results of special relativistic, Invariance of

electric charge, Covariance of electrodynamics, Transformation of electromagnetic fields, Relativistic charged particles in an electromagnetic field. Radiation by moving charges: The Liénard-Wiechert potentials and fields for a point charge, Total power radiated by an accelerated charge.

References:

1. Classical Electrodynamics, *J. D. Jackson*
2. Introduction to Electrodynamics, *D. J. Griffiths*
3. Foundations of Electromagnetic Theory, *J. R. Reitz, F. J. Milford, W. Christy*
4. Modern Electrodynamics, *A Zangwill (Cambridge University Press)*

PHYS04.5: Accelerator Physics (22 Lectures / 3 Credits) (01-PHYS04-505-F)

Course Outcomes:

- Understand different types of accelerators and their applications in industry and research in basic and applied sciences

Course Details:

Introduction to accelerators: History of accelerators. Applications of accelerators. Relativistic kinematics. Guided electromagnetic fields in waveguides and cavities. Transverse beam dynamics: Accelerator coordinates; Guide field; Dipole and Quadrupole Magnets; Hills equation and solution; Betatron oscillations; Twiss parameters; Matrix formulation; stable oscillations; FODO lattice; Chromaticity; sextupole magnets and dynamics aperture.

Longitudinal beam dynamics: Fields and forces; acceleration by time varying fields; relativistic equations; transit time factor; main RF parameters; synchronous particle; synchrotron oscillations; principle of phase stability; RF acceleration for synchronous and for non-synchronous particle; small amplitude oscillations; Oscillations with Hamiltonian formalism.

Linear accelerators: Basic methods of linear acceleration; Fundamental parameters of accelerating structures; Energy gain in linear accelerating structures; Q, Shunt-impedance, transit-time factor; periodic accelerating structures; RFQ; DTL; advantages of superconducting cavities; TEM and TM superconducting cavities; spoke resonators and elliptic cavities.

Advanced topics: Introduction to space-charge effects, Envelope equation, Introduction to wakefields and collective instabilities, Non-linear dynamics in accelerators. Elements of microwave electronics for accelerators, Elements of magnet design.

References:

1. An Introduction to Particle Accelerators, *E. J. N. Wilson*
2. An Introduction to the Physics of High Energy Accelerators, *D. A. Edwards and M. J. Syphers*
3. Principles of RF Linear Accelerators, *T.P. Wangler,*
4. Accelerator Physics, *S.Y. Lee*
5. Theory of Charged Particle Beams, *M. Reiser*
6. Microwave Measurements, *E.L. Ginzton*
7. Lecture Notes on High-Current Beam Dynamics, *I. Hofmann*
8. Radio-frequency Quadrupole, *M. Weiss, CERN-PS/87-51.*
9. RF Superconductivity for Accelerators, *Hasan Padamsee*

PHYS04.6: Computational and Numerical Methods (22 Lectures / 3 Credits) (01-PHYS04-506-F)

Course Outcomes:

- Gain knowledge in basic concepts in computational & numerical skills and apply them for understanding and describing complex physical systems.

Course Details:

FORTRAN90 programming language: Overview and basic concepts, data types, flow control, functions, arrays inputs/outputs, make file, libraries.

Numerical methods: Introduction and sources of computational errors, solution of non-linear equations (Root finding), solution of system of linear equations, numerical interpolation, numerical differentiation and integration, solution of differential equations, solution of partial differential equations.

Data analysis: Classification of errors, error propagation, basics of Monte Carlo techniques, data interpretation using Bayesian approach.

References:

1) Computer Programming in Fortran90 & 95, *V.Rajaraman, Prentice Hall India Pvt. Ltd.*
2) Numerical Recipes, *W.H.Press, S.A.Teukolsky, W.T.Vellering and B.P.Flannery, CUP.*
3) Numerical Mathematical Analysis, *J. B. Scarborough (Oxford and IBH Publishing)*
4) Computer Oriented Numerical Methods, *V. Rajaraman*
5) Data Reduction and Error Analysis for the Physical Sciences, *P. R. Bevington and D. K. Robinson*
6) An Introduction to Error Analysis, *J.R. Taylor*

PHYS04.7: Reactor Physics (15 Lectures / 2 Credits) (01-PHYS04-507-F)

Course Outcomes:

- Understand the basic principle of nuclear power generation and physics design of a reactor.

Course Details:

Basics of reactor physics: Basic concepts of nuclear energy, classification of reactors, characteristics of research, test and power reactors with examples, brief overview of different reactor components,

Neutron induced reactions and their energy behavior: Concepts of binding energy Production of neutrons, Interaction of neutrons with matter, Microscopic cross-section, energy dependence of nuclear cross-sections, fast, resonance and thermal ranges, 1/v law of neuron cross-section, Geometrical limit of cross-section, Nuclear fission process, liquid drop model, Critical energy for fission, fissile, fertile and fissionable materials, Fission products yield, prompt and delayed fission neutrons, concept of ν and h, Macroscopic cross-section, mean free path, reaction rate density, energy release during nuclear fission, fission rate and reactor power, decay heat, fission gammas

Reaction rates and measurement of reaction cross sections: Measurement of cross-sections – Activation and transmission methods, overview of Measurement of partial cross-sections, Introduction to neutron time-of-flight experiments.

Neutron transport and solution to steady state neutron diffusion equation: Definition of neutron flux and current, Fick's law and its validity, neutron transport, Steady state neutron diffusion equation, interface conditions, diffusion coefficient, diffusion length and extrapolation distance. Solution of diffusion equation for point source and plane source in non- multiplying medium.

Neutron multiplication and bare homogeneous reactor: Nuclear chain reaction, multiplication factor, infinite and effective multiplication factor, reactivity, units of reactivity, concept of criticality, non-leakage probability, Bare homogeneous reactor - concepts of material and geometric buckling, conditions for criticality, four factor formula, heterogeneous reactors. Neutron slowing down, slowing down power/ moderating ratio of moderators, slowing down with spatial migration, fermi age concepts, migration length.

Time dependent neutron diffusion equation and reactor kinetics: Time dependent neutron diffusion equation, one group kinetic equation and its solution, role of delayed neutrons, prompt neutron life time, reactor period, one dollar of reactivity, prompt criticality. Xenon and samarium poisons, xenon loads, variation of xenon load with power, reactivity feedbacks of reactivity.

Reactor control and operation: Control rods, reactor safety and shut-down mechanisms, Principles of reactor operation**,** approach to criticality, control rod worth measurement, Concepts of irradiation, burn up, conversion and breeding.

References:

1. Nuclear Reactor Engineering, Reactor Design Basics, *S. Glasstone and A. Sesonske*
2. Nuclear Reactor Engineering: Reactor Systems Engineering*, S. Glasstone and A. Sesonske*
3. Introduction to Nuclear Reactor Physics, *Robert E. Masterson, (CRC Press, 2017)*
4. Nuclear Reactor Physics, *Weston M. Stacey (Wiley, 2007)*
5. Fundamentals of Nuclear Reactor Physics, *Elmer Lewis (Academic Press, 2008)*

PHYS04.8: Health Physics (15 Lectures / 2 Credits) (01-PHYS04-508-F)

Course Outcomes:

- Gain basic knowledge of different types of radiations, doses, shielding, health effects and safety

Course Details:

Introduction: Radiation sources, quantities and units: Natural and Induced radioactive sources, Units of radioactivity, Half-Life and Decay constant, Specific activity -Examples. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (with stress to use only SI units however old and new units relation can be given). Exposure dose relationship

Biological effects: Interaction of radiation with biological matter (DNA damages). Factors, which influence radiation damage of cell. Direct and indirect effects. Stochastic and Deterministic. Acute and Chronic doses -Examples. Radiation syndromes (Hematopoietic, GI and CNS) NVD, LD50/60 -Threshold doses for radiation syndromes.

Radiation detection and measurement: Brief introduction on Charged particle interaction, ionization and excitation, Interaction of gamma radiation with matter. Photoelectic, Compton and pair production (not detailed). Neutron interaction and dose. Ionisation chamber, proportional counter and GM counter working principle. HP instruments Alpha, Beta, Gamma and Neutrons. Buildup concept, shielding for alpha, beta, gamma and neutron sources. Shielding for mixed sources.

Luminescence (theory & materials), Radiation dose measurement (Basics of dose measurements, different methods of radiation dose measurements, Importance and requirement of radiation dose measurements).

Radiation protection program: Types of exposure (occupational, medical and public). National and International regulatory bodies, their role and responsibilities. Latest Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, Justification, Optimization and Dose Limits.

Occupational Radiation Protection: Radiation Safety Officer (RSO). Nature of duties and responsibilities of RSO/Health Physicist. Protection against internal and external exposure. Time, Distance and Shielding. Concept of ALI & DAC (with suitable problems). Modes of entry of radionuclides into the human body leading to internal exposure. Personnel monitoring, workplace monitoring, environmental monitoring. Surface contamination and air activity monitoring. Dosimeters, TLDs, DRD (pocket dosimeters), alarm dosimeters CR-39 etc. Bioassay, whole body counting and Liquid Scintillation Spectrometry (LSS) techniques (not in detail). Role of ESL in environmental monitoring.

Radiotoxicity and classification of laboratories, design of laboratory for radioactive work,

Radiation Protection procedures: Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, Safety during transportation of radioactive sources. Transport index, TREM card. Radioactive waste classification and management.

Emergency Preparedness: Types of emergency, emergency preparedness. Nuclear and radiological emergencies. RDD, IED. International Nuclear Events Scale (INES). Examples of nuclear and radiological accidents. Iodine Prophylaxis

Industrial Safety (Conventional): Basic Principles of industrial safety and industrial hygiene;

References:

1. Introduction to Health Physics, *Herman Cember, 4th Edition (McGRAW-HILL, 2009).*
2. Physics for Radiation Protection, *James E. Martin, 2nd Edition (Wiley -VCH Verlag GmbH, 2006).*
3. IAEA Regional Basic Professional Training Course on Radiation *Protection (Course jointly organized by BARC and IAEA), October 26-December 18, 1998.*
4. Radiobiology for radiologists, *Eric J. Hall, 7th Edition, (Lippincott Williams & Lippincott, 2012).*
5. Accident Prevention Manual for Industrial Operation, *Vol. 2, National Safety Council, 11th Edition, (National Safety Council, USA, 1997).*

PHYS04.9: Atomic & Molecular Physics (15 Lectures / 2 Credits) (01-PHYS04-509-F)

Course Outcomes:

- Understand the role of atoms and molecules in the structure and properties of mater. Describe different types of atomic and molecular spectra with and without external field.

Course Details:

Atomic Physics: Revision of energy levels and structure of hydrogenic atoms, 2 electrons atoms, many electron atoms, fine structure, hyperfine structure. Quantum mechanical treatment of interaction of atoms with external fields, absorption and emission of radiation, electric dipole selection rules. Selection rules.

Molecular Physics: Born-Oppenheimer approximation and molecular energy levels; rotational, vibrational and electronic structure and spectra of molecules; molecular orbital theory. Molecular Symmetry and group theory (point groups): applications to vibrational and electronic spectroscopy of molecules. Selection rules, Mechanism of broadening of spectral lines.

Introduction to atomic and molecular structure calculations: Hartree-Fockself consistent field method, introduction to electron correlation methods like configuration interaction (CI) and DFT (density functional theory); Introduction to use of computational chemistry codes like GAMESS for basic molecular structure calculations.

References

1. Physics of Atoms & Molecules by B.H. Bransden& C.J. Joachain
2. Atomic Physics by C.J. Foot
3. Fundamentals of Molecular Spectroscopy (4ed) by Banwell
4. Modern Spectroscopy (4ed) by J.M. Hollas
5. Spectra of Atoms and Molecules by P. Bernath
6. Chemical Applications of Group theory (3ed) by F.A. Cotton
7. Symmetry & Spectroscopy by D.C. Harris & M.D. Bertolucci
8. Quantum Chemistry by I. Levine

CORE COURSES

ADVANCED COURSES (THEORY)

PHYS04.10: Advanced Nuclear and Astrophysics (15 Lectures / 2 Credits) (01-PHYS04-610-C)

Course Outcomes:

- Provide exposure in the specialized subjects of Nuclear & Particle Physics and Astrophysics.

Course Details:

A. Nuclear Physics:

Review of basic nuclear physics: Basic properties of nuclei, systematic of nuclear ground states (low lying states) properties, size, shape, electric and magnetic moment, nuclei away from the line of stability, isomers, nuclear decay, symmetries. Nuclear Forces: Phenomenological description of nuclear forces, deuteron problem, N-N scattering, microscopic description, meson theory of nuclear forces.

Nuclear structure: Multipole composition of radiation, transition matrix, selection rules for multipole transitions, collective and single particle excitations, shell and collective models, giant resonances, high spin states and shape deformations, relativistic mean field theory, Fermi gas model, weak interaction, beta decay, neutrino interaction and oscillations.

Heavy ion nuclear reaction studies around Coulomb barrier energies: Physical description of heavy ion interactions, heavy ion potentials, elastic scattering, optical potentials. Direct reactions: Inelastic scattering, theories on nuclear transfer reactions, Coupled channels effects. Fusion and fission reactions: Compound nucleus theory, statistical model analyses, Hauser-Feshbach analyses, fusion of heavy ions, fusion cross section around Coulomb barrier energies and channel coupling effects. Particle evaporation spectra and nuclear level densities, nuclear fusion-fission reactions, fission fragment mass and angular distribution, fission time scale.

Giant resonances in atomic nuclei: Definition, Energy and width systematic, Macroscopic and microscopic description, Giant Dipole Resonance (GDR) in deformed nuclei, GDR in excited nuclei, GDR in hot nuclei formed in heavy ion reactions, properties of GDR from high energy gamma spectra using statistical model.

Reactions involving weakly bound projectiles: Special features, comparison with reactions involving strongly bound projectiles. Projectile breakup reactions: direct, resonant and transfer breakup. Surrogate reactions. Nuclear astrophysics. Radioactive Ion Beam (RIB) - Production and applications: Production of RIB-different methods. Exotic properties and physics beyond beta stability. Nuclear reaction studies using RIBs.

High energy interactions: Deep Inelastic Scattering, Nuclear reaction at Relativistic Heavy Ion Collisions, Quark Gluon Plasma (QGP) - a deconfined state, Signatures of QGP: Quarkonia, Jets, Energy loss; Equation of State; High Energy QCD in proton-nucleus interaction and ultra-peripheral collisions, Critical point.

References:

1. Introductory Nuclear Physics, Kenneth S. Krane (Wiley, New York, 1988)
2. Treatise on Heavy-Ion Science, Vol. 2, 3, ed. *D. A. Bromley*
3. Nuclear Structure (Vols. I and II), *A. Bohr and B. R. Mottelson (Benjamin, Reading, Massachusetts, 1969 and 1975).*
4. Theoretical Nuclear Physics, *A. de Shalit and H. Feshbach (Wiley, NY 1974)*
5. Nuclear Structure from A Simple Perspective, *R. F. Casten (Oxford University Press, 1990).*
6. Ultra-relativistic Heavy- Ion Collisions - *R. Vogt (Elsevier Science, Amsterdam, 2007)*
7. Introduction to High Energy Heavy Ion Collisions: *C. Y. Wong (World Scientific, Singapore,1994).*
8. Introduction to Relativistic Heavy-Ion Collisions: *L. Csernai (John Wiley, 1994).*
9. Quark Gluon Plasma 4: *Edited by R. C. Hwa and Xin-Nian Wang (World Scientific, Singapore, 2010.)*

B. Astrophysics:

Radiation Processes in Astrophysics: Concepts of Radiative Transfer, radiation from accelerated charge, bremsstrahlung, Thomson and Compton scattering, synchrotron radiation, thermal and nonthermal distribution of radiating particles, nonthermal synchrotron radiation, synchrotron-self-absorption, synchrotron and Compton cooling, hadronic process, neutral pion decay.

Basic definitions from Cosmology: Universe at large scales – Homogeneity and isotropy, distance ladder, Newtonian cosmology, expansion and redshift, Cosmological Principle, Hubble's law, Robertson-Walker metric, Observable quantities: luminosity and angular diameter distances, Horizon distance.

Particle Acceleration: First and second order Fermi acceleration, Particle acceleration in astrophysical shocks, evolution of particle distribution, kinetic equation, different cases.

Astrophysical sources: Description of various astrophysical source e.g. supernova remnants, pulsars, active galactic nuclei, gamma ray bursts etc. and their observational results. Astronomical techniques: Astronomical Coordinate system: Horizon, Equatorial and Galactic coordinate system. Magnitude of stars and different distance measurement techniques used in astronomy.

Cosmic rays and related experiments: Cosmic ray experiments: historical perspective, Cosmic ray spectrum, GZK cut, off, Hillas plot, cosmic ray and neutrino experiments.

References:

1. Radiative process in astrophysics, *Rybicki and Lightman, John Wiley & Sons Inc, ISBN: 9780471827597, 0471827592*
2. High energy astrophysics, *M. Longair, Cambridge University Press, ISBN: 9780521756181, 0521756189*
3. Quasars and Active Galactic Nuclei, *Ajit K. Kembhavi and Jayant V. Narlikar, Cambridge University Press, ISBN: 9781139174404, (1999).*

PHYS04.11: Advanced Condensed Matter Physics (15 Lectures / 2 Credits) (01-PHYS04-611-C)

Course Outcomes:

- Provide exposure in the specialization of Condensed Matter Physics.

Course Details:

Crystal Structure: Crystal structure of materials, Space group and its application, Crystal structure determination, Powder diffraction, Single crystal growth (basics & methods) and characterization, Structure of disordered materials.

Phase Transitions and Critical Phenomenon: Equation of state, Phase transitions, Landau theory of phase transition, First and second order phase transitions, Critical exponent, Properties near critical points, Materials response under temperature, pressure and magnetic field.

Magnetism and Magnetic Materials: Fundamentals of magnetism, Multiferroics, Magnetoelectrics, Magnetostriction, Spintronics, Frustrated magnetism, Colossal magnetoresistance, Low dimensional quantum magnetism, Spin liquid.

Strongly Correlated Electron Systems: Metal-insulator transition, Charge and orbital ordering, Quantum phase transition, Quantum criticality.

Dynamics of Collective and Non-collective Excitations: Phonon dispersion. Stochastic Processes, Magnetic excitations.

Surfaces, Interfaces and Thin Films: Preparation and structure of thin films, Complex surfaces and interfaces, Thin film multilayer devices.

Soft Matter and Nanostructures: Constituents of soft mater, Structure and interaction, Soft Matter in Biology, Properties, synthesis and applications of nanomaterials.

Energy Materials: Types and sources of energy, Energy storage methods and devices, Solar cells, Fuel Cells, Thermoelectric power generation. Magnetic energy materials: Spin Seebeck effect, Magnetocaloric effect, and Permanent magnets.

References:

1. Solid State Physics, *N. W. Ashcroft and N. D. Mermin (Harcourt College Publishers, London, 1976)*
2. Quantum Theory of Solids, *C. Kittel (Wiley, 1987)*
3. Condensed Matter Physics, *M. P. Marder (John Wiley & Sons, 2010)*
4. Lecture Notes on Electron Correlation and Magnetism (Series in Modern Condensed Matter Physics), *P. Fazekas (World Scientific Publishing Company, 1999)*
5. Soft Condensed Matter, *R.A.L. Jones (Oxford University Press, 2002)*
6. Energy Materials, *D.W. Bruce, D. O'Hare and R.I. Walton (Editors) (Wiley, 2011)*
7. Renewable Energy Conversion, Transmission and Storage, *Bent Sørensen (Academic Press, 2007)*

PHYS04.12: Advanced Laser and Plasma Physics (15 Lectures / 2 Credits) (01-PHYS04-612-C)

Course Outcomes:

- Provide exposure in the specialization of Laser and Plasma Physics.

Course Details:

A. Basics of Laser Physics:

Introduction to Lasers, unique properties of lasers and their importance, coherence, laser spectrum and wavelengths, Wave nature of light, Heisenberg's uncertainty principle, concept of wave packet. Breif overview of energy levels and radiative properties of atoms, molecules, liquids and solids, Boltzmann distribution. Interaction of e-m radiation with materials – spontaneous and stimulated emission, Einstein's coefficients, population inversion. Two level system, three / four level system, rate equation model. Working principle of lasers, stable laser resonator and laser cavity modes, threshold gain and threshold population inversion. Homogeneous and inhomogeneous broadening, spectral hole burning, spatial hole burning. Different Types of Lasers and their properties, Non-linear optical processes and materials, high harmonic generation, Techniques to narrow down laser line widths / increase pulse powers

References:

1. Laser Fundamentals, *W.T. Silfvast,, Cambridge University Press 2004.*

B. Physics & Technology of Arcs:

Production of arcs and its characteristics: Ionization, Cathode processes, Penning effect, AC and DC break down, Paschen's law, Transition to Arc, Arc characteristics and required power supply features, Arc root movement and inherent instabilities.

Thermo-physical Properties of Arc Plasma: Partition function hierarchy, Specific energy and enthalpy from partition function, Non-equilibrium Saha equations, Determination of thermodynamic and transport properties from Chapman Enskog Approach.

Fluid Model of Arc Plasma: Fluid model from kinetic theory, Vlasov equation, Handling of collisional term, Conservation of charge, mass, momentum and energy from moments of Vlasov equation, Generalized Ohm's law, MHD equations, Application of fluid model.

Electromagnetic Interactions in Arcs: Arc root dynamics and instability, Modes and origin, Mutual interaction between arc current and magnetic field, Electromagnetic pumping, Retrograde motion, Skin depth, JxB thrust.

Applications of Arc Plasma Devices: Cutting, Plasma Spraying, Gasification, Nanosynthesis, EDM discharges, Pyrolysis and Extractive metallurgy, Thermo-chemical cathodes, Erosion scenario, Understanding arc plasma behavior in different torches.

Plasma Technology for Renewable Energy and Environment: Plasma for waste management, Waste to energy concept, Pyrolysis, gasification and incineration, Elements of plasma gasifier plants, Principles and operation.

References:

1. Introduction to Plasma Technology: Science, Engineering and Applications, *John Ernest Harry (Wiley-VCH Verlag GmbH & Co, 2011)*
2. Plasma Technology Fundamentals and Applications, *M. Capitelli, and C. Gorse (Eds.) (Springer, 2012)*

ADVANCED EXPERIMENTAL TECHNIQUES

PHYS04.13: Advanced Experimental Techniques in Nuclear & Astrophysics Advanced (15 Lectures / 2 Credits) (01-PHYS04-613-C)

Course Outcomes:

- Expose to advanced nuclear & particle detectors, detection techniques, electronic setup, data acquisition and major experimental setups using detector arrays. Expose to experimental techniques using gamma ray telescopes and atmospheric Cherenkov telescopes.

Course Details:

A. **Nuclear Physics**: Interaction of radiation (heavy charged particles, electrons, gamma rays, neutron and neutrino) with matter, Radiation detectors, General characteristics of detectors: efficiency, resolution and timing properties.
Gas detectors: Basic processes, ionization and charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter. Multi-Wire Proportional Counter (MWPC), Parallel Plate Avalanche Counter (PPAC), Time Projection Chamber (TPC) and Resistive Plate Chamber (RPC), Gas Electron Multiplier (GEM). Semiconductor detectors: Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium (HPGe and Clover) detectors, Compton suppression. Scintillation detectors: Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes. Miscellaneous detectors: Cryogenic detectors, thermal detectors, channeltrons and microchannel plates, hybrid detectors.
Experimental techniques: Particle identification methods using (DE-E) telescope, pulse shape discrimination, Cerenkov radiation technique, time of flight technique, magnetic spectrometers including recoil mass separator. Analog signal processing. Electronics modules for pulse processing: Preamplifiers, amplifiers, timing discriminators. Coincidence (fast and slow) techniques. Data acquisition systems (DAQ). Monte Carlo simulation of detectors to obtain efficiency. Digital signal processing.
Typical experimental setups using Strip detector array, Neutron detector array and Indian National Gamma Array (INGA) and other national and international facilities. Applied nuclear physics: Rutherford Back Scattering (RBS), Nuclear Reaction Ananlysis (NRA), Neutron activation Analysis (NAA), Accelerator Mass Spectroscopy (AMS).
B. **Astrophysics:** Experimental techniques in various wavebands: History of telescopes, resolving power, angular resolution, energy resolution, current and future generation large optical telescopes, X-ray telescopes, gamma, ray telescopes.
Science with gamma, ray telescope: Hadronic and leptonic emissions in astrophysical sources: observational perspective, cosmic ray measurement using VHE experiments, indirect detections of dark matter, estimation of extra, galactic background light using VHE observations, test on photon-ALP oscillation and violation of Lorentz invariance.
Extensive Air Shower (EAS) and Cherenkov radiation: Radiation length, critical energy, development of gamma, ray and hadron generated EAS, Cherenkov radiation: spectral distribution, threshold energy, emission angle, Cherenkov light pool and pulse duration, lateral distribution of Cherekov light for gamma, ray and hadron.
Imaging atmospheric Cherenkov telescopes: Features of Cherenkov telescopes: trigger threshold, flux sensitivity and cosmic ray background rejection, imaging technique, data analysis techniques for Cherenkov telescopes.

References:

1. Radiation Detection and Measurement, *G.F. Knoll, 4th edition (John Wiley & Sons, New York, 2010)*
2. Techniques for Nuclear and Particle Physics Experiments, *W.R. Leo, 2nd Edition. Springer International Student Edition (Narosa Publishing House, New Delhi, 1995).*
3. Very high energy gamma, ray astronomy, *T.C. Weekes, CRC Press (old -Institute of Physics Publishing), ISBN: 9780750306584, (2003)*
4. Astronomy with Your Personal Computer: *Petter Duffett-Smith, Cambridge University Press, ISBN: 9780511564888, (1990)*
5. Extragalactic background light and the gamma ray opacity of the universe, *E. Dwek and F. Krennrich, Volume 43, 2013, Pages 112-133*

PHYS04.14: Experimental Techniques in Condensed Matter Physics (15 Lectures / 2 Credits) (01-PHYS04-614-C)

Course Outcomes:

- Expose to advanced experimental methods on X-rays and neutron scattering, synchrotron radiation, spectroscopy, microscopy and imaging techniques for fundamental understanding of the problems in Condensed matter physics.

Course Details:

X-rays and Neutron Scattering: X-rays vs. neutron scattering, Neutron scattering facilities and instrumentation.

Synchrotron Radiation: Basics of synchrotron radiation, Beamlines and techniques.

Spectroscopy Techniques: Basics of atomic and molecular spectroscopy, Raman, FTIR, EPR, NMR, FMR, Mossbauer spectroscopy, Impedance spectroscopy, UV-Vis absorption techniques and applications.

Microscopy techniques: Optical microscopy, Scanning probe microscopy, Electron microscopy. Techniques for electronic, magnetic, electrical transport, thermal transport, and calorimetric properties.

Imaging Techniques: Overview of different imaging techniques, X-ray, neutron and synchrotron based imagining techniques.

Detectors and Sensors: Single crystal scintillators and applications, X-rays and neutron gas detectors, Development and application of gas sensors.

References:

1. Introduction to the Theory of Thermal Neutron Scattering, *G. L. Squires, Cambridge University Press (1978).*
2. Theory of Thermal Neutron Scattering, *S. W. Lovesey, Clarendon Press (1984).*
3. Neutron Scattering in Condensed Matter Physics, *A. Furrer, J. Mesot and T. Strässle, World Scientific (2009).*
4. An Introduction to Synchrotron Radiation: Techniques and Applications, *P. Willmott (John Wiley & Sons, 2011)*

PHYS04.15: Advanced Experimental Techniques in Laser Physics (15 Lectures / 2 Credits) (01-PHYS04-615-C)

Course Outcomes:

- Expose to high resolution spectroscopic techniques on Emission, Absorption, RIS, LIBS, LIF, etc. and their applications in fundamental and applied areas of Laser spectroscopy

Course Details:

Significance of high-resolution laser spectroscopy. Designing an experiment: Different types of atomic/molecular sources, Laser-atom/molecule interaction, Detection Techniques – light/ions, detectors, Designing an experiment.

High resolution spectroscopic techniques - Emission, Absorption, RIS, LIBS, LIF, etc.

Applications in fundamental and applied areas: Nuclear investigations through atomic spectroscopy, Multi-photon ionization of atoms /molecules, selective excitation /ionization, isotope separation, trace analysis, etc., Manipulation of atoms/molecules using Lasers – laser cooling, optical tweezers. Other advanced topics (e.g. STIRAP, FEL-spectroscopy, Laseratom interaction in high intensity regime)

References:

1. Laser Spectroscopy: Basic Concepts and Instruments, *W. Demtroder, 2nd Edition (Springer Verlag, 1996).*
2. Atomic Physics, *C.J. Foot, Oxford Master Series in Atomic, Optical and Laser Physics (Oxford University Press 2008)*

ADVANCED EXPERIMENTAL TECHNIQUES

PHYS04.16: Research Methodology (01-PHYS04-616-C)

Course Outcomes:

- Understand the basic concepts of research, data collection and presentation, scientific report writing, and ethics in research

Course Details:

Basic concepts of research: Meaning and importance of Research – Types of Research – Selection and formulation of Research Problem – Research Design

Types and methods of research: Classification of research, basic and applied research – similarities and differences, interdisciplinary research, case study, field study, survey of research fields, and methods of research as applied to basic and applied sciences – a few examples.

Data Collection and Presentation: Objectives and classification of data, data organization, presentation and interpretation – general concepts and methods, use of computers and related software for data collection, analysis and interpretation.

Ethics in Research: General ideas on presentation of scientific research, dissemination of research findings different methods such as publishing reports, patents and patent rules, presentation of work in conferences, ethics and norms to be followed in presentation of research findings, plagiarism and its consequences, how to avoid plagiarism in scientific research – a few case study.

Scientific Report Writing: Basic motivation for writing scientific report, content of a research report – a few case studies, methods of preparing research reports, use of computers in preparing reports, quantification of quality of research disseminated through journals or patents.

Attending seminars, colloquia and interaction with the scientists.

References:

1. How to write and Publish a Scientific Paper, *Robert A. Day and Barbara Gastel (Cambridge University Press).*
2. How to Research, *Loraine Blaxter, Christina Hughes and Malcum Tight (Open University Press).*
3. The Craft of Scientific Writing, *Michael Alley, (Springer).*
4. A Student's Guide to Methodology, *Peter Clough and Cathy Nutbrown (Sage Publications).*

PROJECTS

PHYS04.17: Common projects at different divisions (15 Lectures / 2 Credits) (01-PHYS04-617-PR)

Course Outcomes:

- Gain an overall practical experience to decide and apply the appropriate method in future experimental investigations.

PHYS04.18: Common projects at different divisions (30 Lectures / 4 Credits) (01-PHYS04-618-E)

Course Outcomes:

- Get the exposure to the steps needed towards completing a focused topic as well as the research areas of thesis supervisor.

IGCAR
SYLLABUS FOR

Ph.D. in Physical Science
(Program Code: PHYS04)

SYLLABUS SUMMARY

Nuclear Reactor Physics

Course Code	Course Name	Hours	Credits
PY1	Mathematical Methods	45	6
PY2	Computational Methods	45	6
PY3	Introductory Reactor Physics and Engineering	35	4
PY4	Nuclear Physics and Nuclear Data	30	4
PY5	Engineering Drawing and Laboratory Practices and Experimental Methods	20	2
PY6	Reactor Materials	30	4
PY7	Radiation Detection and Measurements	20	2
PY8	Reactor Types and Advanced Reactor Concepts	20	2
PY9	Radiation Shielding Design and Protection	40	5
PY10	Reactor Dynamics and Safety Analysis	35	4
PY11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
PY12	Fluid Dynamics and Thermal Hydraulics	25	2
PY13	Advanced Computational Methods in Reactor Physics	35	4
PY14	Experimental and Operational Reactor Physics	35	4
PY15	Design Methods in Thermal and Fast Reactors and Computer codes	35	4
PY16	In Core of Fuel Management	25	2
Total		**505**	**59**

1. Mathematical Methods (PY1) : (45 lectures)

S.No	Course content
1.	Linear vector spaces, linear dependence and independence, basis and dimension. Linear transformations. Inner product, norm, continuity, convergence, completeness. Hilbert spaces.
2.	Fundamentals of matrices, eigenvalues, eigenfunctions, adjoints, inverse etc sparse matrices; diagonal dominance; non-positive and non-negative matrices; positivity theorems; large set of simultaneous equations.
3.	Functions of a complex variable. Rieman surfaces, Analytic functions Cauchy Rieman conditions and harmonic functions. Contour integration and Cauchy's integration formula. Residue theorem and evaluation of integrals.
4.	Ordinary differential equations - Order and degree of a differential equation, appearance and number of arbitrary constants in the solution of a n-th order differential equation, families of curves and orthogonal trajectories, first order homogeneous and exact equations, methods of reduction of order of some specific differential equations, second order linear homogeneous equations, superposition principle, method of finding second independent solution when one solution is known, qualitative properties of the solution, Sturm comparison theorem, operator methods for second order linear equation with constant coefficients, power series solution for second order linear equations, ordinary and regular singular points of a differential equation, indices corresponding to a regular singular points, hypergeometric and confluent hypergeometric equation, explicit example through solution of Bessel's equation.
5.	Partial differential equations – First order partial differential equations, complete integral and general solution, methods of solution of a first order partial differential equation, second order partial differential equations, Laplace's equation, wave equation, diffusion equations, system of surfaces.
6.	Integral equations – Definition, homogeneous, inhomogeneous, linear, non-linear equations, Fredholm and Volterra equations, eigenfuctions, Schmidt-Hilbert method of solutions.
7.	Integral Transforms. Fourier, Laplace Transforms and the inverse transforms, connection to physical problems Other transforms such as Mellin and Hankel transforms, and transforms generated by Green's function. Applications for obtaining solution of ordinary/partial differential equations.

Books suggested

1. Mathematical Methods for Physicists, G. B. Arfkin and H. J. Weber, Academic Press(2001) Also Prism Books, Bangalore
2. Elements of Partial Differential Equations, I. Sneddon, McGraw Hill (1957)
3. Theory of Functions of a Complex Variable, E. T. Copson, Oxford University Press (1935)

2. Computational Methods in Physics (PY2): (35 lectures + 10 Tutorials)

S.No	Course content
1.	**Computers, Computational Physics and Scientific Programming** a) Introduction to Computational Physics b) Components of a high performance computer- memory hierarchy, CPU design, Vector processing, Virtual memory, Number representation- Arithmetic of Fixed and Floating

point numbers, Machine precision, Errors and uncertainties in computation Types of errors, Error propagation

c) Computing software basics

d) Computer languages, Programming concepts, Programme design, Structured programming, Introduction to Fortran and C, C & Unix, Dialects of C, Functions and Program structure, Basic Data Types, Arrays, Strings, Expressions and Operators, Precedence of C Operators, C Preprocessors, Control Statements, Pointers, Pointer arithmetic, Arrays handling with Pointers, Functions in detail, Input and Output Operations and C file handling Operations, Structures & Unions in C, Dynamic Memory allocation, Macro definitions, Compilation and Execution of C program, Fortran to C Linking procedures.

e) Introduction to Parallel processing, High performance computing, Profiling and tuning, Visualization of scientific data

f) Highlights of FORTRAN-90 programming language. Programming in MATLAB

2. **Numerical Methods**

Linear algebra

a) Matrices

b) Solution of Linear Algebraic Equations and Singular Value Decomposition

c) Eigenvalue problems, Computing Eigenvalues and Eigenvectors

d) Iterative methods for Linear systems

e) Software for linear systems- LINPACK and LAPACK

Solution of Nonlinear equations

a) Bracketing and Bisection

b) Secant Method, False Position Method, and Ridders' Method

c) Newton-Raphson method

d) Software for nonlinear equations

Interpolation, Extrapolation and Numerical Differentiation

a) Differentiation- Forward, backward and central differences

b) Polynomial Interpolation and Extrapolation

c) Rational Function Interpolation and Extrapolation

d) Interpolation using Splines

Optimization methods

a) Optimization in one dimension

b) Multivariate problems- Steepest descent, Newton and quasi-Newton methods, Conjugate gradient methods. Constrained optimization

c) Maximum entropy and Genetic methods

d) Least square fitting, Non-linear least square fitting, Goodness of fit

e) Software for optimization- energy minimization

Numerical Integration

a) Integration- Newton-Cotes integration formulae, Gaussian quadrature

b) Integral equations

Probability , Random numbers and Monte Carlo methods

a) Uniformly distributed Pseudo random numbers

b) Exponentially and Normally distributed Pseudo random numbers

c) Testing of pseudo random number sequences

d) Simulation of radioactive decay

e) Numerical Integration

f) Monte Carlo simulation techniques

Fourier and Wavelet transforms

a) Fast Fourier Transform- Convolution and deconvolution, Correlation, Filtering, Power spectrum estimation

b) Wavelet transforms- Wavelets, de-noising, de-trending, Texture analysis, Pattern recognition, Image compression

Ordinary Differential equations

a) Initial value problems for systems of ode's

b) Runge-Kutta Method, and adaptive step size control

c) Stiff differential equations

d) Boundary value problems

e) Galerkin method

Partial differential equations

a) Finite difference methods for Parabolic, Hyperbolic and Elliptic equations

b) Truncation errors, consistency, stability

c) Introduction to finite element methods.

Tutorials: Assignments of problems and computations based on these and other methods using FORTRAN-77 / FORTRAN-90/ C++

Books Suggested:

1. Computational physics- Problem solving with computers, Rubin H. Landau, Manuel J. Paez, John Wiley & sons 1997.
2. Numerical Recipes in Fortran-77 / F-90 / C, W.H. Press et. al., Cambridge Univ. Press.(1996)
3. A First Course in Computational Physics, P.L. DeVries, John Wiley and Sons (1994)
4. Numerical Methods for Engineering Application, J.H. Ferziger, John Wiley and Sons (1998)
5. Scientific Computing: An Introduction with Parallel Computing, G. Golub and J.M. Ortega, Academic Press, (1993)
6. Scientific Computing: An Introductory Survey, Michael T. Heath, McGraw-Hill, New York,

2002.
7. Computational Physics, J. M. Thijssen, Cambridge University Press, Cambridge, 1999.
8. Guide to Neural Computing Applications, L. Tarassenko, Arnold Publishers, 1998.
9. Genetic Algorithms in Search, Optimization, and Machine Learning, D. E. Goldberg, Addison Wesley, Reading, Massachusetts, 1989.

3. Introductory Reactor Physics and Engineering (PY3): (35 lectures)

S.No.	Course content
	Part I
1.	Basic nuclear physics concepts. Properties of nuclei. Nuclear forces. Nuclear models. Nuclear decay. Liquid drop model and nuclear stability. Nuclear reactions including fission. Compound nucleus formation. Microscopic cross-section. Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	Chain reaction; four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.
5.	**Reactor Kinetics**: Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.
	Part II
1.	Neutron distribution in a system; assumptions in setting up the neutron balance equation; applicability of Maxwell-Boltzmann statistics; Time dependent neutron balance (transport) equation, with delayed neutrons
2.	**Steady State Neutron Transport Equation:** Transport equation – differential & integral forms, Diffusion approximation, One speed neutron diffusion theory, Boundary conditions, Source-sink problem, Sub-critical reactors with flux independent source, Separation of space and energy.
3.	**Slowing Down and Energy Dependence:** Elastic scattering, Inelastic scattering, Anisotropy, average energy loss per neutron, Concept of lethargy. Fermi age theory, age of neutron, Logarithmic energy decrement, Slowing down spectra, Slowing down in hydrogen, Definition of resonance integral, Shape of thermal neutron-Maxwell spectrum.
4.	**Resonance Absorption:** Resonance cross sections, Resolved and unresolved region, Spatial and energy self shielding, Narrow resonance and intermediate resonance approximation, Concept of potential scattering cross section, Resonance integral in homogeneous media, Doppler broadening of resonance and importance for safety.
5.	**Multigroup Diffusion Theory:** Energy group and group fluxes, Flux weighted group constants, One group theory for thermal neutrons, Two group theory, Two group two region

model core with reflector. Adjoint equation.

6. **Reactor Control:** Cold start-up, Hot power operation, Temperature loads, Effects of burnup and fission products. Function of control rods. Theory of control rods, Xenon load during operation, Xenon iodine concentrations after shutdown, Xenon override, Xenon poison out condition, Samarium poisoning. Temperature coefficient of reactivity.

   Density temperature coefficient.

7. **Fast Reactors:** Fast reactors as breeders, comparison of fast and thermal reactors, role of fast reactors in Indian 3 stage nuclear power program

8. Neutron spectrum in FBR, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, delayed neutron fraction, fuel expansion and bowing, sodium void reactivity effect, Optimisation of blanket thickness. Effect of burnup on fuel composition and reactivity coefficients

9. General features of FBR core, specific power, linear rating, fluence, requirement and choice of core materials (fuel, coolant and structural materials), types of fast reactors – pool and loop type. Optimisation of core height and pin diameter. Salient physics aspects of FBTR and PFBR

Books suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C.Edlund. Van Nostrand, 1952.
2. Introduction to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Nuclear Reactor Engineering, Glasstone and Sesonske, Van Nostrand, 1990
4. The Physical Theory of Neutron Chain Reactors, Weinberg A. M. and Wigner E.P.
5. Nuclear Reactor Theory, Bell and Glasstone, Van Nostrand, 1970
6. Physics of Nuclear Reactors, Jakeman D.
7. A. E. Walter and A. B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981
8. Weston M. Stacey, "Nuclear Reactor Physics", John Wiley & Sons, Inc., 2001

4. Nuclear Physics and Nuclear data (PY4): (30 lectures)

S.No	Course content
	Part I - Nuclear Physics
1.	Properties of Nuclei; Binding Energy Curve; Stability Curve – neutron rich isotopes; nuclear interactions: neutron scattering, isotropic and anisotropic scattering. neutron capture, (n,xn) reactions; reaction thresholds, fission; Variation of cross-section with respect to (nuclide) material, reaction and incident energy; Resonance (Resolved/Unresolved) and Continuum regions; Mathematical formalisms to represent these data.
2.	**Nuclear models:** Nuclear potential; liquid drop, shell and optical models. Fission process; Fission barrier; (n,f) - thermal and high energy neutron induced fissions; Fission products and decay; FP elemental mass/isotope chains and distribution; prompt fission and delayed fission neutron energy distributions; energy yield per fission; neutron yield in fission with neutron energy (nu-p); photo neutron.
3.	Important neutron reactions with fuel, control and structural materials in reactor systems.

4. High energy proton interactions with heavy metals; spallation process; spallation products; neutron source distribution from spallation.

Part II - Nuclear Data

1. Four major kinds of nuclear data, viz. nuclear constants data, nuclear structure data, nuclear decay data, and nuclear reaction data. Importance to application areas, like therapeutic treatments, agriculture, and nuclear energy. Kinds of data, like neutron interaction data, neutron/gamma production data, gamma-atom interaction data, etc., pertinent to reactor physics applications.

   Measurements and model based predictions; Transmission experiment for total cross-section, measurement of differential scattering cross-section; Time of flight method, sources of errors in measurement – energy resolution; Optical model, Statistical Model, etc.; Examples of model based computer codes.

2. **Nuclear data Evaluation:** Problems of scarcity and/or abundance of nuclear data, need of nuclear data evaluation; Evaluated nuclear data files (ENDF), ENDF/A, ENDF/B,JENDL and JEFF; General purpose and Special purpose libraries; Sublibraries for neutron, photon, and charged particle interactions, Fission product yields and decay data; Problems of multiple evaluations; Formats and procedures; MAT, MF, MT conventions; Representation of different kinds of data, tabulated and parametric representations, single/multi level resonance formalisms in the resolved/unresolved region, BW formulation, partial & total widths, negative resonance energies, interpolation schemes. IAEA-NDS; Related websites.

3. **Nuclear data Processing:** Need for processing of an evaluated data Steps of processing; Simplifying assumptions and tolerances; Precautions on consistency and accuracy. Popular processing cods: PREPRO and NJOY and their modules, Linearisation: Advantages of linearization; interval halving procedure, tolerance (error criterion), probable pitfall – position of maximum deviation; Program LINEAR.

   Resonance Reconstruction. Doppler broadening: Effect of target temperature on cross-sections – for low energies, for resonances and for threshold reactions; kernel broadening approach, submerging small resonances due to broadening. Validation of evaluated and processed cross-sections.

4. **Multigrouping:** Consideration for deciding the number of groups and group limits. Neutron cross-section averaging: conservation of reaction rate, transport cross-sections, flux and current weighting, self-shielding, dilution and temperature dependences, multigroup cross-section set, effective cross-sections, mixture cross-sections, collapsing of cross-sections, group-to-group transfer cross-sections; Anisotropy and Legendre moments. GROUPIE/GROUPR programs; Validation of multigroup cross-sections.

   Photon production cross-sections; photo-atomic interaction cross-sections; coupled multigroup cross-section set; GAMINR program.Activation cross-sections; relevance of residual nuclear levels. Displacement cross-sections; relevance to radiation damage in reactor materials.

Books suggested:

1. Handbook of nuclear reactor calculations: Vols I-III, Yigel Ronen (Ed.) CRC Press, West PalmBeach, Florida (1986).
2. ENDF – 102, Data Formats and Procedures for the Evaluated Nuclear Data for ENDF – VI, M.Herman (Ed.) BNL-NCS-44945-05, (2005)
3. Special Issues on Evaluated Nuclear Data File ENDF/B-VII.0, J.K.Tuli, Nuclear Data Sheets, Vol-107 (2006)
4. Introduction to Nuclear Reactor Theory, Lamarsh J.R., ANS, (2002)

5. Engineering Drawing and Laboratory Practices (PY5 & PY5A): (20 lectures)

S.No	Course content
1.	**Machine Drawings Projections:** orthographic – 1st & 3rd Angles pictorial; Oblique: Perspective.
2.	Introduction; Indian and International standards for drafting and related subjects.
3.	**Line, lettering and dimensioning:** Outline hidden lines, Centre lines, Dimensional lines, Extension/Projection lines, Construction lines, Section lines, Leader/pointer lines, Cutting plane lines, Border lines, Short & long break lines, Representation of welded joints.
4.	**Dimensioning and tolerancing:** Definition and general principles, Arrangement of dimensions - Chain and parallel dimensioning, method of dimensioning common features; Rules for inscription of tolerancing. Limits fits. Tolerances and surface finish.
5.	**Scales, lines and lettering:** Recommended scales; Different type of lines, their illustration and application; Recommended size of letters and numerals.
6.	**Sections:** Full Section, Half section, Partial section, Revolved section.
7.	**Projections:** Orthographic – 1st & 3rd Angles; Pictorial – Oblique and Isometric
8.	**Conventional representation of common features and sections:** Conventional representation of gears and gear assembly, Threads, springs, bearing, welded joints. Hatching, sectioning, cutting planes.
9.	**Fastenings:** Bolts, studs, screw, washers, set screw, split pins.
10.	Brief Introduction of AutoCAD and its use, common drawing and edit commands.

Laboratory Practices:

1. Errors in measurement. Accuracy and precision. Software, data analysis, filtering and plotting.

   Electronic components of detector systems.Analog electronics, Electromagnetic interference, shieldind and grounding of electronic equipments. Measurement of temperature, pressure, mass, volume and flow. Instrument time constant and response time.
   Production and measurement of (low pressures)vacuum and high pressures.
   Production and measurement of high temperature and low temperatures.

   Computer hardware. Intelligent systems, Computer control and automatic data acquisition. User friendly experimental automation with G (graphical) language.

Books suggested:

1. Indian Standard Code of Practice for General Engineering Drawings (Second Revision); Bureau of Indian Standards.
2. Geometrical and Machine Drawing by N.D. Bhatt; Charotar Publishing House, Anand (WR), India

6. Reactor Materials (PY6): (30 lectures)

S.No	Course content
1.	Properties of fuel materials. Uranium metal, Uranium dioxide, Carbide and nitride fuels. Plutonium fuel materials. MOX fuels. Thorium fuel materials. Fabrication of fuel pellets: sintered and vibropacked.
2.	Dispersion type fuels. Inert matrix fuels, Metallic fuels, sol-gel process. Fuel for HTRs – coated particle / TRISO/ spherical fuel balls for high powered systems.
3.	General requirements of structure and clad materials. (neutronic and physical) Aluminum and alloys. SS and low alloy steels. Nickel alloys. Zirconium and alloys. Properties of moderator and coolant materials. Graphite, Beryllium, water and heavy water. Liquid metals. Heat transfer coefficients.
4.	Mechanical properties of materials. Stress-train relationships. Ductile and brittle failure. Ductile to brittle transition, Fatigue failure, Creep and dilation.
5.	Stress analysis, Thermal stress in fuel clad. Thermal stress in hollow cylinder with no heat generation, Thermal stress in hollow cylinder with exponential heat source, Factors affecting thermal stress.
6.	Radiation effects in materials. Atomic displacements. Mechanisms in radiation damage, General irradiation effects in metals. Thermo-physical properties of fuel (pellet) materials; variations with burnup Temperature dependent swelling. Helium embrittlement. Typical limits of irradiation damage
7.	Corrosion of metals. Chemical corrosion, erosion and fretting corrosion, Stress- corrosion cracking, Hydrogen embrittlement. Fuel clad failure process.
8.	Advaced materials for future FBR, ADS and high temperature reactor. Ferritic steels, oxide dispersed steels and carbon based materials

Books suggested:

1. Nuclear Reactor Engineering, Glasstone and Sesonske, Van Nostrand.
2. Fundamental Aspects of Nuclear Reactor Fuel Elements, D.R. Olander, ERDA report, TID 26711-P1 (1976).

7. Radiation Detection and Measurement (PY7): (20 lectures)

S.No	Course content
I	**Interaction of radiation with matter:**
1.	Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe-Bloch formulae), Cherenkov radiation. Energy loss of electrons and positrons – Electronic stopping and energy loss by Bremsstrahlung radiation.
2.	Interaction of photons – Photoelectric absorption, Compton scattering, pair production, Electromagnetic shower in high energy photon and electron interaction with matter.
3.	Interaction of Neutrons – elastic scattering, radiative capture, positive Q-value reactions such as (n,p), (n,gamma), (n,fission) and hadron shower production at high energies.

II **Radiation detectors:**

1. General characteristics of detectors – efficiency, response in energy, time, position and corresponding resolutions, recovery time or count rate handling capability.
2. Gas detectors Basic processes, Q-V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter.
3. Semiconductor detectors Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium detectors (planar and cylindrical geometry). Photovoltaic cells, charged coupled devices.
4. Scintillation detectors. Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes.
5. Techniques and detectors for neutron and spectrum measurements. Fission ionization chambers. Boron filled and coated detectors. Gamma compensation. Self powered neutron detectors.
6. Pulse processing instrumentation, preamplifiers(charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), single channel analyzers, timing discriminators(leading edge and constant fraction types), gate and delay generators, coincidence(fast and slow) units, linear gate and stretchers, time to amplitude converter(TAC), scalers and rate dividers, analog to digital converter(ADC), charge to digital converter(QDC), time to digital converter(TDC), data acquisition systems (multichannel analysers and computer based multiparameter systems).
7. Experimental techniques and simulation - Particle identification methods (pulse shape discrimination, Cerenkov radiation), Compton suppressed high purity germanium detectors for high-resolution gamma spectroscopy, magnetic spectrometers including recoil mass separator. Monte Carlo simulation of detectors.

Books suggested:

1. Techniques for Nuclear and Particle Physics Experiments – W.R. Leo, 2nd Ed. (Springer International Student Edition published by Narosa Publishing House, New Delhi 1995).
2. Radiation Detection and Measurement – G.F. Knoll, 3rd edition (John Wiley, New York 2000)
3. Nuclear Radiation Detectors – S.S. Kapoor and V.S. Ramamurthy (Wiley Eastern Ltd, New Delhi 1986)
4. Radiation Detectors, C.F.G. Delaney and E.C. Finch (Clarendon Press 1992).

8. Reactor Types and Advanced Reactor Concepts (PY8): (20 lectures)

S.No	Course content
1.	**Thermal Reactors:** History. Development of Gas Cooled Reactors (GCR). Reactor types AGR and RBMK. Development of BWR. Development of PWR and VVER. Development of PHWR and SGHWR.
2.	**Fast Reactors:**

History. Development of LMFBR.

3. **Advanced Reactors:**

Different generation of nuclear reactors. Evolutionary improvements and revolutionary improvements. High Temperature Reactor(HTR) and Advanced Heavy Water Reactor (AHWR).

Metal fuelled FBR and increased fuel breeding.

Accelerator driven systems (ADS)

Fusion Systems. JET and ITER. Concept and need for tritium breeding.

4. **Indian Reactors (Experimental and power producing):** For each type of reactor - brief principles of the reactor; typical Power/ Research reactor system; Fuel cluster/assembly; number of channels; core; coolant/moderator/reflector/blanket and shield as the case maybe; average neutron energy spectrum; control and shut down systems.

- APSARA/ CIRUS/ DHRUVA
- PHWR –India (220, 540 and 700 MWe)
- LWRs
- BWR (TAPS 1&2, modern BWRs,)
- VVER (KK)
- FBTR and PFBR

5. International Initiatives in Advanced Nuclear Systems: INPRO (IAEA) and GEN-IV. US proposal GNEP. International concerns. Nonproliferation, (proliferation indices), NPT, FMCT, CTBT.

Books Suggested:

1. W. Marshall ed. Nuclear Power Technology, Volumes I to IV, Clarendon Press, Oxford, (1984).

9. Radiation Shielding Design and Protection (PY9): (40 lectures)

S.No **Course content**

1. **Basics of radiation physics and dosimetry**

Radiation sources, its interaction with matter; natural and induced radioactive sources, half-life, decay constant, specific activity; basic interaction mechanisms of alpha, beta, gamma/x-rays and neutrons with matter (*summary only*).

Definition of various dosimetric terms (exposure, absorbed dose, equivalent dose, effetive dose, concept of radiation and tissue weighting factors and their importance, Activity, Specific activity (SI units and Old units), radiological, biological and effective halflife and their relation and their importance. Concept of ALI and DAC with suitable problems.

Human Body: cells, tissues and organs, structure of cell, cellular effects. Factors which influence the damage of cell. Interaction of radiation with biological matter. stochastic and deterministic effects. Acute and delayed effects. LD 50/60, Doubling dose. Radiation toxicity, Risk factor.

2. **Radiation Protection**

Radiation protection philosophy, objectives and principles of radiation protection ALARA, stochastic and deterministic effects, justification, optimization and dose limitation, Dose limits to occupational workers and members of public, Dose constraints, Investigation limits. Types

of exposure (natural, occupational, medical and public).

External and internal exposures; internal routes of intake of radioactive material. Use of personal dosimeters (TLDs, pocket dosimeters). Calculation of dose, Exposure measurement: Free air and air wall chambers (concept of wall thickness should be given), exposure-dose relationship, Fundamentals of ICRP respiratory model, ingestion, Gastro intestinal track model, wholebody counting and bioassay techniques.

Atomic Energy Act, National and international regulatory bodies, their role and responsibilities, Radiation protection rules, Safety during transport of radioactive materials, Radioactive waste classification and management.

3. **Radiation Shielding**

Shielding concepts- gamma shielding- Attenuation factors. Buildup factor concept for homogeneous and multiple layers. Semi-analytical methods for gamma shield design. Dose rates of gamma rays for various source geometries. Gamma energy dependence of dose. Half layer thickness of different materials. Heat generation.

Neutron shielding. Shielding in thermal reactors. Importance of shielding in fast reactors. In-vessel shields and reduction of dose to components and operating personnel. Activation of structural material and heat generation. Shielding in accelerators and fusion systems.

Computational problems. Transport theory methods. Large problem size and large flux attenuation. Importance of anisotropy effects in scattering. Neutron slowing down and need for fine energy treatment. Monte Carlo methods. Streaming through gaps, voids and pipes. Analytical methods. Complementary shielding.

Selection of shield materials. Shielding from mixed sources. Life of shield materials.

4. **Nuclear Emergency management**

Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, countermeasures. Aerosol physics for core disruptive accidents, Atmospheric transport processes, environmental impact studies.

Books suggested:

1. Nuclear Radiation Detection - W.J. Price, McGraw Hill (1964)
2. Radiation Detection and Measurement - G.F. Knoll, John Wiley and Sons (1989)
3. Biological Effects of Radiation – J.E. Coggle, Taylor and Francis (1983)
4. Atoms,Radiation and Radiation Protection by James E.Turner, Wiley (2007)
5. Problems and Solutions in Radiation Protection by James E. Turner et al., Wiley, (1988)
6. Introduction to Health Physics – Herman Cember, McGraw Hill (1996)
7. Introduction to Radiation Protection –Alan Martin and Samuel Harbison, Chapman and Hall (1986)
8. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998.
9. Radiation Shielding- Three volumes of Compendium on Radiation Shielding, O.Sisman and J. Jaeger et.al., ed. (1975)
10. Radiation Shielding Manual T Rockwell et.al ed. AEC-US, (1958).

10. Reactor Dynamics and Safety Analysis (PY10): (35 Lectures)

S.No	Course content
1.	**Reactor Dynamics**
	Neutron kinetics and thermal effects. Feed back effects. Time constants. Loosely and strongly coupled reactor systems; Reactor size and eigenvalue separation; fundamental and higher modes.
	Description of main reactor systems. Coolant system behaviour. Plant dynamics (open loop and closed loop). Flow perturbations. Reactivity perturbations. Thermal perturbations. System stability. Linear and non-linear stability analysis; Nyquist critera; Liapunov methods.
	Xe dynamics equations; spatial and time dependent oscillations and stability.
	Safety concepts. Defence in Depth (5 levels)
	Accident Categories / classification: Design basis events (DBE) and Beyond DBE (BDBE). Loss of Regulation Accident(LORA), Transient Over Power Accident(TOPA), Loss of Coolant Accident(LOCA), Loss of Flow Accident(LOFA), cold coolant additions – with shut down action; Anticipated Transients with out SCRAM(ATWS)- Un protected Loss of Flow (ULOF) and Unprotected Transient over Power (UTOP).
	Accident scenarios in thermal and fast reactors. Brief description of accidents at Three Mile Island, Chernobyl and FERMI reactor.
	Computer codes for modeling accidents in thermal and fast reactors. RELAP and SAS4A.
	Kinetics of ADS.
2.	**Safety Systems**
	Engineered safety systems. Safety Critical Systems (SCS); Safety Groups, SCS, actuation systems, safety support systems.
	Shut down Systems. Different shut down states; Shut down margins (SDM). Guaranteed shutdown states (GSS).
	General safety criteria. Examples of safety analysis of PHWR, LWR and FBR.
3.	**Introduction to Reliability and Probabilistic Safety Analysis (PSA)**
	Probability, random variable, probability distributions used in Reliability Analysis; uniform, exponential, Weibull, Normal and χ^2 distributions, Central Limit Theorem.
	Basic component reliability models, definition and other measures of reliability such as Availability, failure frequency, dependability, fail safe design, safe failures/unsafe failures.
	Reliability Block Diagram, series and parallel systems, minimal cutsets, Combinatorial (Fault Tree / Event Tree) and State Space methods (Markov Models), Binary Decision Diagram.
	Common Cause Failures, Human Reliability Analysis: Models of Common Cause failures and Human Reliability Analysis, independence, redundancy, diversity.
	Probabilistic Safety Assessment of Nuclear reactor, measures of risk, core damage frequency, Level-1, Level-2, Level-3 PSA (introduction).

Books suggested:

1. Fast Reactor Safety, John Graham, Academic Press (1972).

2. The Technology of Nuclear Reactor Safety, Vol-I and II, T.J.Thompson and J.G.Beckerley, MIT Press (1971).
3. Reactivity Coefficients in Large Fast Power Reactors, H.H.Hummel and D.Okrent, ANS (1970).

11. Fuel Cycle Physics and Introduction to Fuel Cycle (PY11) : (30 lectures)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.
8.	Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9.	U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10.	Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11.	Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12.	Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13.	Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14.	Isotopic separation operation of bred uranium in thorium cycles to remove U-232. MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Fluid Mechanics and Thermal Hydraulics PY12 (25 lectures)

S.No	Course content
1.	**Fluid Mechanics**
	Fluid continuum – Properties of fluids – Methods of describing fluid motion – Kinematics of fluid streamlines, streak lines, path lines – equation of Continuity, Euler's equations of motion – Navier Stokes equations.
	Hydrostatics – Manometry – Fluid force on planes and curved surfaces, – Aerostatics – variation of pressure, temperature and density with altitude – stability of atmosphere – Fluids subjected to uniform linear acceleration and uniform rotation.
	Analysis of fluid motion in integral form – Concept of a system and a control volume – equations of continuity, energy, linear momentum and angular momentum as applied to a control volume in fluid flow and their applications to propellers, pumps and turbines.
	Dimensional analysis, similitude and model testing – Laminar and turbulent flows – Viscous effects – Boundary layer – Separation phenomena – Losses in pipes.
2.	**Thermal hydraulics**
	Conduction: Steady state conduction in one and two-dimensional systems – One dimensional unsteady state conduction; analytical and numerical methods. Heat generation in cylindrical and plate fuel elements; Steady state heat transfer from fuel to coolant; concept of $\int KdT$; Axial temperature distribution in the fuel element; Maximum clad surface temperature.
	Convection: Basic equations, Boundary layers; Forced convection: External and internal flows, correlations, Natural convection. Natural circulation cooling during pump trip transients; flow coastdown; decay heat removal; natural circulation in advanced reactor concepts, flow instabilities.
	Radiation heat transfer: Basic laws, Properties of surfaces, view factors, network method and enclosure analysis for gray – diffuse enclosures containing transparent media, Engineering treatment of gas radiation.
	Boiling heat transfer: bubble nucleation; transition and film boiling (a) pool boiling and (b) flow boiling; heat transfer coefficients in pool and flow boiling. Horizontal and vertical surfaces. Two-phase flow; flow regimes; mixture quality; void fraction; mixture density; pressure drop.
	Concept of pressure drop in nuclear channels: objectives and methods of flow orificing; orificing in BWRs and FBRs. Hot spot factors; classification; determination of subfactors; overall hot spot factor-statistical and multiplicative approaches.
	Condensation: Surface tension- bulk Condensation – Dropwise condensation on solid surfaces, Film condensation, Nusselt's theory.
	Critical heat flux: mechanism of dryout and Departure from Nucleate Boiling (DNB); thermal margin – MCHFR; MDNBR; critical power concept.

Books Suggested:

1. Thermal Hydraulic Fundamentals, Neil E. Todreas, Hemisphere (1990).
2. Fluid Mechanics, F. Dougles et al., Pearson Education, 2006.

3. Heat Transfer, J.P. Holman, Eighth Edition, McGraw Hill, 1997.
4. F.P. Incropera and D.P. Dewitt, "Fundamentals of Heat and Mass Transfer, John Wiley and Sons, Fourth Edition, 1998.
5. Fast Breeder Reactors, Waltar A.E. and Reynolds A.B, Pergamon Publishers, New York, 1981.

13. Advanced Computational Methods in Reactor Physics (PY13): (35 lectures)

S.No.	Course content
1.	**Methods of solving neutron Diffusion equation:** Finite differencing of diffusion equation. Centre and corner mesh differencing schemes. Rectangular and triangular (hexagonal) meshes; Inner and outer iteration schemes. Acceleration methods for inner iteration scheme. Spectral radius and determination of acceleration parameter. Acceleration methods for outer iteration scheme. Power iteration and dominance ratio.
2.	Modern nodal methods. General weighted residual methods. Finite element method- its advantages and disadvantages. Coarse mesh rebalancing.
3.	Estimation of fundamental and higher harmonics; subtraction methods
4.	**Methods of solving neutron transport equation** **(i) Lattice:** (a) P_N method (b) Discrete ordinates method (c) Collision probabilities methods Collision probability method in 1-D and 2-D geometries. Interface current method. (d) Characteristics method.
5.	**(ii) Core and Shield:** Discrete ordinates methods in 1-D, 2-D and 3-D geometries. Diamond differencing scheme. Computer code ATES-3. Monte Carlo methods for core calculation; deep penetration problems. Computer code MCNP.
6.	Detailed burnup chain with all minor actinides. Solution of the burnup equations. Constant flux and constant power approximations. (ORIGIN
7.	Differencing of kinetic equations in time. Approximate solution of point kinetic equations. Space time kinetics. Adiabatic approximation. IQS; explicit and implicit time differencing methods.

Books suggested:

1. E.E.Lewis and W.F. Miller, Computational Methods of Neutron Transport, Wiley (1984) and ANS (1993).
2. G.I.Bell and S. Glasstone, Nuclear Reactor Theory, Van Nostrand (1970).
3. A.F. Henry, Nuclear Reactor Analysis, MIT Press (1975).
4. M. Clark and K.F. Hansen, Numerical Methods of Reactor Analysis, Academic Press (1964).

14. Experimental and Operational Reactor Physics (PY14): (35 lectures)

S.No	Course content
	I. Experimental Reactor Physics (10 hrs)
1.	Source and power range neutron detectors; Neutron sources- requirement vis-à-vis reactor type-External localised sources in LWRs and FBRs - internal distributed spontaneous fission / photo-neutron sources in PHWRs. Different steps of initial start-up in different research and power reactors.

2. Moderator experiments-measurement of diffusion length, age, migration length. Exponential experiment-Alpha dieaway (decay) experiment. Subcritical multiplication experiments-Critical mass measurements.

3. Low power experiments at criticality for validation of reactor physics evaluations-Measurement of neutron flux-Thermal and fast-Activation analysis-cadmium ratio-General methods of flux measurement- foil/wire activation methods, Measurement of buckling, power peaking and power distribution.

4. Neutron spectrum unfolding; differential measurements for reaction rates.

5. Dynamic methods of reactivity evaluation Reactor Period measurements-Measurement of reactivity-control Rod Calibration-power run-down experiments-reactivity coefficients measurements –Temperature and void coefficients measurements. Dose and shielding experiments-cross-section measurements.

6. Reactor noise methods- Process parameter measurements using neutronics-coolant flow measurement with N-16 gamma signals- failed fuel detection using delayed neutrons and noble gas fission products.

7. **Critical Facilities:**

   Thermal – ZERLINA, AHWR-CF, PURNIMA (1,2,3) ZED-2

   Fast – GODIVA (US), ZEBRA (UK), ZPPR (US), MASURCA (France), BFS (Russian).

8. **Subcritical Facilities with source:** MUSE, YELINA, PURNIMA-SCF, AHWR-C with source.

II. Operational Reactor Physics (20 hrs)

1. First Approach to Criticality; low power physics experiments; control requirements; general control schemes (auto or manual control as the case may be); spatial power control; nominal operation, power rise schemes; set-back and step back (as applicable); Reactivity balance in operating reactors.

2. Thermal power estimation using secondary and primary parameters – station heat balance. Assembly/ Bundle power, channel power, Linear Heat Rating (LHR): operational and safety limits; Bundle power envelops in PHWRs.

3. Failed fuel detection – delayed neutron monitoring; Fission Product (FP) gammas and volatile-gaseous FPs Back ground activities in the coolant.

4. Research Reactors: APSARA/CIRUS/DHRUVA – application. FBTR operation and applications. KAMINI operation and applications

5. Power Reactors: Operation of 220 and 540 MWe PHWRs : Incore flux mapping system BWR (TAPS- 1&2), PWR / VVER , PFBR

Books Suggested:

1. Experimental Reactor Physics, A.Edward Profio, John Wiley and Sons.

15. Design Methods in Thermal and Fast Reactors including Computer Codes (PY15): (35 lectures)

S.No **Course content**

I. Thermal Reactors

1. Popular multigroup nuclear data libraries and their group structure.
2. Spatial heterogeneity in different thermal reactors. Wigner-Seitz cell approximation. Self shielding effects in space and energy. Neutron transport treatment. Computer codes MURLI and CLUCOP.
3. Fuel assembly heterogeneity and supercell concept. Neutron transport treatment. Computer codes –SUPERB, CLUB, CASMO. Analysis of plate fuel assemblies. Special treatment of burnable absorbers and control rods.
4. Treatment of hexagonal lattices, EXCEL, TRIHEX.
5. WIMS Methodology ; HELIOS Computer code
6. Generation of cell and assembly parameters as a function of burnup and boron concentration in moderator.
7. Core computations. Core follow up and refueling. Computer codes DIF3D, VENTURE and COMESH. Core simulation codes TRIVENI and COMETG.

II. Fast Reactors

1. Popular multigroup libraries and their group structure.
2. Treatment of slowing down and energy self shielding. Heterogeneity effects in absorber rods. Computer code COHINT.
3. Breeding ratio and its variation with core material geometry. Radial and axial heterogeneous designs. Oxide, carbide and metal fuel and their effect on core safety parameters.
4. Hexagonal geometry effects. Optimisation of blanket thickness. Sodium void reactivity effects. Fuel burnup modeling.
5. Fuel management schemes in FBTR and PFBR. Effects on breeding ratio and power distribution. Computation of peak linear heat rating from measured outlet temperature distribution.
6. Computer code FARCOB. Code system ERANOS.

Books suggested:

1. R.J.J. Stammler and M.J.Abbate, Methods of Steady State Reactor Physics Nuclear Design, Academic Press (1983).
2. Handbook of nuclear reactor calculations: Vols I-III, Yigel Ronen Ed. CRC Press, West Palm Beach, Florida (1986).

16. In Core Fuel Management (PY16): (25 lectures)

S.No **Course content**

1. General in-core fuel management schemes. Advantages and dis-advantages of on-line and batch fuelling. Initial and equilibrium core concepts.

   PHWR: Online fueling; refueling strategies; core burnup - power distribution optimization; time average and snap shot evaluations; theory of computer code TAQUIL. Average exit burnup. Core followup; theory of TRIVENI code. Channel Power Peaking Factor (CPPF). Rules of channel selection. Fuelling in PHWRs: (220 & 540) Discharged bundle data – Pu production & Pu-vector.

2. **BWR:** Initial fuel loading; equilibrium cycle Batch fueling concepts; different core loading concepts – checker board, out-in, sector symmetric. Cycle length and Haling principle. SDM demonstration. Control rod pattern. Power distribution optimization. Core followup computer code COMETG. Minimum Critical Heat Flux Ratio (MCHFR).
3. **PWR and VVER:** Initial loading, equilibrium loading. Boron poison management. Fuel enrichment change and use of burnable absorber. Departure from Nucleate Boiling Ratio (DNBR).
4. **AHWR:** Basic principles of fuelling
5. **HTR:** Basic principles of fuelling

suggested:

1. P. Silvennoinen, Reactor Core Fuel Management, Pergamon Press (1976).
2. R.G. Cochran and N. Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

Homi Bhabha National Institute, RRCAT, Indore

Ph.D. in Physical Science
(Program Code: PHYS04)

Raja Ramanna Centre for Advanced Technology, Indore

Courses offered at HBNI, RRCAT for
Ph. D. in Physics
M.Tech. in Engineering Physics
(Specialization in Accelerators and Lasers)

- Total credit requirement for Ph. D. (Physics) : 60

Core courses	28 credits
Elective courses	20 credits
Laboratory experiments	04 credits
Two reading courses	08 credits

- Total credit requirement for M.Tech. (Engineering Physics) : 60*

Core courses	38 credits
Elective courses	12 credits
Laboratory experiments	04 credits
Short term project	06 credits

* An additional course (Foundation course) of 5 credits is offered to M.Tech. students as a bridge course.

Contents

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Syllabus for Ph. D. (Physics)

A : Core Courses

03PHYS04-001-C: Engineering Mathematics Credit (3)

Complex Analysis: Analytic functions, Cauchy-Reimann conditions, Cauchy integral theorem, Laurent expansion, conformal mapping, singularities, calculus of residues, evaluation of definite integrals.

Vector Calculus: Gradient, divergence and curl operations and their physical interpretations, vector integrations, Gauss theorem, Stokes theorem.

Matrix: Basic concept of matrix algebra, symmetric, skew-symmetric and orthogonal matrices, eigenvalues and eigenvectors of a matrix, hermitian, skew-hermitian and unitary matrices, illustration of symplectic matrices in particle transporting accelerator.

Integral Transform: Fourier integral, Fourier transform and inversion theorem, Fourier transform of derivative, convolution theorem, transfer function, Laplace transform, Laplace transform of derivatives, convolution theorem, inverse Laplace theorem.

Ordinary and Partial Differential Equations: Review of ordinary differential equations, introductions to partial differential equations, classification of partial differential equations, boundary and types of partial differential equations, solutions of one dimensional diffusion equation, two-dimensional Laplace equation, use of integral transform in solving partial differential equations. Introduction to difference equations.

Probability and Statistics: Bayes' formula, random variables, expected value and variance, discrete and continuous distributions, location parameters, joint distributions, conditional distributions and independence, covariance and correlation, bivariate normal distribution, Poisson process, the central limit theorem, statistical inference (with an aim to better understand and analyze experimental data), point estimators, estimating variance, confidence intervals, comparing two samples, estimation methods, hypothesis testing, goodness of a fit.

References:

1. "Mathematical Methods for Physicist", G. Arfken
2. "Mathematical Methods for Scientists and Engineers", Donald A. McQuarrie
3. "An Introduction to Probability: Theory and its Applications- Vol.1 and Vol 2", William Feller
4. "Ordinary Differential Equations" V.I. Arnold
5. "Advance Engineering Mathematics", Erwin Kreyszig

03PHYS04-002-C: Magnet Physics and Technology: Credit (4)

Origin of Magnetism: Classical and quantum concepts, magnetic moments, angular momentum and quantization of angular momentum.

Classification of Magnetism: Diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetism.

Role of Magnets in Accelerators: Dipole, quadrupole, sextupole, and combined function magnets, DC and fast cyclic magnets, septum magnets, and kicker magnets.

Fundamentals of Magnet Design: Magnetic circuit, dipole, quadrupole, sextupole and higher order multipole magnets and coil design, B-H curve.

Application of Magnetic Materials in Accelerators: Materials for DC magnets: low field magnets, high field magnets, permanent magnets, and shielding.

Materials for AC Magnets: Silicon steels, laminated Ni-Fe alloys, and Ferrites. Numerical methods for magnet simulation: computer code and related mathematical formalism, methods of optimization, multipole expansion, Fourier representation of magnetic field.

Magnet Technology: Fabrication procedures, tolerances, and economic issues.
Methods of magnetic field measurements: magnetic induction, search Coil, Hall probe, and nuclear magnetic resonance.

Superconducting Magnets: Basic concept of superconducting magnets, magnet geometries for dipole magnets, superconducting materials, need for twisted composite conductors, hot spot temperature, current densities, quench, training of magnets and persistent switch.

Geodesy and Alignment of Accelerators: Introduction, survey and alignment as applicable to accelerators and its requirement. Position sensitive elements and their typical tolerances for alignment, fiducial references and adjustment system, fiducial posts and targets, and techniques of fiducialsation. Features of support elements and their adjustments during alignment.

Network and Alignment Procedure: Defining coordinate systems, control networks-types, survey procedure, data adjustment and error analysis.

Survey and Alignment Instruments and Toolings: Electronic theodolite, optical level, laser Interferometer, distinvar, inclinometer, offsetmeter etc. Different types of targets and sensors.

References:

1. "Iron Dominated Magnets", Jack T. Tanabe
2. "Synchrotron Radiation Sources - A Primer," Herman Winick
3. "Iron Dominated Electromagnets, Design, Fabrication, Assembly Measurements", Jack T. Tanabe
4. "Conventional Magnets,Proceedings of CAT- CERN Accelerator School, Nov. 1993, Page 23," Neil Marks
5. "Classical Electrodynamics," J. D. Jackson
6. "Superconducting Magnet Systems," H. Brechna
7. "Physics of Magnetism," S. Chikazumi
8. "Soft Ferrite its Applications", E.C Snelling
9. "Permanent Magnet Materials Their Applications," Peter
10. "Modern Ferrite Technology", Alex Goldman

03PHYS04-003-C: Laser Physics and Technology: Credit (4)

Basic Formalism: Spontaneous and induced transitions, Einstein's approach, A and B coefficients, conditions for light amplification and oscillations, and characteristics of laser light. Homogeneous and inhomogeneous broadening of the transitions, spectral narrowing in a laser, gain saturation, spatial and spectral hole burning and their consequences, Lamb dip spectroscopy and its applications.

Propagation of optical beams in free space and in dielectric slab waveguides, Hermite-Gaussian beam modes, and ABCD law for Gaussian beam propagation.

Optical resonators, concept of cavity modes, resonators with spherical mirrors, resonance frequencies of optical resonators, losses in optical resonators, stable/ unstable resonators, Kirchoff's diffraction treatment for transverse modes.

Methods For Obtaining Population Inversion: Optical pumping, coherent and incoherent pumping, one- and two-photon processes, pumping geometries, pump sources, electrical pumping by discharge in gases, excitation mechanisms, self sustained and e-beam sustained operation, chemical pumping, and gas dynamic pumping.

Laser Dynamics: Laser oscillation, three and four level lasers, rate equation modeling, power in laser oscillators, optimum output coupling low- and high-loss regimes, multimode laser oscillation and mode locking. Different techniques of mode locking. Relaxation oscillations, cavity dumping and Q-switching. Techniques of Q-switching. Pulse compression techniques for ultrashort pulse generation. Spectral control of laser output, tunability of output frequency, single frequency operation, and frequency stabilization.

Physics and Technology of Specific Laser Systems: Solid state lasers, vibronic lasers, semiconductor diode lasers, diode pumped solid state lasers, fiber lasers, dye lasers, atomic and molecular gas lasers, chemical lasers, excimer lasers, free electron lasers. Measurement of parameters of a laser system.

Nonlinear Optics: Crystal optics, electro-optic effect, wave propagation in nonlinear media, phase matched second harmonic generation, optical parametric oscillator, two-photon absorption, stimulated Raman scattering, frequency mixing in gases and vapours, self-focusing, optical bistability and optical phase conjugation. Quantum optics: second quantization, non-classical effects.

References:

1. "Laser Fundamentals", W. T. Silfvast
2. "Laser Electronics", J. T. Verdeyen
3. "Lasers", A. E. Siegman
4. "Quantum Electronics", A. Yariv
5. "Laser Physics and Technology, Proc. of the school on Laser Physics and Tech." Eds. P. K Gupta, R. Khare
6. "Nonlinear Optics", R. W. Boyd
7. "Elements of Nonlinear optics", P. N Butcher and D Cotter

03PHYS04-004-C: Electromagnetic Theory: Credit (3)

Electrostatics: Laplace equation and the uniqueness theorems, variational approach to solutions of the Laplace and Poisson equations. Formal solutions of electrostatic boundary value problems with Green function. Method of relaxation for 2D electrostatic problems, method of images, separation of variables and special functions, finite element method, and multipole expansions. Electrostatic field in matter.

Magnetostatics: Maxwell equations of magnetostatic, macroscopic Maxwell equations in magnetic material and boundary conditions on B and H, and solution of boundary value problems in magnetostatics.

Electromagnetic Wave: Wave equation, solutions in free space, plane waves, Gaussian beams, equations in material media, dispersion relations, Fresnel's laws of reflection and refraction, total internal reflection and evanescent waves. Lorentz transformation of electromagnetic fields.

Wave-guides, Resonant Cavities and Optical Fibers: Hollow metallic waveguides, dielectric waveguides, optical fibers, resonant cavities, and elements of microwave transport line.

Radiation by Moving Charges: Lienard-Wiechert potentials and fields, power radiated by an accelerated charge, Larmor's formula, and angular distribution of emitted radiation.

References:

1. "Electromagnetic Theory", D. J. Griffith
2. "Classical Electrodynamics", J. D. Jackson
3. "Electrodynamics: An introduction including quantum effects", H. J. W. Muller-Kirsten
4. "Microwave Devices and Circuits", S. Y. Liao.

03PHYS04-005-C: Accelerator Physics and Beam Diagnostics: Credit (4)

Introduction: Motion under electric and magnetic fields. DC and RF acceleration. Relativistic kinematics, Brief history and review of particle accelerators.

Synchrotron/Storage Rings: Accelerator magnets - dipole, quadrupole and sextupole magnets. Multipole expansion method. Equation of motion, betatron oscillations, weak and strong focusing, transfer matrices, beam stability, twiss parameters, motion of particles with momentum deviation, momentum compaction, and chromaticity. Magnetic field errors, closed orbit distortion and its correction, resonances - integer and half integer, beam acceleration, synchrotron oscillations, phase stability, transition energy, beam emittance, Liouville's theorem, single turn injection, H-injection, and fast extraction.

Beam Transfer Lines: FODO cells, quadrupole triplet, phase space matching, emittance dilution.

Synchrotron Radiation Sources: Synchrotron radiation, Radiation damping, quantum excitations, equilibrium beam emittance, and beam lifetime.

Linear Accelerators: DC accelerators, various types of RF accelerators, EM mode in a simple structure, Q-factor, shunt impedance, transit time factor, filling time, energy gain, dispersion curve, TW and SW accelerators, and beam dynamics in LINACS.

Cyclotrons: Basic principle of cyclotron, resonance condition, orbit stability, limitations of classical cyclotrons, AVF cyclotrons, injection, central region, extraction, time structure, energy resolution, and beam emittance.

Microtrons: Classical microtrons, basic equations, and Racetrack microtrons.

Beam Diagnostics: Physical principles, charge collection, secondary emission, Ionization, fluorescence, scintillation, capacitive pick up, magnetic pick up, wall current, synchrotron radiation detection, and optical transition radiation.

Instrumentation: Faraday cup, secondary emission wire monitor, beam loss monitor, beam profile monitor, beam position monitor, DC beam current transformer, fast current transformer, wall current monitor, photomultiplier, photo diode, image dissector, and streak camera.

References:

1. "Particle Accelerator Physics", Helmut Wiedemann, Springer
2. "Introduction to Accelerator Physics", Arvind Jain, Macmillan India
3. "CERN Accelerator School Proceedings, Fifth General Accelerator Physics Course, 1992 (Available online)"
4. "The principles of circular accelerators and storage rings", P.J. Bryant and K. Johnsen, Cambridge University Press
5. "Principles of RF linear accelerators", T. Wangler, John Wiley and Sons
6. "Collective phenomenon in synchrotron radiation sources", S. Khan, springer
7. "Physics of collective beam instabilities in high energy accelerators", A. Chao, John Wiley and Sons

03PHYS04-006-C: Reactor Physics, Radiation Physics, and Safety Issues of Credit (3)

Health Physics: Radiation sources - radioisotopes, natural and manmade sources, radioactive series, reactors, accelerators, radiation facilities, solid, liquid and gaseous activity. Control measures - time, distance, decay, shielding, administrative control, radioactive discharge, waste disposal, and exposure control.

Interaction of Radiation with Matter: Interaction of light and heavy charged particles, photons, and neutrons. Interaction of high energy charged particles, electromagnetic cascade, and Hardronic cascade.

Radiation Quantities, Units, and Regulatory Recommendations: Dosimetric quantities, exposure, absorbed dose, equivalent and effective dose, committed dose, ALI, DAC, ICRP, AERB, and dose limits.

Biological Effects of Radiation: Somatic and genetic effects, stochastic and deterministic effects, and LD30/50.

Detection of Radiation: Ionisation chamber, proportional counters, GM tubes, scintillation detectors, semiconductor detectors, thermoluminiscent dosimeters, direct reading dosimeters neutron detectors, BF3 and He3 tubes, Rem-meters, CR-39-foils, pulsed radiation detection. Low and high energy radiation detection.

Reactor Physics: Introduction to nuclear energy - fission and fusion, interaction of neutrons with matter; fission process and energy release, fission cross-section, fissile and fertile materials. Chain reaction, neutron cycle and lifetime, criticality and classical four-factor formula. Thermal and fast systems, slowing down of neutrons, conversion and breeding of fissile materials, concept of neutron flux and current, neutron diffusion theory, critical size and mass, reflected systems and reflector saving, heterogeneous systems. Reactor kinetics, reactivity and importance of delayed neutrons, reactivity changes and coefficients, fission product poisoning, control devices, uranium and thorium fuel cycles and enrichment processes.

Accelerator Safety: Types of accelerators, prompt and residual radiation, source terms, radiation hazards, radiation safety systems, shielding, radiation monitoring, non-ionizing radiation safety, RF and MW safety, magnetic field safety; ozone safety, safety at synchrotron radiation beam lines, spallation neutron sources, and accelerator driven sub-critical systems.

References:

1. "Nuclear Reactor Engineering Vol-1", Samuel Glasstone and Sesonske
2. "Health Physics", Herman Cember
3. "Radiation Detection & Measurement", G. F. Knoll
4. "Atoms, Radiation & Radiation Protection", James Turner
5. "Physics for Radiation Protection", James Martin
6. "Radiological Safety Aspects of the Operation of Electron Accelerators, IAEA Technical Report Series. 188", W.P. Swanson
7. "Radiation Protection for Particle Accelerator Facilities NCRP Report No.144"
8. "Radiological Safety Aspects of the Operation of Proton Accelerators. IAEA Technical Report Series. 283", R. H.Thomas.
9. "A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators Nuclear Technology", A. Sullivan

03PHYS04-007-C: Numerical and Mathematical Techniques and Scientific — Credit (5)

Numerical Methods

System of Linear Algebraic Equations: Direct methods - Gauss elimination and Gauss Jordan methods. Iterative methods - Jacobi, Gauss-Seidel and Successive over relaxation (SOR) methods. Eigenvalue problem .

System of Nonlinear Equations: Newton-Raphson and Secant methods. Roots of polynomials, synthetic division of polynomials, and Baristow method.

Interpolation, Extrapolation, Error and Regression Analysis: Types of errors their analysis.

Numerical Integration: Newton-Cotes, Gauss quadratures, trapezoidal, Simpson's 1/3 and 3/8 rule. Numerical differentiation - forward, backward and central difference quotient.

Differential Equation: Solution of ordinary differential equations. Solution of partial differential equations. Fast Fourier transformation.

Statistical Distributions: Poisson and Gaussian distributions. Monte Carlo simulation, pseudo random numbers, and central limit theorem.

Finite Element Method (FEM)

Introduction: Basic concepts of finite element method, application of finite element method, finite element method versus classical methods, finite element method versus finite difference method, and advantage of finite element method.

Integral Formulations for Numerical Solutions: Variational method, collocation method; subdomain method, weighted residual methods, Rayleigh-Ritz method, Galarkin's method, and least squaremethod

Elements, Nodes, and Co-ordinate Systems: Introduction, element shapes, nodes, nodal unknowns, and coordinate systems

Shape Functions: Introduction, polynomial shape functions, convergence requirement of shape function, and derivation of shape functions.

Introduction to Stiffness (Displacement) Method: Definition of the stiffness matrix, derivation of the stiffness, matrix, assembly of the total stiffness matrix, properties of the global stiffness matrix.

Application of Finite Element Method in Heat Transfer Problem: Fundamentals, one dimensional finite element formulation, and problems.

Fundamentals of Computers: Computer architecture, application of computers, input and output devices, latest processors, desktop PC and servers.

Networking Basic: TCP/IP, DNS, Internet, and Intranet.

Operating System Basic: Linux, windows, shell programming, and CLI, vi, multithreading, multiuser, multitasking, hyper threading, file permissions, and ssh.

Fundamentals of programming: Algorithm, flow charts, high-level languages like Fortran and C, and steps for creating a simple program.

Introduction to C Programming Language: Program structure, header files, basic data types, variables, and declarations.

Operators and Declarations in C: Relational, logical, increment, and decrement operators. Expressions and precedence of operators. Input and output operations, control statements, iterative loops, arrays, and pointer;

Overview of Scientific Computing: Languages and compilers and scientific libraries.

Overview of Trends and Techniques: Sequential, parallel computing, cluster and grid computing.

Architecture Taxonomy: Traditional architecture, Flynn's classical taxonomy, SISD, SIMD, MISD, and MIMD Models.

Steps for Creating a Parallel Program: Decomposition of the program, communication, computations, and composing the results. Parallel example-array processing.

References:

1. "Numerical Methods for Engineers with Personal Computer", S.C Chapra and R. P. Canale
2. "Numerical Analysis", R. L. Burden and J. Douglas Faires
3. "An Introduction to Numerical Analysis", K.E. Atkinson
4. "Numerical Method", E. Balagurusamy
5. "Numerical Methods for Engineers", D. V. Griffiths and I. M. Smith
6. "Data Reduction and Error Analysis for the Physical Sciences", P. R. Bevington and D. K. Robinson
7. "Finite Element Analysis", S. Krishnamurthy
8. "Introduction to the Finite Element Method", Desai and Abel
9. "An Introduction to the Finite Element Method", J. N. Reddy
10. "Concepts and Applications of Finite Element Analysis", R. D. Cook
11. "Finite Element Modeling for Stress Analysis", R. D. Cook
12. "Finite Elements and Approximation", O. C. Zienkiewicz and K. Morgan

03PHYS04-008-C: Materials Science and Technology- I: Credit (4)

The structure of materials (metals and alloys, ceramics and glasses, polymers, composites, low dimensional materials, smart materials). Defects in materials, transport properties of materials, mechanical and thermal properties of materials, electrical, magnetic, galvanometric properties, superconductivity. Optical, nonlinear properties of optical materials, quantum size effects. Electronic materials (like spintronics, and other functional materials). Introduction to symmetry and ferroelectric materials.

References:

1. "Solid State Physics", N. W. Ashcroft N. D. Mermin

2. "Principles of the Theory of Solids", J. M. Ziman
3. "Introduction to the Physics of Electrons in Solids", B. K. Tanner
4. "Introduction to the Electron Theory of Metals", U. Mizutani
5. "Introduction to Superconductivity", A. C. Rose-innes E. H. Rhoderick
6. "Physics of Superconductors: Introduction to Fundamentals Applications", V. V. Schmidt; edited by P. Mueller A. V. Ustinov
7. "Superconductivity", Charles P. Poole, Horacio A. Farach Richard J. Creswic
8. "Shape Memory Materials", Ed. K. Otsuka C.M. Wayman.
9. "Phase Transformations in Materials", Ed. Gernot Kostorz.
10. "Magnetocaloric Effect its Applications", A. M. Tishin Y. I. Spichkin.
11. "Callister's Materials Science Engineering", R. Balasubramaniam.
12. "Engineering Materials 1: An Introduction to Properties, Applications Design", Michael F. Ashby David R. H. Jones.
13. "The Physics of Solids", R. Turton
14. "Dielectric Phenomena in Solids", Kwan Chi Kao.

03PHYS04-009-C: Applications of Lasers in Nuclear Science, Industry and Medicine Credit (3)

Laser Applications: High resolution spectroscopy, ultra-fast spectroscopy, laser cooling, laser metrology, holography and its applications in NDT, optical data storage information processing, and optical communication. Laser photochemistry, laser application in biology and medicine

Laser Isotope Separation: Principles of selective photonic action, selective photonic action on atoms or molecules, atomic and molecular schemes for laser isotope separation, lasers for isotope separation, and uranium isotope separation technology employing lasers.

Laser Material Processing: Laser material interaction, Laser cutting, welding, surface hardening, laser surface re-solidification, laser surface alloying, and cladding, laser shock-hardening, laser rapid manufacturing, laser application in decontamination and decommissioning of nuclear installations.

03PHYS04-010-C: Applications of Accelerators in Nuclear Science, Industry and Medicine Credit (3)

Synchrotron Radiation and its Applications: Properties of synchrotron radiation, various types of sources like BM, wavelength shifter, wiggler, and undulators. Beamline design and

synchrotron optics. Applications of synchrotron radiation to condense matter physics, surface physics, biology and Industries

Industrial and Medical Applications of Accelerators: Accelerators for industrial and medical applications. Beam characteristics for medical and industrial applications.

Radiation Processing Using Accelerators: Radiation cross-linking, radiation curing, polymerization, de-polymerization, and radiation grafting. Dose distribution in the irradiated products.

Typical applications: Treatment of wire and cables, viscose rayon sheets, rubber products, heat shrinkable tubes, and sheets. Flue-gas treatment, waste water treatment, electron beam applications in food irradiation and sterilization.

Accelerator Based Radiotherapy: Clinical requirements of an accelerator for radiotherapy. Various components of radiotherapy machine. Photon beam therapy and electron beam therapy. Quality assurance in radiotherapy accelerator.

Applications of Accelerators in Nuclear and Particle Physics: Evolution of nuclear physics with energy of the incident beam. Nuclear physics and related phenomena at incident beam energy less than 10 MeV/nucleon, between 10 and 100 MeV/nucleon, and more than 100 MeV/nucleon. Nuclear physics with radioactive ion beams (RIB).

Spallation Source: General introduction, applications to condense matter, and nuclear physics.

03PHYS04-011-C: Vacuum Physics and Technology: Credit (2)

Vacuum Theory: Definitions - throughput, conductance, pumping speed etc. Pressure equations, mean free path, monolayer formation time. Units of vacuum, pressure regions in vacuum.

Vacuum Systems and Components: Vacuum pumps - rotary pumps, dry pumps, turbomolecular pump, titanium sublimation pump, non-evaporable getters, and sputter ion pump. Vacuum gauges - capacitance gauge, Pirani, thermocouple gauges, BA gauge, penning gauge, partial pressure gauge. flanges and seals, vacuum valves and leed throughs.

Vacuum System Design and Development: Design considerations, sources of gas load (vaporization, thermal desorption, diffusion, permeation, electron and ion stimulated desorption etc). Materials, fabrication techniques and leak detection. Processing to achieve ultra high vacuum.

References:

1. "Handbook of Vacuum Science and Technology", Ed. Dorothy M. Hoffman, Bawa Singh, John H. Thomas III and John H. Thomas III
2. "Vacuum Technology -3rd edition", A. Roth
3. "A User's Guide to Vacuum Technology - July 4, 2003", John F. O'Hanlon
4. "Vacuum Engineering Calculations, Formulas", Armand Berman
5. "Vacuum Technology-CERN Accelerator School", CERN

03PHYS04-012-C: Quantum Mechanics: Credit (6)

For Ph. D. (Physics) only

Mathematical Background and Postulates: Illustrations and application of postulates by using simple two-level systems and two-slit interference experiment.

Quantum Mechanics of Composite Systems: N-particle system, identical particles, symmetrization and antisymmetrization postulates, concept of density matrix, properties of density matrix, pure and mixed states.

Symmetry: Symmetries in quantum mechanics, space and time translation, time reversal symmetry and parity invariance. Rotational invariance, angular momentum, spin, and addition of angularmomenta.

Approximate Methods: Variational methods, Wentzel-Kramers-Brillouin (WKB) method, time-independent perturbation theory, time dependent perturbation theory, adiabatic and sudden approximations, Fermi-Golden rule.

Scattering Theory: Born approximation, partial wave analysis, two particle scattering.

Relativistic Quantum Mechanics: Klein-Gordon equation, Dirac equation, electron spin, and positron.

Advanced Topics: Quantization of electromagnetic field, coherent, and squeezed states, interaction of radiation with matter, spontaneous emission and Lamb shift, entangled state, EPR paradox and Bell's inequality.

References:

1. "Principle of Quantum mechanics", Ramamurthy Shankar
2. "Quantum Mechanics, Vol. I and II", C. Cohen-Tannoudji, B. Liu, F. Laloe
3. "Modern Quantum Mechanics", J. J. Sakurai

03PHYS04-013-C: Research Methodology: Credit (0)

(Lecture: 20, Credit: 0)

Research Methodology: Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

Documentation: Preparing scientific papers/reports, scientific presentations.

Laboratory safety: Safe practices in laboratory.

Research ethics*:* Ethical conduct in science, ethical issues in scientific publication, awareness of plagiarism and other scientific misconducts.

Probability and Statistics: Bayes formula, random variable, expected value and variance, discrete and continuous distributions, joint distributions, conditional distributions, covariance and correlation, normal distribution, Poisson process, central limit theorem and its applications,
definition of precision, accuracy, systematic and random errors**,** propagation of errors in experimental data and their estimation, estimation of variance and confidence intervals.

Mathematical modeling: Measurement of functional relationships, order of magnitude analysis, dimensional analysis, goodness of a fit, linear regression and data fitting.

Data Security: Introduction to Data Security, Data security requirements, Different Cyber threats to Data & possible Solutions, Basic concepts of Cryptography & Data encryption algorithms, Research opportunities in Data Security.

Data management: Data planning, handling, modelling, analysis, visualization, Different Data Models, Data Management Software, Data Backup & Storage

References:

1) Research Methods for Science, M. P. Marder (Cambridge University Press
2) The Ethics of Science, An Introduction, David Resnick (Taylor and Francis, 2005)
3) Avoiding plagiarism, self-plagiarism, and other questionable writing practices: A guide to ethical writing, Miguel Roig
4) Advance Engineering Mathematics, E. Kreyzwig (Wiley, 2006)
5) An Introduction to Probability: Theory and Applications Vol. 1 and 2, W. Feller (Wiley)

B : Physics Based Elective Courses

03PHYS04-001-E: Statistical Physics: Credit (4)

Classical and Quantum Statistical Mechanics: Introduction, postulates, microcanonical, canonical and grand canonical ensembles, partition and grand partition functions and their properties.

Ideal Bose Gas: Introduction, chemical potential, equation of state and thermodynamic properties, system of phonons, system of photons, Bose-Einstein condensation, Bose-Einstein condensation in dilute atomic gases, and superfluidity.

Ideal Fermi Gas: Introduction, equation of state and thermodynamic properties of degenerate Fermi gas. Neutron stars, conduction electrons in metals, and cold Fermi atomic gases.

Phase Transition: Mean-field theories, symmetry, order parameters, break-down of mean-field theories, critical phenomena and renormalization group.

Non-equilibrium Phenomena: Elementary ideas, irreversibility, study of Brownian motion, random walk model, Langevin force equation, fluctuation-dissipation theorem, Fokker-Planck equation, Glauberdynamics.

References:

1. "Fundamental of Statistical and Thermal Physics", F. Reif
2. "Statistical Mechanics", R. Pathria
3. "Statistical Mechanics", K. Huang

03PHYS04-002-E: Modern Optics: Credit (4)

Geometrical and Physical Optics: Wave front, phase, image formation, resolution, optical path, monochromatic and chromatic aberrations, wave front aberrations, complex representation of EM wave.

Optical Elements: Lens, effective and back focal lengths, shape factor and controlling of aberrations by bending, centering errors. Autocollimator and its applications. Prisms, right angle, penta, dove, corner cube, rhomb, Parallel plate, beam splitters (plane, cube and penta). Polarizers (wire grid, sheet, glan, and Wollaston prisms), Polarization beam splitters, wave plates (quarter and half wave plates).

Interferometers and Optical Measurements: Two and multi-beam interference, Intensity equation for two beam interference, contrast/visibility of interference fringes, temporal and spatial coherences.

Important Interferometric Configurations: Fizeau, Twyman Green, Mach-Zehnder, Jamin, lateral shearing, and Sagnac/ cyclic path interferometers.

Surface Imperfections: Surface flatness, form/figure error, surface roughness, and scratches and digs

Interferometric Testing: Surface form, parallelism, inhomogeneity differential interference contrast. Working principle and applications of Nomarski microscope.

Phase Shifting Interferometry: Principle, phase shifting techniques, and phase unwrapping.

Measuring Micro-scale Devices: Scanning white light interferometers (SWLI).

Overcoming Diffraction Barriers: Scanning near field optical microscope (SNOM).

Metamaterials

Introduction: Maxwell's equations, dispersion, reflection refraction, phase group velocities, photonic band gap crystals, electromagnetic metamaterials.

Negative Refractive Index: Introduction, designing negative refractive index materials, periodic structures, negative refractive index for various frequency regions, anisotropic isotropic materials, double negative metamaterials, nonlinear metamaterials.

Applications: Subwavelength imaging, concept of perfect lens, Veselago-Pendry lens, plasmonic cloaking invisibility.

Optics of Metals Nanomaterials: Electromagnetic waves in metals, skin depth, plasma frequencies, local field enhancements, focusing light beyond diffraction limit.

Optics of Nanoparticles: Optics at subwavelength regimes, dispersion in nanocomposite materials, effective medium theories, Clausius-Mosotti Maxwell-Garnett theories, extraordinary transmission through very small apertures.

Plasmonics: Introduction, electronics versus plasmonics, plasmonic components, manipulating light with plasmonic nanostructures.

Fiber Optics: Basics, Components Systems

Optical Fiber Geometry: Step index fiber, graded index fiber, double-cladded fiber, microstructured fiber. Modes in optical fiber, dielectric slab wave guide, propagating modes of the symmetric slab waveguide, even odd TE modes, characteristic equations, mode cutoff conditions, TM modes, ray optics explanation of modes in a dielectric slab waveguide. Basic equations physical constraints in round optical fibers, the fields in the core cladding, boundary conditions characteristic equation, characterization of modes, mode cut-off conditions, TE, TM hybrid modes, single mode optical fiber, linearly polarized modes, power distribution in optical fiber.

Characteristics of Optical Fiber: Losses in optical fiber: intrinsic impurity absorption loss, waveguide scattering loss, microbending macrobending loss, coupling splicing loss. Dispersion in optical fiber, group velocity dispersion, material dispersion, waveguide dispersion, polarization mode dispersion, dispersion management in optical fiber. Birefringence in optical fiber.

Nonlinear Fiber Optics: Nonlinearities in optical fiber, Kerr nonlinearity, self phase modulation, self focusing, cross phase modulation, four wave mixing, stimulated Brillouin scattering, stimulated Raman scattering. Ultra short pulse propagation, derivation of nonlinear Schrödinger equation (NLSE), ultra-short pulse propagation through fiber, soliton, similariton Gaussian pulse. Effect of gain loss on pulse propagation, interplay of dispersion, nonlinearity gain.

Fiber Optic Components Devices: Directional couplers, coupled mode equations, power transfer characteristics, transfer matrix of a coupler, super modes of a coupler, effect of fiber dispersion. Fiber gratings, Bragg diffraction, photosensitivity, fabrication techniques, grating characteristics, grating as an optical filter, nonuniform (chirped) grating. Fiber interferometer, fiber-ring resonator, Febry-perot resonator, Sagnac interferometers, Mach-Zehndar interferometers. Isolators circulators, Faraday effect, optical isolator, optical circulators. Fiber based system, fiber based sensors, temperature pressure sensors. Fiber laser amplifier, doped fiber, gain in doped fiber, basic construction of fiber laser amplifier. Mode-locked fiber laser: basics of mode-locking dynamics, nonlinear polarization rotation, saturable absorber, basic construction of a mode-locked fiber laser with a highlight of different mode-locking regimes, all-fiber integration.

References:

1. "Applications of Nonlinear Fiber Optics", G.P. Agrawal
2. "Erbium Doped Fiber Amplifiers", P.C. Becker, N A Olsson, and J R Simpson
3. "Introduction to Fiber Optics", Ajoy Ghatak, K Thyagarajan
4. "Lightwave Technology", G. P. Agrawal
5. "Plasmonics: Fundamentals and Applications", Stefan A. Maier (Springer)
6. "Plasmonics and Plasmonic Metamaterials - Analysis and Applications", Ed. Gennady Shvets , Igor Tsukerman (World Scientific)
7. "Metamaterials-Theory, Design, and Applications", Ed. Tie Jun Cui, David R. Smith and Ruopeng Liu (Springer)
8. "Optical Metamaterials: Fundamentals and Applications", Wenshan Cai, Vladimir Shalaev (Springer)

03PHYS04-003-E: Advanced Accelerator Physics: Credit (4)

Ion Sources: Emission processes and Child Langmuir Law, positive and negative ion sources, atomic and molecular phenomena in ion sources, beam extraction and transport.

Proton and Heavy Ion Accelerators: Introduction to acceleration of protons and heavy ions, RFQ, different type of cavities/accelerating structures, including SCRF, and introductory beam transport.

Instabilities in Linear Accelerators: Basics of beam instabilities, short and long range instabilities.

Other topics: FEL, Linac based synchrotron sources, laser plasma acceleration, and ADS.

03PHYS04-004-E: Plasma Physics and Technology: Credit (4)

Basic Plasma Physics: Definition of plasma, concept of temperature, Debye shielding, plasma parameter, criterion for plasma, variety of plasmas.

Plasma Behaviour: Single particle motion in electric and magnetic fields, collisions, plasma as fluid, kinetic approach.

Waves in Plasmas: Dielectric function, plasma oscillations, electromagnetic equations, dispersion relations.

Methods of Plasma Production: Electrical discharge, ohmic heating, RF heating, plasma production by lasers and particle beams, Tokamak plasma, Z-pinch, Theta pinch

Plasma Processes: Ionization, recombination, plasma equilibrium.

Radiation from Plasmas: Emission processes, spectral characteristics.

Plasma Diagnostic Methods: Density and temperature diagnostics using plasma radiation

Plasma Heating by Laser Beams: Propagation of laser beam in plasmas, inverse Bremsstrahlung, resonance absorption, parametric processes, second harmonic generation, filamentation, self-focusing.

Laser Plasma Interaction at Ultrahigh Intensities: Ultrahigh intensity parameters, multi-photon ionization, tunnel ionization, above threshold ionization, high harmonic generation.

Applications of Laser-plasma: Electron acceleration, x-ray lasing, inertial confinement fusion and fast ignition.

References:

1. "Introduction to Plasma Physics and Controlled Fusion Volume 1: Plasma Physics", Francis F. Chen
2. "Fundamentals of Plasma Physics, 3rd Ed.", J. A. Bittencourt Springer
3. "Principles of Plasma Spectroscopy", Hans R. Griem
4. "Principles of Plasma Diagnostics", I H Hutchinson
5. "The Physics of Laser Plasma Interactions", W. L. Kruer
6. "Short Pulse Laser Interaction with Matters: An Introduction", P. Gibbon

03PHYS04-005-E: Materials Science and Technology-II: Credit (4)

Methods for Growth and Synthesis of Materials: Introduction to phase diagrams and phase transitions. Methods of crystal growth: Solution growth, Czochralski method, Bridgman method, zone refining and other novel techniques. Methods for thin films preparation: Thermal vapor deposition, electron beam evaporation, chemical vapour deposition, MOCVD, sputtering, molecular beam epitaxy, sol-gel etc. Methods for ceramic synthesis: Powder preparation, consolidation and sintering. Nanomaterials: Top down and bottom up approaches.

Characterization Techniques: UV-VIS-NIR spectroscopy, FTIR and Raman spectroscopy. X-ray and neutron diffraction techniques. Polarized light microscopy, scanning electron microscopy, transmission electron microscopy, scanning probe microcopy, confocal microscopy. Thermal methods: Differential scanning calorimetry, differential thermal analysis and thermo gravimetric analysis.

References:

1. "Crystallization", J. W. Mullin
2. "Introduction to Phase Equilibria in Ceramics", Clifton G. Bergeron, Subash H. Risbud
3. "Crystal Growth Technology" Hans J. Scheel, Tsuguo Fukuda
4. "Etching of Crystals. Theory, Experiment, and Application", K. Sangwal
5. "A Guide to Materials Characterization and Chemical Analysis", John P. Sibila
6. "UV Spectroscopy: Techniques, Instrumentation and Data Handling (Vol. 4)" B.J. Clark, T. Frost, M.A. Russell
7. "Infrared and Raman Spectra of Inorganic and Coordination Compounds, Part A: Theory and Applications in Inorganic Chemistry", K. Nakamoto
8. "Infrared Spectral Interpretation: A Systematic Approach", Brian Smith
9. "Electron Microscopy and Analysis", Peter J. Goodhew, John Humphreys and Richard Beanland
10. "Transmission Electron Microscopy: A Textbook for Materials Science", David B Williams, C. Barry Carter,
11. "Scanning Probe Microscopy: The Lab on a Tip", Ernst Meyer
12. "Thermal Methods of Analysis: Principles, Applications and Problems", Peter J Haines
13. "Fundamental of Ceramics", Micheal W. Barsoum
14. "Introduction to the Principles of Ceramic Processing", James S. Reed
15. "Thin Film Deposition", Donals L. Smith

03PHYS04-006-E: Advanced Course on Atom-Photon Interactions:

Interaction of Light with Matter: Hamiltonian description, multipolar approximation, review of the time dependent perturbation theory, concept of transition amplitude, semiclassical theory of a two level atom coupled to a single mode radiation field, density matrix, optical Bloch equations, semi-classical laser theory.

Coherent Effects: Coherent population trapping (CPT), electromagnetically induced transparency, laser without population inversion, mechanical effects of light and its application in laser cooling and trapping.

Quantum Field: Quantization of electromagnetic field, interaction of quantized radiation with matter, Jaynes-Cummings model, quantum dissipative processes, atom in the vacuum field and spontaneous emission, resonance fluorescence.

Elementary of Theory of Coherence: Quasi-probability distribution functions, classical light and Non-classical light, coherent state, squeezed state and its experimental realization, atom-photon and atom-atom entanglement, multiparticle Entanglement, Entanglement in Quantum Information Processing.

Interaction of Atom with Intense Light Field: Virtual absorption and multiphoton ionization, generalized Fermi-Golden Rule, above threshold ionization, Volkov state and KFR theory, high harmonic generation, Floquet theory, many-body correlation effects and non-perturbative field effects, and S-Matrix theory.

References:

1. "Quantum Optics", Marlan O Scully and M Suhail Zubairy
2. "Elements of Quantum Optics", Pierre Meystre and Murray Sargent
3. "Laser Physics", Murray Sargent, Marlan O Scully and Willis E Lamb
4. "Photon and Atoms: Introduction to Quantum Electrodynamics", C. Cohen-Tannoudji, J. Dupont-Roc, G.Grynberg

03PHYS04-007-E: Advanced Beam Dynamics: Credit (4)

RMS envelope equation, beam matrix approach, concept of stationary states for beam distribution functions.

Transverse beam dynamics in a solenoid, Busch emittance, transverse and longitudinal beam dynamics in RF field, Panofsky-Wenzel theorem and its applications, wakefields and impedances in linear accelerators.

Emittance growth mechanisms and approximate techniques to estimate the emittance growth, beam halo. Bunch compressors and coherent synchrotron radiation (CSR), emittance growth due to CSR.

Beam dynamics with ion trapping and electron clouds

Coupling of electromagnetic power to RF cavities, beam loading and its implications, Slater perturbation theorem and its applications.

Computational methods in accelerator physics, symplectic integration, Lie Algebraic methods.

References:

1. "Theory and Design of Charged Particle Beams", Martin Reiser.
2. "RF Linear Accelerators", Thomas P. Wangler.
3. "Advanced Beam Dynamics", Bruce Carlsten and Steve Russell, a course offered at US Particle Accelerator School, Univ. of California, 2005.
4. "Computational Methods in Beam Dynamics", Robert Ryne, a course offered at US Particle Accelerator School, Univ. of California, 2005.
5. "Advanced Accelerator Physics Course", CERN Accelerator School Proceedings", CERN-95-06-V1-V2.
6. "Neutralization of Accelerator Beam by Ionization of the Residual Gas", Y. Baconneir, A. Poncet and P. F. Tavares, Lecture notes, CERN.

03PHYS04-008-E: Course on Bio-Photonics: Credit (4)

Introduction: Scope of bio-photonics, interaction of light with cells and tissues: absorption, scattering and depolarization of light .

Basics of Biology: Cell structure and organization, structure and function of biomolecules, metabolism and energetics. General methods for biophysical and biochemical analysis, mechanism of cell death.

Light Propagation in Tissues: Rayleigh and Mie scattering, multiple scattering and propagation of light in tissues, Radiative transport and diffusion approximation, effect of boundary conditions, numerical approaches for determining irradiance at surface and interior of scattering objects, techniques for determination of optical properties of biological samples.

Optical Imaging Through Turbid Medium: Trade-off between resolution and depth of imaging, use of spatial filtering, polarization gating and time-gating for optical imaging, high resolution imaging using coherence gating, Optical coherence tomography (OCT) and diffuse optical tomography.

Optical Spectroscopy for Biomedical Diagnosis: Elastic scattering spectroscopy for disease diagnosis, Fluorescence and Raman spectroscopy for diagnosis.

Optical Techniques for Micro-manipulation: Optical tweezers and micro-beams, radiation pressure and force on microscopic objects, gradient and scattering force, applications of optical tweezer.

Optical Microscopy: Recent Developments: Contrast methods in optical microscopy, techniques for single molecule imaging, scanning laser microscopy, multi-photon microscopy and near-field techniques.

Optical Methods for Bio-sensing Applications: Surface plasmon resonance based sensors, quantum dots and functionalized nanoparticles as biosensors approaches for label-free sensing, opto fluidics and lab-on-a-chip approach.

Effect of Light on Biological Tissue: Basic principals of photobiology, photo-acceptors, action spectra and light induced signaling mechanism, Ligh effect based on endogenous photosensitizers, use of exogenous photosensitizers for photodynamic therapy and photo anti-microbial therapy, biological effects of narrow bandwidth light.

References:

1. "Biomedical Photonics Handbook", Editor-in-Chief Tuan Vo-Dinh
2. "Optical Tweezers: Methods and Applications", Ed. Miles J. Padgett, Justin Molloy, David McGloin
3. "Introduction to Biophotonics", Paras N. Prasad

03PHYS04-009-E: Concepts in X-Ray Physics: Credit (4)

X-ray and Their Interaction With Matter: X-ray waves and photons, sources of X-rays, X-ray scattering from an electron and atom, refractive index including absorption, coherence, Kramer-Kroning relationship.

Refraction and Reflection of X-rays: Refraction and phase shifting in scattering, Snell's law and Fresnel equation in X-ray region, reflection from homogeneous slab and multilayers, rough interfaces and surfaces, examples of refractive and reflective X-ray optics and curved mirrors.

Kinematical Diffraction and Resonant Scattering: Laue condition and reciprocal space, Ewald sphere, lattice vibration, the Debye-Waller factor, Lorenz factor, application of kinematical diffraction, structure factor and basics of structure solving, phase problem in crystallography, anomalous diffraction and some examples, introduction to Rietveld refinement method.

Diffraction by Perfect Crystals: Kinematical reflection from few layers, basics of dynamical theory, Darwin's theory of extinction depth, integrated intensity, standing waves, higher order reflection, effect of absorption, asymmetric Bragg geometry, DuMond diagrams, applications in synchrotron X-ray monochromators, X-ray Topography.

X-Ray Absorption: X-ray absorption from isolated atoms, extended X-ray absorption fine structure (EXAFS), near edge X-ray absorption (XANES), EXAFS equation, basics of EXAFS data acquisition and sample preparation, Transmission versus fluorescence modes of EXAFS.

X-Ray Fluorescence: Theoretical details and data analysis, details of the experimental technique, sample preparation, trace element quantification and related issues.

Photo Emission Spectroscopy and X-Ray Magnetic Circular Dichroism: Basics of photoemission and inverse photoemission, experimental setup, photoelectron and Auger electrons, core level binding energies, chemical shifts, lineshapes and background, valence band structure determination, resonant photoemission, angle resolved photoemission and band structure determination, spin polarized photoemission, basics of XMCD

References:

1. "Elements of Modern Optics", Jens Als-Nielsen & Des McMorrow

2. "Dynamical Theory of X-ray Diffraction", Andre Authier
3. "Soft X-Rays and Extreme Ultraviolet Radiation", David Attwood

03PHYS04-010-E: Physics of Semiconductor Quantum Structures:

For Ph. D. (Physics) only

Introduction to Semiconductor Nanostructures: Review of condensed matter and semiconductor physics, scientific and technological significance of nanostructures and mesoscopic structures, characteristic length scales for quantum phenomena, energy states of carriers in free space of different dimensionality, effect of quantum confinement on carrier energy states, density of states for semiconductors of reduced dimensionality, key ideas on effect of quantum confinement in electronic properties, transport phenomenon and interaction of photons with materials, and applications of nanostructured semiconductors.

Growth of Semiconductor Nanostructures: Homo and hetero epitaxial growth, nucleation and nucleation kinetics, strain in lattice mismatched systems, psudomorphic growth and critical thickness, growth modes: Volmer-Weber (VW) or planer growth, Frank-van der Merwe (FM) or island growth and Stranski-Krastinov (SK) nucleation and growth, fundamental and principle of physical and chemical vapor deposition methods: Pulsed laser deposition, molecular beam epitaxy, chemical vapor deposition, atomic layer deposition, sputtering. Bandgap engineering and growth of quantum well structures, key issues in growth of quantum wires, quantum dots and super lattices, Fundamental characteristics of semiconductor nanostructures.

Properties and Characterizations of Semiconductor nanostructures: Optical processes in low dimensional semiconductors: Excitons, free carriers and defect level induced optical transitions, optical phonons and polaritrons, Basic principles and key issues of optical spectroscopy techniques for nanostructured semiconductors; absorption, reflection, photoluminescence, photoluminescence excitation and surface photovoltage spectroscopy. Transport in semiconductor nanostructures: conductance, resonant tunneling, hot electrons; transport in magnetic field, semi-classical and quantum approach, Aharonov-Bohm effect, Shubnikov-de Haas effect, introduction to quantum Hall effect. Principles of application of devices based on Semiconductor nanostructures: photodetectors, lasers, resonant tunneling diodes and solar cells etc.

References:

1. "Material Science of Thin Films: Deposition Structures", Milton Ohring
2. "Solid State Electronic Devices", Jaspreet Singh
3. "Physics of Low-Dimensional Semiconductors", Davies John H
4. "Semiconductor Devices Design", Jaspreet Singh and Umesh K Mishra
5. "Semiconductor Materials", B. G. Yacobi
6. "Semiconductor Nanostructures", Ed. D. Bimberg
7. "Semiconductor Optoelectronics: Physics Technology", J. Singh

C : Engineering Based Elective Courses

for M.Tech (Engineering Physics) only

03ENGG01-001-E: Power Supplies: Credit (4)

AC-DC Converters: Single phase and three phase diode and controlled rectifiers, effect of source inductance, ripple and harmonic analysis, 12-pulse rectifier, firing angle control schemes, THD and power factor, filters - passive and active, passive and active damping of filters.

Power factor Correction: Effects and limiting standards for line current harmonics, Passive PFC techniques, ActivePFC.

DC-DC Converters: Principle of operation, steady-state analysis of buck, boost, buck-boost converters, Isolated dc-dc converters- forward, flyback and bridge converters, pulse width modulator and control of dc-dc converters.

Principles of Feedback Control System: Negative feedback, Stability criteria- gain and phase margin, steady state errors, transient response, current loop and voltage loop acting together.

Magnet power supplies in Accelerators: Requirements, Load characterisation, DC and ramping type power supplies, Pulsed power supplies.

High current magnet power supplies: Stability requirements, current cycling, Field stabilization.

Power supplies for superconducting magnets : Load requirements, quench detection, protection and training.

Laser and Plasma power supplies: Load characterisation, Gas discharge, Ballast requirements, CW/Pulsed operation, Current stabilisation, Power coupling schemes to gas discharges.

Thermal Management: Heat transfer, Heat sink design, Water- cooled heat sinks.

03ENGG01-002-E: Power Electronics: Credit (4)

Power Semiconductor Devices: Diode, SCR, MOSFET, IGBT, Static and switching characteristics, Safe operating areas, Drive requirements and circuits, Introduction to the properties of emerging materials and devices, High voltage switches, Turn-on and turn-off snubbers.

Modelling and Analysis : Introduction to modelling and analysis techniques for dc-dc converters, Averaged equivalent circuit modelling and analysis, small-signal analysis with an illustrative converter, Feedback control of power converters: Feedback controller design, voltage- mode control and current- mode control.

Soft-switching Converters: Concept of soft-switching, Load resonant converters: concept and

definition, ac analysis of converters and modes of operation, Full bridge zero voltage switching converter: Phase shifted PWM, Operation and analysis of converter in steady state.

High frequency Magnetics: Ferrites- characteristics and types, skin effect, proximity effect, parasitic components- origin, minimisation and characterisation, design of high frequency magnetic components, introduction to planar magnetics.

Electromagnetic Interference: Measurement techniques, LISN, separation of common mode and differential mode noise, limiting standards and mitigation techniques, design of high frequency filters.

03ENGG01-003-E: Advanced Course on RF and Microwaves: Credit (4)

Microwave Networks: S-parameters, Matrix representation of Microwave networks and its properties, cascade networks, periodic network system and application, mixed mode S parameters and their applications.

Generation of RF power for accelerators: Design requirements, RF power amplifiers using tetrode & triodes and solid state devices, klystrons, IOT, Gyrotron, Cooling and protection, Grounding and shielding.

High Power RF transmission: design aspect of high power RF transmission, directional couplers, dividers, combiners, high power waveguide and coaxial transmission lines, circulators, bends, magic-T, microwave windows, dummy loads, RF couplers.

Accelerator cavities: Characterizing RF cavity, determination of important cavity parameters, Fundamentals of beam-cavity interactions. RF power coupling to cavity.

Low level RF components and systems: Planar circuits, microstrips, substrate materials, lumped and distributed circuits, mixer circuits, phase shifters, filters, switches, couplers, dividers/combiners, Low level RF signal processing and RF feedback systems.

RF systems for accelerators: Design and configuration of typical RF system, Safety interlocks and operation of RF system.

RF/Microwave measurements: Specialty of high frequency measurements, Measurement of RF power, impedance, VSWR, frequency and phase. Measuring instruments used in RF/microwaves, passive and active detectors, spectrum analyzer, VNA calibration systems, Vector measurement with VNA, peak and average power meters, impedance analyzer, frequency counter.

03ENGG01-004-E: Advanced Data Acquisition and Control Systems:

Components of data acquisition system and their selection, signal conditioning modules, polling, hand-shaking, interrupt and event driven, DMA, data sampling methods.

Embedded system software concepts and development tools assembly and HLL, assembler,

compilers, linker, librarian, resident monitors, source level debuggers, in-circuit & in application programming (ICP/IAP) and logic analyzer. In circuit emulator (ICE), object code and HEX file formats, FPGA & CPLD architectures, logic cell structures, programmable interconnect and I/O ports, programming technologies and VHDL, implementation of combinational and sequential circuits, timing issues in FPGA synchronous circuits.

Centralized v/s distributed control system, PAC and PLCs, PC software issues and virtual instrumentation, VISA, image acquisition, data logging, online and offline data processing, data presentation and reporting, BUSES for digital data communication.

PC buses: PCI & PCI Express specifications mechanical, electrical functional.

Back plane buses: VME, CPCI, PXI, VXI mechanical electrical functional specification.

Buses for instrument network: Asynchronous & synchronous communication standards, bus, ring, net topologies, RS-232, RS-485, USB, LAN-Hub, GPIB, Ethernet, field bus serial port expansion cards on PCI, Converters: USB-GPIB, USB-Serial.

Real-time system concepts, timeliness vs speed, hard vs soft real time, scheduling method, concurrency, process & thread concepts, inter process communication and synchronization.

Software reliability: Software implemented fault tolerance, reliability and availability, safety issues. Software reliability standards and practice.

Process control elements, Set point, disturbance, servo system, regulatory system, analog vs digital control systems, Z - transform for digital control systems, feedback control system, continuous time domain PID controllers. Feed forward and cascade controls, digital controllers, digital form of PID controller, Z-transform based dead beat and Dahlin's algorithms, programmable logic controllers and applications, compensator design and stability criterion.

References:

1. "Process Control Systems: Application Design and Tuning", F.G. Shinskey.
2. "Modern Control Systems", K. Ogata, Prentice Hall (India)
3. "Chemical Process Control", G. Stephanopoulos.
4. "Digital System Design with VHDL and Synthesis: An Integrated Approach", K C. Chang.
5. "Digital System Design and Prototyping Using Field Programmable Logic and Hardware Description Language", Zoran Salcic.
6. "VHDL Made Easy", David Pallerin.

03ENGG01-005-E: Reliability Engineering: Credit (4)

Basic engineering statistics: Basic probability, random variables, probability density and cumulative distribution functions of engineering importance such as the binomial, poisson, normal, exponential, weibull, etc. Random sampling and sampling statistics and distribution of sampling statistics, such as the Chi-Square and Students test, point and interval parameter estimation, test of hypothesis, examples to solve on continuous and discrete distributions, mathematical equations relating to hazard rate, reliability, cumulative failure probability and

failure probability (density) function, Bath-tub curve - explanation of different parts of the life characteristic curve and corresponding failure distributions.

Quality and reliability, QA/QC concepts - Acceptance sampling plans, quality measurement, quality improvement and control methods with applications in design, development, and manufacturing, modern quality management philosophies, engineering/statistical methods including process control, control charts, process capability studies, loss functions, design of experiments, and total quality management (TQM) topics.

Reliability, availability and maintainability concepts and principles, reliability statistical analysis concept overview and application, accelerated life testing concepts, principles and application, qualitative and quantitative accelerated life testing principles, life-stress relationships and application to electronic components and semiconductor devices, software reliability issues, reliability prediction for electronic systems, system reliability concepts and case studies, role of redundancy in system reliability, design for reliability concepts and case studies, degradation analysis and case studies, reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software, hardware reliability analysis of electronic and computer based C&I systems based on MIL-STD-217, methods of measuring the reliability effectiveness of complex engineering systems, optimization theory, preventive maintenance models, and statistical analysis.

03ENGG01-006-E: Advanced Course in High Voltage Engineering: Credit (4)

High Voltage Technology: Introduction, classification of voltage levels, high voltage in electric supply network, major components of a high voltage network.

Electrostatic Fields and their Control: Electric field intensity, electric strength, classification of electric fields, degree of uniformity of electric fields, control of electric field intensity.

Dielectric Materials and their Behavior in Electric Fields:

a. Insulating Behavior of Air and other Gaseous Dielectrics: Generation of charge carriers: impact ionization, thermal ionization and photo-ionization, Negative ion formation, Breakdown by avalanche discharge (Townsend Mechanism); Breakdown voltage characteristics in uniform fields (Paschen's Law) Practical factors affecting the breakdown voltage: Corona, Fields non-uniform, high pressure and vacuum.
b. Liquid Dielectrics in High Voltage applications: Mineral insulating oils, Dielectric properties of insulating liquids, Dielectric power losses in insulating materials, Breakdown in liquid dielectrics, Aging of mineral insulating oils.
c. Solid Dielectrics and their Behavior in Electric Fields: Classification of solid insulating materials, Breakdown and pre-breakdown phenomena in solid dielectrics, Partial discharge and its effects on dielectrics.

Generation of High Voltages:

a. Alternating voltages: single step-up transformer, Transformers in cascade, Voltage control

of testing transformers, Series resonant circuits.

b. Direct Voltages: Half wave and full wave rectification, Voltage doublers and cascade circuits.

c. Impulse Voltages: Single stage impulse generator, Multistage Marx generator, Practical Impulse Generators.

High Voltage Test & Measurement: Types of tests, Power frequency tests, DC voltage test and Impulse withstand test, Peak voltage measurements by spark gaps, Sphere gaps and uniform field gaps, Voltage measurement using ammeter in series with high impedance, Voltage measurement using potential dividers, Generating voltmeter, Voltage and current transformers.

High Voltage Design and Applications: Design considerations of high voltage bushings, power cables, transformers and switchgears; high voltage applications and electrostatic hazards.

High Voltage Safety and Protection.

References:

1. "High Voltage Engineering", E. Kuffel and W S Zaengl.
2. "High Voltage Measurement, Testing and Design", T J Gallagher and A J Pearmain
3. "High Voltage Insulation Engineering", Prof. Ravindra Arora and Prof. Wolfgang Mosch
4. "High Voltage Technology", L. L. Alston

03ENGG01-007-E: Digital Signal, Image Processing and Applications:

Introduction: Digital image, steps of digital image processing systems, elements of visual perception, connectivity and relations between pixels. Image acquisition: Frame grabber, optics and illumination Simple Operations - Arithmetic, Logical, geometric operations.

Mathematical Preliminaries: 2D LTI systems, 2D convolution, correlation, 2D random sequence, 2D spectrum.

Image Transforms: 2D orthogonal and unitary transforms- properties and examples. 2D DFT, histogram, image smoothening, image filtering, Sharpening, thresholding.

Image Segmentation and Analysis: Edge detection, line detection, curve detection, Edge linking and boundary extraction, boundary representation, region representation and segmentation, morphology-dilation, erosion, opening and closing.

Image understanding and recognition: Matching by templates, classifiers models, statistical, matching shapes by contour and texture.

Review of LTI systems: Fourier transform for discrete-time signals and its properties, comparison with continuous-time Fourier transform. Discrete time signals, sequences, representation of signals on orthogonal basis, sampling and reconstruction of signals.

Signal analysis using the Fourier transform, impulse function and complex exponential signal, modulation and frequency translation, duality, Fourier transform of periodic signals,

correlation, energy and power spectral density, Hilbert transform, Fourier transform of finite-duration discrete - time sequences.

Z-transform, Discrete Fourier Transform (DFT), Fast Fourier Transform algorithm and applications. Design of FIR & IIR digital filters, effect of finite register length in FIR filter design. Overview of DSP processors, FPGAs.

Typical applications in Lasers and Accelerators.

Reference:

1. "Digital Image Processing", Rafel C Gonzalez, and Richard E Woods.
2. "Fundamental of Digital image processing", A K Jain.
3. "Fundamentals of Electronic Image Processing", A R Weeks Jr.
4. "Practical Image Processing in C; Wiley professional Computing", Dr. Craig A Lindsey.
5. "Digital image processing: concepts, algorithms, and scientific applications", Jaehne, Bernd.
6. "Digital Imaging: Theory and applications", Burdick Howard E.
7. "Two dimensional signal and Image processing", Lim Jae S, V Oppenheim Allan.
8. "Discrete-Time Signal Processing", A. Oppenheim, R. Schafer and J. Buck.
9. "Signals and Systems", Oppenheim, Willsky and Nawab.
10. "Discrete Time Signal Processing", A.V. Oppenheim and Schafer.
11. "Digital Signal Processing: Principle, Algorithms and Applications", John G. Proakis and D.G. Manolakis.
12. "Theory and Application of Digital Signal Processing", L.R. Rabiner and B. Gold.
13. "Introduction to Digital Signal Processing", J.R. Johnson.
14. "Digital Signal Processing", D. J. DeFatta, J. G. Lucas and W. S. Hodgkiss.

D : Laboratory Experiments (Credit :4)

Experiments relating to lasers, accelerators and general electronics techniques will be offered. A student needs to carry out twelve experiments (4 each from laser, accelerator and electronics related areas) in two phases with a total working time of 72 hours which will carry 4 credits.

03PHYS04-001-L Lasers and Applications

1. Measurement of spectrum and spectral width of diode laser and their dependence on current.
2. Study of characteristics of a Q- switched Nd:YAG laser.
3. Second harmonic generation: phase matching and maker fringes.
4. Saturated absorption in atomic vapour: Doppler broadening, natural line width, power broadening.

5. Study of light propagation through fiber: coupling efficiency, bending losses, splicing and connecting fiber.
6. Studies on Nitrogen laser pumped dye laser.
7. Parametric study of a XeCl Excimer laser.
8. Output power characteristics of a diffusion-cooled CO2 laser.
9. Determination of severance energy for cutting mild steel with CO2 laser.
10. Determination of laser power coupling efficiency in Nd-YAG/CO2 laser welding of stainless steel.

03PHYS04-002-L Accelerators Related Areas

1. Electrical resistivity measurement on metallic samples at low temperature.
2. Parametric studies of magnetic materials and operating point of magnets.
3. Outgassing of materials, discharge cleaning and ESD studies.
4. Estimation of radioactivity and shielding attenuation coefficient measurements.
5. Determination of cooling power of a cryocooler.
6. Electron gun: Operation and experimental studies.
7. Proton ion source: Operation and experimental studies.
8. X-ray fluorescence studies using radioactive source.
9. Calibration of cryogenic sensors.

03PHYS04-003-L Electronics

1. Study of stepper motor, dc motor drive and position feed-back.
2. Study of different transducers and their interfacing.
3. Communication buses and protocols, buses for distributed embedded processing.
4. G.U.I. software familiarization and applications.
5. Digital image processing and their applications.
6. Current and voltage regulated power supplies and change from one another.
7. Study of flash lamp and measurement of flash lamp current and K0 factor.
8. Characterization of RF components.
9. Fast current transformers: Study and measurement of response.

03PHYS04-001-R E : Reading Courses (Credit : 8)

Ph. D. scholars will work on two reading courses each of four credit worth. For each reading course, a Ph. D. scholar is expected to do self reading (under the guidance of his/her Ph. D. supervisor) of a review paper or book(s)/monograph(s) of specialized subjects related to the

area of his/her proposed area of research. Alternatively he/she may also work out and comprehend a research paper or a part of research paper relevant to his/her Ph. D. work. The topic and the structure/contents of the two reading courses should be decided by the guide in consultation with the respective doctoral committee and the Ph. D. scholar. The two reading courses should be approved by the respective doctoral committee.

The two reading courses will be evaluated on the basis of the detailed reports that will be prepared by the scholar and presentations, which will be held at the end of first year (in the month of August). The total marks for each reading course is 150 with 100 and 50 for report and presentation respectively.

BACK TO MAIN

Ph.D. in Physical Science
(Program Code: PHYS04)

Syllabus for
Doctoral Course

Variable Energy Cyclotron Centre

Department of Atomic Energy
1/AF Bidhan Nagar, Kolkata 700 064

Total credit: 60. Duration: one year. The 40 credit basic courses tabulated serially in I to XII are common to all. After completion of this 40m credit, a student may either choose: [2 advance courses from XIII to XIX (2×4=8 credit)] or [one advance course (4 credit) + Self Study Course(equivalent to 4 credit)] and finally a project equivalent to 12 credit.

04PHYS04-001-C Mathematical Physics: Credit: 3

Linear vector spaces, Linear operators and matrices, Systems of linear equations. Eigen values and eigen vectors, infinite-dimensional vector spaces: Hilbert space & Hermitian operators. Linear ordinary differential equations, Special functions. Linear partial differential equations in physics, Separation of variables method of solution. Complex variable theory; Analytic functions. Taylor and Laurent expansions, Classification of singularities, Analytic continuation, Contour integration, Method of steepest descent. Integral equations and Green functions, Ideas about nonlinear equations, Approximation methods : WKB approximation, Fourier and Laplace transforms.

Introduction to finite and continuous groups. Group representations and operations, Permutation group and its representations, Lie group and Lie algebras. SU(2), SU(3) and SU(N) groups, Poincare groups. Introduction to manifolds, Tangent Vectors and tangent spaces, Vector fields, Differential geometry, Riemannian manifolds and Gauge theories.

Suggested *Books :*

1. A Course in modern Mathematical Physics : Groups, Hilbert Space and Differential Geometry, *Peter Szekeres*
2. Mathematical Methods for Physics and Engineering: A Comprehensive Guide, *K.F. Riley, M. P. Hobson, S. I. Bence*
3. Complex Variables: Introductions and Applications, *M. J. Ablowitz* and *A. S. Focas*
4. Geometrical Methods of Mathematical Physics, *Bernard Shutz*
5. Lectures on Advanced Mathematical Methods for Physicists, *S. Mukhi & N. Mukunda.*

04PHYS04-002-C Quantum Mechanics: Credit: 3

Approximation methods in quantum mechanics : W. K. B. and variational methods and applications. Time independent perturbation theory (for non degenerate and degenerate cases) and its application to helium atom, Stark and Zeeman effects, Time dependent perturbation theory and Fermi golden rule, its applications to beta decay theory and principle of detailed balance.

Collision theory : Born series and interaction pictures : Propagator in quantum mechanics. Measurements in Quantum Mechanics, EPR paradox, Hidden variables and Bell's inequality.

Relativistic quantum mechanics : Klein-Gordon and Dirac equations and their solutions, Gamma matrices Non relativistic limit of Dirac equation; Parity inversion and time reversal, Bilinear covariants, Charge conjugation.

Lagrangian formulation : Symmetries of Lagrangian density, Noether's theorem, Energy-momentum tensor T^{uv}-its origin & physical meaning of different components.

Path integral formulation of quantum mechanics and its Applications.

Suggested Books :

6. Quantum Mechanics, *Leonard I. Schiff*
7. Quantum Mechanics, *Eugen Merzbacher*
8. Quantum Mechanics, *A. S. Davydov*
9. Principle of Quantum Mechanics, *R. Shankar*
10. Relativistic Quantum Mechanics, *James D. Bjorken and Sidney D. Drell*
11. (i) Quantum Mechanics : Non-Relativistic Theory & (ii) Classical Theory of Fields, *L.D. Landau and E.M. Lifshitz*
12. Quantum Mechanics and Path Integrals, *P. Feynman and A.R. Hibbs*

04PHYS04-003-C Classical Mechanics: Credit: 2

Newton's Laws (Definition of inertial frames, Galilean group)

Lagrangian formulation: Lagrangian and its properties, Minimum action principle, Euler-Lagrange's equations, Constrained motion, Cyclic coordinates, Noether's theorem. Application: Two body problem, Restricted three body problem.

Hamiltonian formulation: Legendre transformation, Generalized momentum, Phase Space, Hamilton's equations of motion, Liouville's theorem, Fixed points and Linear Stability analysis, Phase portraits, Symplectic nature of Phase Space, Poisson Brackets, Canonical Transformations, Generating functions, Action-Angle variables, Hamilton-Jacobi equation, Singular Lagrangian and examples like time crystal/ Gauge field theory.

Connection of classical mechanics with quantum mechanics

Generic Scattering crosssection, crosssection with 1/r potential. Secular perturbation theory

Integrability, Kolmogorov-Arnold-Moser theorem, Elements of Chaos theory.

Suggested Books:

1. Mathematical Methods of Classical Mechanics, V I Arnold
2. Classical Mechanics, T W B Kibble and F H Berkshire
3. Classical Mechanics, H Goldstein
4. Classical Mechanics, L D Landau and L M Lifshitz

04PHYS04-004-C Statistical Mechanics Credit: 3

Distribution functions: Mean Values and standard deviations; Gaussian limit of the binomial distribution, distribution of several random variables. Gibbsian statistical ensembles: Micro-canonical, Canonical and Grand Canonical ensembles. Gibb's theorem: Information entropy: Fluctuations: Quantum statistics: Bose-Einstein statistics, Fermi-Dirac statistic and passage to the classical limit. Ising Model: Theory of phase transitions and critical phenomena-Critical exponents and universality, Phase transformation kinetics: Homogeneous and Heterogeneous nucleation, Spinodal decomposition

Non-equilibrium statistical mechanic: Liouville's equation, BBGKY hierarchy, Boltzmann equation, Fokker-Planck Equation and Brownian motion.

04PHYS04-005-C Classical Electrodynamics: Credit: 3

Maxwell equations, Macroscopic electromagnetism, conservation laws: Maxwell's displacement current, Vector and scalar potential, Gauge transformations, Lorentz gauge and Coulomb gauge, Green's theorem of the wave equation, Poynting's theorem and conservation of energy and momentum, Boundary value problems and numerical techniques.

Plane electromagnetic wave and wave propagation, Wave guides and resonant cavities: Place wave in a non-conducting medium, Linear and circular polarization, Fields at the surface and within conductor, Cylindrical cavities and Wave-guides, Modes in a rectangular Wave-guide, Energy flow and attenuation in a Wave-guide.

Radiating systems, Multiple fields and radiation: Fields and radiation of a localized oscillating source, Electric dipole field and radiation, Multipole expansion and electromagnetic fields, Properties of multipole fields, energy and angular momentum of multipole radiation, Sources of multipole radiation : Multipole moments.

Relativistic electrodynamics: The special theory of relativity, The Lorentz transformation and basic kinematic results of special relativistic, Invariance of electric charge, Covariance of electrodynamics, Transformation of electromagnetic fields, Relativistic charged particles in an electromagnetic field.

Radiation by moving charges: The Lienard-Wiechert potentials and field for appoint charge, Total power radiated by an accelerated.

Suggested Books:

1. Classical electrodynamics, *I. D. Jackson.*
2. Modern Electrodynamics, A Zangwill, Cambridge University Press, 2016

04PHYS04-006-C

a. Research Methodology: Credit: 0

1. Research – meaning, characteristics and types, steps of research, research ethics and plagiarism.

2. Introduction to patent laws – patent laws, process of patenting a research finding, copy right, cyber laws.

3. Scientific presentation procedure

4. Scientific seminars by faculties'.

Suggested books:

a. Research Methodology: Methods and Techniques, C.R. Kothari

b. Computational Methods and Programming: Credit: 3

1. Scientific programming- Procedural programming and Object oriented programming (examples in Fortran and C++)

2a. Simulation techniques - Random variables, discrete and continuous, Montecarlo techniquesand application of Montecarlo tecniques, Techniques of dynamical simulations.

2b. Statistics and treatment of Statistical analysis of data: - estimation and propagation of error, curve fitting, least square methods, Confidence limit.

3. Numerical techniques – Integration, differentiation, diagonalization of matrices, root finding (bisection and Newton-Raphson method); Interpolation techniques; ODE, PDE, Runge-Kutta method, Solution of numerical problem using different numerical technique.

Suggested books:

1. Numerical Mathematical Analysis by James Blaine Scarborough, Oxford and IBH Publishing
2. Computer oriented numerical methods , V. Rajaraman
3. Data reduction and error analysis for the physical sciences, By Philip R. Bevington and D. Keith Robinson
4. An Introduction to Error Analysis (University Science Books, Mill Valley,California, 1982) by J.R. Taylor.

04PHYS04-007-C Experimental techniques and methods: Credit: 5

1. Philosophy of experimental science - laboratory safety, measurement of various physical properties with appropriate transducers, Vacuum - production methods and measurement techniques, Cryogenics - production and measurement, Workshop practice and basics of engineering drawing.

2. Material Characterization techniques – Electrical, Magnetic, and Optical property measurements, X-ray diffraction, neutron scattering and electron scattering techniques, Surface structure and topography (Scanning Electron Microscopy) and surface property measurements (Scanning Probe Microscopy), Phase changes.

(Differential Scanning Calorimeter), Mechanical property measurement: Tension and compression testing, Micro and Nano-indendation techniques, Characterization of defects and their detection (Positron Annihilation Spectroscopy, Transmission Electron Microscopy)

Suggested books:

a. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Yang Leng
b. Characterization of materials, Elton Kaufmann

Detectors and Techniques for Nuclear and High Energy Physics

(a) Interaction of Radiations with matter: Interaction of charged particles, Electrons, photons, Neutrons, Muons and neutrinos with matter.

Radiation exposure and Dose

(b)Basics of detectors: General properties of radiation detectors, Simplified detector model, Modes of detector Operation, Pulse height spectra, Energy resolution, Detector efficiency, Working principle and properties of different types of detectors - Gas detectors, Scintillation Detectors, Semiconductor Detectors

(c) Basics of nuclear electronics: Pre-amplifier, amplifier, discriminators, gate and delay generators, Analog to Digital Converter, Time to Amplitude Converter and the basics of data acquisition systems.

(d) Experimental Nuclear physics techniques and detectors: Charged particle spectroscopy and particle identifications, Gamma ray spectroscopy, Fast neutron spectroscopy and detectors related to the different techniques

(e) Experimental High Energy Physics techniques and detectors: General concept of building a HEP experiment, coverage and options, tracking detectors, calorimeters, vertex detectors, muon chambers, neutrino detectors, particle identification detectors in HEP. Data analysis in HEP: General approach of data cleanup, calibration, track reconstruction, reconstruction of events, challenges in each stage.

Suggested books:

a. Radiation Detection and Measurement, Glenn F. Knoll
b. Nuclear Radiation Detectors, S.S. Kapoor and V. Ramamurthy
c. Techniques for Nuclear and Particle Physics Experiments: A How-To Approach, William R. Leo
d. Experimental Techniques in High-energy Nuclear and Particle Physics, edited by Thomas Ferbel
e. Introduction to Experimental Particle Physics, Richard Clinton Fernow

f. Data Reduction and Error Analysis for the Physical Sciences, Philip Raymond Bevington, D. Keith Robinson
g. Data Analysis Techniques for High-Energy Physics, edited by R. Frühwirth, M. Regler

04PHYS04-008-C Basic Field Theory: Credit: 3

Lorentz invariance and Relativistic kinematics. A preview of fundamental particles and their interactions. Review of classical field theory : Principle of least action, Lagrangian formulations for continuous system and fields.

Symmetries and conservations lows, Noether's theorem, Introduction to field quantization: Canonical quantizations of scalar, Spinor and gauge fields.

Principle of gauge invariance: Global and local gauge transformations, Abelian gauge fields.

Interaction fields : Perturbation expansion of correlation functions, Wick theorems, Feynman diagrams, S-matrix and cross section, Calculations of cross section and decay rates for elementary processes.

Suggested Books :

1. An introduction to Quantum Field Theory, *M. E. Peskin and D. V. Schroeder*
2. Quantum Field Theory, *L. H. Ryder*
3. Field Theory, *P. Ramond*
4. Gauge Field theory, *S. Pokoroski*
5. Quantum field theory, *L. S. Brown*

04PHYS04-009-C Basic Accelerator physics: Credit: 3

Introduction to accelerators: History of accelerators. Types of particle accelerators. Basic principle of Cockcroft-Walton, Van-de-graaff, Tandem, Linear accelerator, Cyclotron, Synchrotron, Storage rings and Betatron. Accelerators in India.

Transverse Beam Dynamics: Two dimensional field expansion, Field calculations of magnetic focusing and bending optics, Particle equations of motion, Thin-lens and Quadrupole focusing, Edge focusing, Solenoid focusing, Hill's equation, Phase advance in periodic focusing lattices, Transfer matrix technique, Transfer matrices for drift space, dipole, quadrupole, Stability criterion, Beta function, Courant-Snyder invariant and Twiss parameters, Beam emittance.

Longitudinal Beam Dynamics: Longitudinal Equation of Motion, Off-momentum orbits in synchrotrons, Transition and Momentum compaction, Phase stability, Synchrotron oscillation, Longitudinal emittance.

Cyclotron: Basic principle of cyclotron, Resonance condition, AVF cyclotron, Synchro-cyclotron, Betatron tunes, Shape of the cyclotron magnet, Injection, Extraction, Beam quality-time structure, energy resolution and emittance. Room temperature and Superconducting cyclotron.

RF Linear Accelerator: Principle of Linear accelerator, Wideroe and Alveraz linac, Transit time factor, Accelerating field and dispersion curve, Ion linac, Empty cavity and Loaded cavity, Travelling wave and standing wave structures.

Ion Sources: Principle of ionization, Ion sources for positive ions - Duoplasmatron, PIG, ECR, Ion sources for negative ions- surface, volume and charge exchange, Beam formation, ECR ion source and beam transport line.

Synchrotron and storage rings: Basic principle of Synchrotron, Electron and ion Synchrotron, Synchrotron radiation source, Total radiated power, Properties of Synchrotron radiation, Wiggler and undulator.

Application of accelerators: Research applications, Medicine, Industry etc.

04PHYS04-0010-C Basic Condensed Matter Physics: Credit: 3

Crystal structure and crystallography : Bravais lattice – Primitive vectors, Primitive unit cell, Conventional unit cell, Reciprocal lattice and Brillouin zone, X-ray diffraction, Comparison with electron and neutron diffraction.

Electronic structure of solids : Band structure of solids, Introduction to many body problem, Single particle approximation, Hartree-Fock methods, Bloch theorem, Tight binding method, Introduction to Density functionalal theory.

Lattice vibrations : Phonons-Debye model for specific heat of solids-lattice dynamics-phonon spectrum. Electrical & thermal transport in solids, Role of electron-phonon interaction-Boltzmann transport equation.

Magnetism : Origin of magnetism, Quantum theory of diamagnetism and paramagnetism, Heisenberg's exchange interaction and ferromagnetism, Introduction to superexchange, Direct exchange and double exchange,

Superconductivity & Superfluidity : Phenomenological description of superconductivity, Interaction between electron and phonon, Cooper pair, Meaning of energy gap, Meissner effect, London theory, Classification of superconductors, High temperature superconductors, Outline of the microscopic BCS theory, Ginzburg-Landau theory. Superfluidity in liquid He. Landau's critical velocity, Two-fluid model.

Dielectric properties of solids : Static dielectric constant, Electronic and ionic polarization of molecules, Ferroelectricity- dipole theory, Inter-band transitions, Kramers-Kronig relations, Polarons, Excitons, Optical properties of metals and insulators.

Defects in solids: Classification of defects, Role of dislocations in material behavior. Irradiation effects in solids, Concept of DPA, Introduction to nuclear reactor.

04PHYS04-011-C Basic Nuclear physics: Credit 3

1. Nuclear structure: Chart of Nuclide, Nuclear Ground State Properties (Mass, binding energy, moments etc.), Introduction to nuclear models, liquid drop model, mean field concept and basic shell model, Nuclear shapes and Deformed shell model, Introduction to Gamma-ray spectroscopy, Gamma ray selection rule, single particle states, collective states, Methods of production of excited states in nuclei, Present day challenges.

2. Nuclear reactions: Nuclear reaction kinematics, Nuclear radius and methods of determination of nuclear radius, Scattering theory (partial wave analysis etc.), Statistical model (compound nucleus), Fusion-evaporation, Fusion-Fission, Concept of Level density and Temperature and methods of its experimental estimation, Resonances, Breit-Wigner formula.Introduction to different nuclear reactions: Coulomb excitation, Direct reactions, Multi-nucleon transfer, Deep inelastic collision, Multi-fragmentation and spallation. Introduction to the present day interest in nuclear reaction studies.

3. Radioactive Ion Beam (RIB): What is RIB and why it is important, Basics of the methods of production of RIB, Challenges in doing experiments using RIB, RIB facilities in the world.

04PHYS04-012-C Laboratory experiments: Credit 6 (Each student will carry out minimum of 6 experiments)

The experiments that will be carried out will make the students familiar with different types of detectors and nuclear electronics required for nuclear physics experiments and high energy physics experiments. The students will also carry out specific materials science experiments.

1. Operation of vacuum pumps and gauges
2. Thickness measurement of thin foils
3. Calibration and energy resolution of different types of radiation detectors (e.g, Si, CsI(Tl), HPGe, BaF_2 , etc.)
4. Thickness uniformity test of different detectors
5. Characterization of a neutron detector
6. Characterization of a gaseous detector (Gas electron multiplier/avalanche counter)
7. Efficiency measurement of different types of γ detectors
8. Characterisation of samples using XRD (X-ray diffractometer)
9. Measurement of stored energy in deformed samples using DSC (differential scanning calorimeter)
10. Measurement of mechanical strength of different materials using universal testing machine.
11. Characteristion of samples using Scanning Electron Microscope and Energy Dispersive X-ray Analysis.
12. Nanostructuring by ion beam.
13. Preparation and characterisation of Nanoparticles by sol-gel method.
14. Measurement of muon life time
15. Characteristic study of wavelength shifter fibres
16. Fabrication and characterization of a scintillator detector.

04PHYS04-013-C Advanced Nuclear Structure: Credit: 4

Nuclear Models (HF, HFB), Microscopic-macroscopic model and total energy calculations (Strutinsky method), Introduction to Density Functional Theory, Electromagnetic moments, Different modes of excitation in nuclei, Giant resonances, Gamma ray spectroscopy and nuclear structure, Construction of level scheme, Spin and parity assignment of nuclear levels, Lifetime measurement of nuclear levels, Observables and deduced quantities, Nuclear Isomerism, Introduction to total Absorption Spectroscopy and beta-delayed neutron emission.

04PHYS04-014-C Advanced nuclear reaction: Credit: 4

Damped nuclear collision: General features, Kinetic energy loss, Angular distribution, Angular momentum dissipation, Time scale, Phenomenological and theoretical models for heavy ion collision, Dissipative forces: one-body, two-body dissipation. Fission dynamics: Dynamical models of fission, Quasi fission, Synthesis of super heavy elements (SHE), Heavy-ion physics at low and intermediate energies: Intermediate mass fragments emission, Reaction near Fermi energy domain, Hot nucleus, Multi-fragmentation, Liquid-gas phase transition, Theoretical models of multi-fragmentations, simulations and QMD model. Nuclear astrophysics: Nuclear resonances, Deep-sub-barrier fusion, Astrophysical S-factor, Gamow peak, Calculation of nuclear reaction rates and its use in calculating primordial and Stellar abundances; Equation of State for dense nuclear matter, β-equilibrium, Compact stars.

04PHYS04-015-C Advanced Accelerator physics: Credit: 4

Introduction: Sources of charged particle, Lorentz force and equation of motion, Hamiltonian of a charged particle, Charge particle motion in electromagnetic fields, Planer diode without and with space charge.

Basic beam parameters: Definition of beam parameters, Beam energy, Beam current, Time structure, Peak and average beam current, Beam size, Transverse beam dimensions, Bunch length, Energy spread, Beam emittances, Beam formation, Buncher, Beam chopper.

Beam optics and transport elements: Accelerator coordinate system, Paraxial ray equation for axially symmetric systems, Series representation of electric and magnetic fields, Paraxial ray equation, Solutions of the paraxial ray equations, Electrostatic lenses, Solenoidal magnetic lens, Larmor frame, Aberrations, Transfer matrix of transport elements, Stability condition, Beam envelope, Beam matrix, Transport notations, Basic focusing modules and different kinds of imaging, Telescopic system, Coupled systems, Transfer matrices of solenoid and Skew quadrupoles. Quadrupole doublet and Triplet.

Transverse and longitudinal beam dynamics: Beam envelope equation, Courant-Snyder invariant and emittance, Normalized emittance, Twiss parameters, Liouville's Theorem, Periodic system, FODO and FOFO Cell. Magnet imperfections, Dipole field and Quadrupole gradient errors, Resonances in circular accelerators. Off momentum orbit, Dispersion function, Momentum compaction, Transition energy, Negative mass, Dispersion matching, Chromaticity and its corrections. Longitudinal equation of motion, Phase stability and synchrotron oscillations, Fixed points, Bucket, Separatrix.

Beam with space charge: Space charge effects, Uniform beam model with elliptical symmetry, Applied and self fields, Beam envelope equation with space charge, Pervience, Beam transport in a uniform and periodic focusing channel, Tune shift and current limits, Envelope oscillations, modes and instabilities, Linear beam model with charge neutralization, Space charge compensation. Vlasov model, K-V and Waterbag distribution, Stationary distributions in a uniform focusing channel, RMS emittance, Concept of equivalent beams, RMS envelope equations, Sources of emittance growth, Filamentation of phase space, Wake fields and image charge effects**.**

Linear accelerators: Particle Acceleration in an RF Field, Energy Gain in an RF Gap, Transit-Time-Factor, Shunt impedance, Quality factor, Phase and group velocities, Periodic Structures, Floquet Theorem and Space Harmonics, Traveling-Wave Linac Structures, Constant-Impedance and Constant-Gradient Structure, Independent-Cavity Linacs, Wider¨oe Linac, H-Mode Structures, Alvarez Drift-Tube Linac, Coupled-Cavity Linacs, Accelerating Structures for Superconducting Linacs, Transverse dynamics in a Linac, Transverse RF Focusing and Defocusing, Quadrupole Focusing in a Linac, Longitudinal dynamics in Linac, Longitudinal Focusing, Stability analysis, Separatrix, RF Bunching, Beam dynamics in RFQ accelerator.

Storage rings and synchrotron radiation: Radiation from moving charges, Coulomb regime, Radiation regime, Radiation sources, Bending magnet radiation, Wavelength shifter, Wiggler magnet radiation, Undulator radiation, Radiation power and angular distribution, Quantum fluctuation, Beam lifetime.

Advance accelerators: Free electron laser, Plasma accelerators, Spallation neutron sources, Rare ion beam (RIB) facilities. Accelerators driven subcritical systems (ADSS).

04PHYS04-016-C Advanced High Energy Physics Credit: 4

Renormalization in quantum field theory: One loop radiative corrections in quantum electrodynamics (OED), Power counting and the index of Divergence, dimensional regularizations and renormalizations. Calculations of one loop diagrams in QED.

Quantum Chromodynamics (QCD): Non-abelian guage theory, one loop diagrams and running coupling, Pertubative QCD.

Structure of hadrons: Proton form factor, Deep inelastic scattering of electron off proton, Parton evolutions.

Heavy Ion collisions at Ultra Relativistic Energies : Quark Gluon Plasma, Hadrons in thermal bath, Thermodynamics of strongly interacting matter, QCD phase transition in the laboratory, Space time evolution and signals of quark gluon plasma.

Space time evolution of Quark Gluon Plasma and relativistic hydrodynamics.

Suggested Books :

6. An introduction to Quantum Field Theory, *M. E. Peskin and D. V. Schroeder*
7. Quantum Field Theory, *L. H. Ryder*
8. Field Theory, *P. Ramond*
9. Gauge Field theory, *S. Pokoroski*
10. Quantum field theory, *L. S. Brown*
11. Introduction to High Energy Heavy Ion Collisions, *C. Y. Wong*
12. Quark Gluon Plasma from Big Bang to Little Bang, K. Yagi, T. Hatsuda ,and Y. Miake.

04PHYS04-017-C Advanced Materials Science – I (Effects of radiation in metals and alloys): Credit: 4

Interaction of radiation with matter: Interaction of electromagnetic radiation, neutrons and charged particles with matter, Concept of nuclear and electronic energy loss, Differential cross section in projectile target collision

Radiation Damage Event: Neutron-nucleus interactions, Interaction between ions and atoms, Ionization collisions.

The displacement of atoms: Elementary displacement theory, Modification to Kinchin-Pease displacement model, Displacement cross-section

Damage cascade: Displacement mean free path, Primary recoil spectrum, Cascade damage energy and cascade volume, stages of cascade development, behaviour of defects within the cascade

Radiation induced defect formation: Point defect formation, Thermodynamics of point defect formation, Diffusion of point defects, Dislocations.

Radiation enhanced diffusion and reaction rate theory: Point defect balance equation, Radiation enhanced diffusion, Defect reactions, Reaction-rate controlled processes.

Radiation induced segregation (RIS): RIS in concentrated binary alloys and ternary alloys, Effect of local composition changes on RIS.

Phase stability under irradiation: Radiation induced segregation, Radiation induced precipitation, Meta-stable phases, Amorphization.

Unique effects of ion irradiation: Ion irradiation techniques, Composition changes, Other effects of ion implantation like grain growth, Texture, Dislocation microstructure.

Simulation of neutron damage with ions : Aspects of radiation damage relevant to ion irradiation, Advantages and disadvantages of various particle types, Emulation of neutron irradiation damage with proton, Irradiation parameters for particle irradiation, Effects on mechanical properties due to irradiation hardening, Embrittlement, Irradiation creep and growth.

04PHYS04-018-C Advanced Material Science II   Credit: 4

Multi-functional materials: Ferroelectricity, Multiferroic materials, Ferroelasticity, Magnetoelectric coupling, Conducting polymer and nanocomposites.

Nano-particle Physics: Introduction to nanoscale physics, nano mechanics, nano electronics, nano photonics, spintronics, various nano structured materials and their synthesis processes, probing of nano materials by advanced tools, applications of nano materials.

Advanced oxide materials: Crystal field splitting, John Teller distortion, Zener double exchange model, Mott insulator, Theory of superconductivity, Manganites, Density functional theory, Magnetic properties of solids, d0 ferromagnetism, Defect characterization in oxides by positron annihilation techniques, Mossbauer spectroscopy in oxides.

Suggested Books:

1. Solid State Physics, A J Dekker
2. Physics of Nanostructures, Dresselhaus and Dresselhauss
3. Transition Metals Oxides: An introduction to their electronic structure and properties, P A Cox.

04PHYS04-001-E Advanced High Energy Physics (Experiment) : Credit 4

Introduction to Relativistic Heavy-Ion Collisions-Experiments: Flow-chart from beam to Physics.

Relativistic Kinematics: Lorentz transformation; frequently used reference frames, Rapidity, pseudo-rapidity, invariant cross-section Collision and decays;

Distribution Functions: particle production and measurement in high energy collisions. ;

Detector Simulation in High Energy Physics: Requirement of detector simulation, Introduction to Geant4, Illustration with an example. ;

Physics of collisions: Synchrotron and Storage ring, Energy, Cross-section, Luminosity, Event rate, beam parameters.

Introduction to data analysis: hits, primary vertex, tracks, secondary vertex, trigger and pile-up.

Raw Data processing: Concept of detector and electronic noise, Detector calibration, Acceptance and Efficiency estimation, event and physics trigger selection, analysis for physics objectives.

Particle identification in high energy experiments: dE/dx, Range, TOF technique, Transition radiation.

Different techniques of Background and Error estimation.

Yield Calculations (Including Detector effects).

Global Observables: Multiplicity, (pseudo)rapidity distributions, invariant yields. ;

Centrality of events: Glauber Model, experimental methods.

Quarkonia suppression: Quarkonium spectroscopy, dynamics of quarkonium production in elementary collisions, cold nuclear matter effects, Debye screening, experimental observables and interpretation,

Correlations and Fluctuations: Concepts, BE correlations, Two particle angular correlation, physics interpretation**.**

Collective Flow: Radial flow, anisotropic flow: different flow harmonics and methods of extraction.

Physics of Jets: Formation, Energy loss, Jet reconstruction in high energy collisions (methodology), Importance.

Books:

1. Introduction to high energy Heavy-Ion Collisions, C. Y. Wong
2. Quark Gluon plasma from Big Bang to Little Bang, K. Yagi, T. Hatsuda and Y. Miake
3. Phenomenology of Ultra-Relativistic Heavy-Ion Collisions, Wojciech Florkowski
4. A Short Course on Relativistic Heavy Ion Collisions, Asis Kumar Chaudhuri
5. Ultrarelativistic Heavy-Ion Collisions, Ramona Vogt

04PHYS04-001-P Project work equivalent to 12 credit.

Total credit: 60

Contact:
Dean-Academic (Physical Sciences)
Variable Energy Cyclotron Centre
Department of Atomic Energy
1/AF Bidhan Nagar, Kolkata 700 064
Email: daps@vecc.gov.in

Ph.D. in Physical Science under SINP (Program Code: PHYS04)

BACK TO MAIN

Semester I

17 weeks during August–December, out of which 16 weeks are classes and 1 week for exams.
2 weeks festival holidays

Sl No	Course code	Name of the courses	Credit
1	CNM	Computational & Numerical Methods	6
2	SM2	Statistical Mechanics	6
3	QM2	Quantum Mechanics	6
4	OPT1	Optional course 1	6

Calculation of credit
For CNM/SM2/QM2: 2 Classes per week x 1.5 hour = 3 hr, tutorial = 2 hr, home assignment and self-study = 7 hr. Total 12 hr.
In 16 weeks = 16 x 12 = 192 hr. 1 credit = 30 contact hr. Total credit = 192 / 30 = 6.
For LAB: Lab hours per week = 12 hr. In 16 weeks = 12 x 16 = 192 hr = 6 credit.

Semester II

17 weeks during January–April, out of which 16 weeks are classes and one week for exams.

Sl No	Course code	Name of the courses	Credit
1	RM	Research Methodology	6
2	OPT2	Optional course 2	6
3	OPT3	Optional course 3	6
4	OPT4	Optional course 4	6

Optional and Lab courses are offered by various Division

Calculation of credit
For RM: Per week 2 classes x 1.5 hour = 3 hr, tutorial = 2 hr, home assignment and self-study = 7 hr. Total 12 hr.
For LAB: Per week 2 classes x 1.5 hour = 3 hr, Lab assignment = 6 hr, self-study = 3 hr. Total 12 hr.

1st & 2nd weeks of May are Holidays

Summer Semester

11 weeks during mid May–July.

Sl No	Course code	Name of course	Credit
1	PRO	Project	12

Presentation of project thesis in the 3rd week of July.

Calculation of credit
Project work per week = 30 hr, Self-study = 4 hr, Total = 34 hr. In 11 weeks = 11 x 34 = 374 hr = 12 credit.

Computational & Numerical Methods (CNM)

Introduction to Numerical Analysis; Error Analysis; Linear Algebra; Interpolation and Extrapolation; Differentiation and Integration; Root Finding and Optimization; Differential Equations; Python instalation, libraries and environment; Comparison of modern programing languages; Modern Scientific Computing using Python and C++; Interpolation and Fourier transform; Differential equations; Random numbers and multidimensional integration.

Reference

J.M. Thijssen, Computational Physics, H. Gould et al, Introduction to Computer Simulation Methods; R.M. Martin, Electronic Structure, Basic Theory and Practical Methods; T. Pang, An Introduction to Computational Physics; R.H. Landau and M.J. Paez, Computational Physics; B. Stroustrup, C++ Programming language; S. Meyers, More Effective C++.

Statistical Methods (SM2)

Landau theory of phase transitions, Critical Phenomena, Kosterlitz-Thouless transition, Renormalization group, Ising model in one-dimension, Mean field solution of two-dimensional Ising model and Onsager solution, Theory of fluctuations (Central limit theorem, Law of large numbers, Random motion and Diffusions), Exactly solvable models (N-vector model, Spherical model in arbitrary dimension), Hydrodynamics (Viscosity, Navier-Stokes Theorem), Heat conduction in one-dimension, Out of equilibrium scenarios.

Reference

Kerson Huang, Statistical Mechanics, 2ed; R. K. Pathria & P. D. Beale, Statistical Mechanics, 3ed; M. Plischke & B. Bergersen, Equilibrium Statistical Physics, 3ed; P. M. Chaikin & T. C. Lubensky, Principles of Condensed Matter Physics, Reviews.

Quantum Mechanics (QM2)

Scattering Theory – Elastic and inelastic; Time dependent perturbation theory; Many particle Systems; Relativistic Quantum Mechanics; Path Integral Techquines; Theory of Measurements.

Reference

J.J. Sakurai, Modern Quantum Mechanics, Rev Ed; A. Messiah, Quantum Mechanics, Vol I & II; C. Cohen-Tannoudji et al, Quantum Mechanics, Vol I & II; H. Weyl, The Theory of Groups in Quantum Mechanics; L.D. Landau & E.M. Lifshitz, Quantum Mechanics, 3ed; J.D. Bjorken & S.D. Drell, Relativistic Quantum Mechanics; E.P. Wigner, Group Theory and Quantum Mechanics; L.S. Schulman, Techniques and Applications of Path Integration; A.L. Fetter & J.D. Walecka, Quantum Theory of Many-particle Systems; J.A. Wheeler & W.H. Zurek (Ed), Quantum Theory of Measurement

Research Methodology (RM)

Ph.D. thesis, Psychological and social factors during Ph.D., Students' role during Ph.D., Supervisors' role during and after Ph.D., Overview of research planning, Time management, Fair scientific practices.

Ethics in natural sciences, Avoiding research that cause unjustified risk to people, Jeopardizing the environment or convert public resources into private profits, Striving for objectivity (in the research process and in presentation of results), Handling uncertainties.

Literature survey, Critical use of existing knowledge, Finding a research problem, Scientific publishing, Classification of conferences and journals, Judging whether a material is publishable, Refereeing process, Criticizing own and others' work.

How to give seminars, How to use various softwares, How to use various instruments, How to interact with people, How to apply for jobs, Plagiarism in science – what to do and what not to do.

As a concrete example, each student will be asked to write a “prototype thesis” in a given area under a “supervisor”. The student will apply the knowledge, ethics and best scientific practices to produce this thesis. Each student will have to defend the thesis as well.

Reference

C.R. Kothari & G. Garg, Research Methodology: Methods And Techniques; U. Flick, Introducing Research Methodology: A Beginner's Guide to Doing a Research Project; L. B. Christensen, R. B. Johnson & U. A. Turner, Research Methods, Design, and Analysis, 11 ed; J. Krishnamurti, What Are You Doing with Your Life?

As optional courses: Quantum Field Theory I & II, General Relativity, Group Theory and Differential Geomery, Particle Physics, Nonequilibrium Statistical Mechanics, Condensed Matter Theory, Nuclear Physics and several Experiments in various Labs, are offered.

Syllabus for IPR's PhD Program as per HBNI guidelines

Ph.D. in Physical Science
(Program Code: PHYS04)

For applicants with
M.Sc. in Physics, Applied Physics & Engg. Physics

INSTITUTE for PLASMA RESEARCH Bhat, Gandhinagar

Enrollment under HBNI, Mumbai

Syllabus for IPR's Ph.D. Program

Trimester-1

Sr. No.	Subjects	Code	Lectures hrs.	Credits
1	Fundamentals of Plasma Physics – A	FPP – A	32	4
2	Fundamentals of Plasma Physics – B	FPP – B	32	4
3	Plasma Production and Measurements-I	PPM – I	32	4
4	Mathematical Methods – I	MM – I	32	4
5	Electromagnetic Theory – I	EMT – I	32	4
6	Mechanics –I (Classical Mechanics)	MEC-I	32	4
7	Laboratory Practical – I	LAP – I	64	4
	TRIMESTER – I		**256**	**28**

Trimester-II

Sr. No.	Subjects	Code	Lectures hrs.	Credits
1	Advance Plasma Physics – A	APP – A	32	4
2	Advance Plasma Physics – B	APP – B	32	4
3	Plasma Production & Measurement – II	PPM – II	32	4
4	Mathematical Methods – II	MM – II	32	4
5	Electromagnetic Theory – II	EMT – II	32	4
6	Mechanics –II (Fluid & Statistical Mechanics)	MEC – II	32	4
7	Numerical Methods and Advance Computing	NMAC	32	4
8	Laboratory Practical – II	LAP – II	64	4
	TRIMESTER – II		**288**	**32**

Trimester-III

Sr. No.	Subjects	Code	Lectures hrs.	Credits
1	Research Methodology	RM	8	1
2	Introduction to Materials Science	MS	8	1
3	Credit Seminar	CS	--	3
4	Mini Project	PROJ	--	4
	TRIMESTER – III		**16**	**9**

Total credit = 69

Duration: 1st August to 31st July (next year)
Course pattern: 3 trimester courses with 1 Project
Evaluation: Tests (Mid-term and Final) in each trimester, Presentations/Seminar in each trimester, Assignment and OGCE at the end of Trimester III

TRIMESTER – I

Total Credit – 28; Total subjects – 7;

Each course – 2 h Lectures per week per subject;

1. Fundamentals Plasma Physics (A); (32 Lectures ; 4 credit)

- **Overview (Plasma Physics and Applications)**
  Applications of Plasma: (industrial, space, biomedical, agriculture, fusion)
  Definition of Plasma (Saha Ionization, Macroscopic Neutrality, Debye Screening, Plasma frequency).
  Description of collective behavior, derivation of plasma frequency (slab model), Debye length, Plasma Criteria, Classification of plasmas.

- **Charged Particle Interaction**:
  Collision Processes in Plasma binary collisions (derivation of Rutherford scattering), derivation of collision frequency ν_{ei} (large angle collisions, cumulative effect of many small angle collisions, Coulomb logarithm), Mean free path, electron-electron, electron-ion, electron-neutral, rate constant.
- **Particle Orbit Theory:**
  Energy Conservation, Equations governing Single Particle Drifts in Constant electric and Magnetic field, Concept of Guiding center, Larmor radius, Magnetic moment, Plasma diamagnetism, Magnetization current, ExB Drift. Equations governing Single Particle Drifts in Non-uniform magneto-static Fields (Grad-B Drift, Curvature Drift).

- Magnetic mirror and trap, Adiabatic invariance and its utilization – (Magnetic moment, J and Magnetic flux in an inhomogeneous field).
- Drift in time-varying electric and Magnetic field (electromagnetic field) - Polarization drift, Ponderomotive forces, Guiding center approximation.

2. Fundamentals of Plasma Physics (B) ; (32 Lectures ; 4 credit)

- **Statistical description of plasma**
  Concepts of Distribution function, Boltzmann equation, Moments of the Boltzmann Equation, Maxwell-Boltzmann Distribution (Determination of the Constant Coefficients, moments of Maxwell-Boltzmann Distribution, RMS, Most probable speed, Speed and Energy distribution function.

  Average Values and Macroscopic Variables (average density, mass, flow velocity, temperature, pressure dyad, heat flow vector, Random Particle Flux, Kinetic Pressure and Heat Flux)

- **Macroscopic Transport Equations**
  Relation of Plasma Physics and Ordinary Electromagnetics (Maxwell equation)
  Fluid Equation of Motion (Convective Derivative Concept, Stress Tensor, equation of continuity, equation of state, energy transport equation)

- **Fluid Drifts**

  Fluid Drift Parallel to B (Boltzman relation for electrons, Physics interpretation, Quasi-neutrality & Plasma Approximation);
  Drifts Perpendicular to B (Diamagnetic Drift, physics interpretation)

- **Elementary Waves in Warm Plasma**

i. Basic Wave Concepts of Phase and group velocity, plane wave solution, Energy Flux, Dispersive Media, Linear perturbation
ii. Electrostatic waves in Cold un-magnetized plasma – Plasma Oscillation, Electron Plasma Wave, Validity of Plasma approximation, Ion Sound Wave,
iii. Comparison of Ion and Electron Plasma Wave, discussion of $k\lambda_D << 1$, plasma parameter).

3. Plasma Production and Measurements – I; (32 Lectures ; 4 credit)

- **Fundamentals of Vacuum Science:**

  Concepts of gas laws, inter-atomic distance, molar volume, Avogadro number, partial pressure, adsorption of gas atoms at surface.
  Vacuum Measurements – Pressure and flow measurements, different range of Vacuum, Concepts of Vapour pressure, different types of pressure measurement devices and different pumps.
  Concepts of mass flow rate, conductance calculation, pumping speed, volume flow rate, through-put.

- **Fundamentals of Gaseous Discharge:**

  Charge Particles under Constant Electric Field (E/p), Ionization processes in Plasma – Plasma interaction with surfaces, charge exchange processes, thermionic emission, field emission, electron multiplication.
  DC breakdown at low pressure, Paschen Law, condition for self-sustenance. Classification of d.c discharge – glow, abnormal glow, arc, Characteristics of Cathode glow, positive column and anode glow.

- **Equilibrium Discharge Properties**

  D.C & A.C Plasma conductivity, plasma resistivity, Mobility and Diffusion with/without Magnetic field, Ambipolar Diffusion

- **Plasma Sheaths**

  Bohm Criteria, Familiarity with different types of Sheaths –Child Langmuir, Matrix sheath, Significance of Pre-Sheath, Current-Voltage Characteristics of a Probe in Plasma (theory)

- **Discharge Modeling**

  Energy loss mechanism in Dc discharge, Particle and Energy Balance, Estimation of Plasma density and Temperature by Global Model

4. Mathematical Methods – I ; (32 Lectures ; 4 credit)

- **Ordinary Differential Equations (ODE):**. First and higher order linear ODEs with constant and variable coefficients, method of undetermined coefficients and functions.
  Non-homogeneous linear equations: method of variation of parameters. Green's function method, Nonlinear ODEs of first and higher orders: method of successive approximation,

Stability for a linear system of ODEs. Applications of ODEs in plasma physics with examples.

- **Approximate Methods for solving ODE:** Power series method of solution for linear ODEs: Legendre, Laguerre and Hermite ODEs and their solutions, Picard's method, Perturbative method, Poincare-Lindstedt Method, WKB method.
- **Complex Analysis:** Introduction to complex variables, function of a complex variable, continuity and differentiability of complex function, Cauchy-Riemann conditions, Analytic functions and singularities, representation of an analytic function by a convergent infinite series, complex integration, method of residue. Applications of complex analysis and complex integration in plasma physics: e.g., Landau damping, Fourier transforms etc.
- **Difference Equations (DE):** Introduction, linear difference equations of first and higher order with constant coefficients. Use of DE for solving ODE and PDE: first order fluid equation.

5. Electromagnetic Theory-I ; (32 Lectures ; 4 credit)

- **Electrostatics:**

  Fundamentals of electrostatics and its application: Coulomb's law, Principle of superposition, Gauss law with emphasis on symmetry requirements for the law to be applicable, Field near conductor, conducting sphere with cavity, concept of electrostatic shielding, electric breakdown and lightning, Capacitors; solution to problems (of the type that tests the understanding).Electrostatic potential, potential energy for various charge configuration.

  Uniqueness theorem, boundary conditions for electric fields, method of image (discussions beyond conventional configurations), Separation of variables, boundary value problems in curvilinear coordinate systems (Poissons and Laplaces equations), Multipole expansion of potentials.

  Green's function method for solving boundary value problems (derivation, Dirichilet, Neuman and mixed boundary conditions.
- **Magnetostatics:**

  Fundamental of magneto-statics drawing analogy to electrostatics,
  Biot-Savart, Amperes Laws, Vector Potential.
  Methods for solving boundary value problem in magneto-statics
  Multipole expansion.
- **Electrodynamics :**

  Laws of electrodynamics (Maxwell's equations) and its relevance in Plasma production, measurement.

  Application of electrodynamics: Current Transformer, Some applications in plasma (e.g B-dot and E-dot probe); self and mutual inductance, Magnetic levitation, eddy currents etc.

  Time dependent and time independent vector potential in different Gauges (coulomb and Lorentz gauge).

6. Mechanics-I (Classical Mechanics); (32 Lectures ; 4 credit)

- **Lagrangian mechanics:** Introduction to Newtonian mechanics, Advantage of Lagrangian mechanics over Newtonian mechanics, Constraints, principal of virtual work, Lagrange multiplier. D'Alembert's principle, generalized coordinates. Lagrange's equation of motion and its applications, e.g., Spherical pendulum, particle in EM fields.

- **Central force:** Two-body central force problem, Kepler's problem, and Scattering problem, relation with plasma physics.
- **Hamiltonian mechanics:** Need of Hamiltonian mechanics, Legendre transform, Hamilton's equation, Hamilton's principle of least action. Applications to classical systems.
- **Canonical transformations (CT):** Definition, generating functions, properties and examples of CT, Poisson bracket (PB) representation, invariance of PB under CT. Applications to classical systems.
- **Hamilton Jacobi Theory:** Hamilton Jacobi equation, Hamilton's principal function, action and angle variable, adiabatic invariants. Applications in plasma physics.
- **Canonical perturbation:** Anharmonic oscillator, time independent and dependent perturbations.

7. Laboratory Practical – I (64 Hrs ; 4 credit)

(To be carried out in different labs through student-group wise orientation)

- **Experimental Electronics**

  Application of Operational Amplifier, Summing amplifier (AC+DC), Differential Amplifier, Inverting and non-inverting amplifier, design of regulated DC power supply: tuneable ± 15 Volt power supply circuit, Design of analogue filter circuits: low pass, high pass and band pass filter circuits, Converting AC signal to a square wave and ramp signal.

  Assessment – Practical report on each devices and description of circuit with experimental data.

- **Characteristics of DC Discharge**

  Operation of rotary and diffusion pumps, creating vacuum from atmosphere and back, leak detection experiment, estimation of pumping speed, Paschen Breakdown Experiment, Measurements of current-voltage (DC impedance) characteristics of a discharge

  Assessment – Practical report on experimental data and description of the underlying theory

- **Computer Laboratory Practical through numerical programming**:
  - Root finding: Study of different methods its salient features, programming one method.
  - Interpolation and extrapolation programing: Study of different methods and features, Programming one method.
  - Differentiation and Integration programming: Study of different methods and features, Programming one method.
  - Basic single charge particle trajectory simulations in standard electric field and magnetic field.

  Assessment – Practical report with brief understanding of the underlying theory and programming results

TRIMESTER – I ends

TRIMESTER – II

Total Credit – 32; Total subjects – 8;

Each course: 2 hr Lectures per week;

1. Advanced Plasma Physics (Part-A); (32 Lectures ; 4 credit)

- **Waves and instability in inhomogeneous plasma:**
  Derivation of generalized Cold plasma dielectric constant.
  Electrostatic Waves, Electromagnetic Waves (B=0, propagation along the B and Perpendicular to B),CMA Diagram
  Concept of Instabilities (Classification, growth rates)
  Derivation of the dispersion relation for Drift waves, effect of finite ion inertia, excitation of drift wave instability by electron ion collisions.
  Two-fluid, Gravitational Instability
- **Kinetic Description of Plasma**
  Many body description for plasma**,** The Klimontovich Dupree system of equations.
  BBGKY Hierarchy, Boltzmann equation, Vlasov Equation, Fokker-Planck Equation.
  Properties of Vlasov Equation, Equilibrium Solutions
  Kinetic Instability – Two Stream Instability and negative energy waves
  Derivation of derivation for dispersion relation for electrostatic waves (Langmuir and ion sound) in warm plasma, Concept of Landau damping.

2. Advanced Plasma Physics (Part-B); (32 Lectures ; 4 credit)

- **Non-Linear Effects in Plasma**
  KdV equation, Solitary Wave Equations, Generation of Ion Acoustic Shock Waves.
- **Magneto-hydrodynamics:** Introduction to Basic MHD Equations (Ideal MHD, Resistive MHD), Generalized ohms law, Magneto-hydrodynamic Wave (Alfven and Magnetosonic waves), MHD energy.
- **Application of MHD:** Magnetic Viscosity and Reynold Number, Frozen of Magnetic Field lines in plasma Instabilities in Magnetized Devices, Pinch Effect – Kink , Sausage, Instabilities, Ideal Magnetohydrodynamics – Equilibrium in Cylindrical and Toroidal Plasma Devices;
- **Introduction to Tokamak Physics**

3. Plasma Production and Measurements – II; (32 Lectures ; 4 credit))

- Fundamentals of different types of Plasma Sources and its discharge circuits:
  - RF Capacitive Discharge
  - RF Inductive Discharge
  - ECR and Wave based (Helicon) discharge

- Principles of Spectroscopic and Laser Diagnostics:
  Basic introduction to spectrum and spectral lines based on Atomic and Molecular

structure, Introduction to Emission, Absorption and Fluorescence spectroscopy, Einstein's coefficients for transitions, Importance of Spectroscopic databases, Understanding of different spectroscopic models (Corona, CR model, LTE model), methodologies (absolute, line ratio) and its application suitability for an experiment.

- Microwave and Interferometric diagnostic techniques:
  Fundamentals of Microwave interferometry and its methodology. Understanding of a Microwave system and its parts and accessories.

4. Mathematical Methods-II; (32 Lectures ; 4 credit)

- **Partial Differential Equations (PDE):** Introduction, Classification of PDEs (elliptic, parabolic and hyperbolic type), First order PDEs, complete integral and general solution, methods of solution of a first order and second order PDEs, Separation of variables, Method of characteristics etc., Some important equations (Laplace equation, wave equation, heat conduction or diffusion equation), Green's function method for PDEs.
- **Integral equations:** Definition, homogeneous, inhomogeneous, linear, non-linear equations, Fredholm and Volterra equations, eigen-functions, Schmidt-Hilbert method of solutions. Applications of integral equations.
- **Integral Transforms:** Fourier Transforms, Laplace Transforms and the inverse transforms, connection to physical problems. Other transforms such as Mellin and Hankel transforms, and transforms generated by Green's function. Applications for obtaining solution of ordinary/partial differential equations. Applications and relevance in plasma physics.

5. Electromagnetic Theory-II; (32 Lectures ; 4 credit)

- **EM wave in bounded region**: Wave equation and their solution, Poynting's theorem, Reflection at a plane-conducting boundary, Reflection and refraction at a plane between dielectric.
- **Introduction to waveguides:** TEM, TE, TM modes, Transmission line theory (including Impedance matching, Smith chart), waveguide and cavity resonator theory; Dielectric waveguide, Optical Fiber.
- **Gauges:** Electromagnetic Potential theory and its solution with various Gauges (Lorentz and Coulomb Gauges).
- **Radiation:** Radiation by an accelerated particle, Elements of Antenna Theory, Advanced and Retarded Green functions; Lienard-Wiechert potentials; dipole radiation and Larmor's formula; spectral resolution and angular distribution of radiation from a relativistic point charge; synchrotron radiation; collision problems; Bremsstrahlung and Cerenkov radiation.
- **Scattering of electromagnetic waves:** Rayleigh and Thomson scattering, radiation damping.
- **Relativistic electrodynamics:** Lorentz Transformations, Four Vectors, Covariant and contra-variant tensors, Electrodynamics in Tensor Notation. Relativistic Potentials. Invariance.

6. Mechanics – II (Fluid Mechanics+ Statistical Mechanics);
(16+16 = 32 Lectures ; 4 credit)

Fluid mechanics:

- **Dimensional analysis and its application**: Techniques to generate dimensionless quantity:- Rayleigh's Indicial method, Buckingham Π (PI) method; Introduction of dimensionless quantities like: Reynold's no., Froude's no., Euler's no., Weber's no., Mach's no., Relation between model and 1:1 size prototype, Model analysis, Similitude theory.
- **Types of flow with their mathematical description** : Ideal flow, Real flow, Newtonian flow, Non-Newtonian flow, Steady and Unsteady flow, Uniform and Non-uniform flow, Laminar and Turbulent flow, Compressible and Incompressible flow, Rotational and Irrotational flow, 1D-2D-3D flows.
- **Dynamics of flow:** Bernoulli's theorem and its applications in real system
- **Kinematics of linear flow of incompressible fluid:** Introduction to Eulerian frame, Lagrangian frame, Specification of the flow field, Concept of convective field, Continuity equation, Velocity Potential function and Stream function, Flow net and their applications to analyze for superimposed flow, Vorticity distribution (line and sheet vortices). Navier-Stock's equation, Expression for stress tensor.
- **Kinematics of rotational flow of incompressible fluid:** Flow at large Reynolds's number, Vorticity dynamics, Kelvin's circulation theorem, Lagrange's theorem, Vorticity laws for inviscid fluid (having no viscosity).
- **Instabilities:** Introduction to Rayleigh-Taylor instability, Kelvin-Helmholtz instability in fluid.

Statistical Mechanics:

- **Classical Statistical Mechanics*:*** Introduction, postulates, Statistical description of many body systems: The many body distribution function and Liouville's equation, one and two particle distribution functions.
- **Non-Equilibrium Phenomena:** Elementary ideas, study of Brownian motion, random walk model, Langevin's force equation, fluctuation-dissipation theorem, Fokker-Planck equation.
- **Non-equilibrium dynamics:** Noose-Hoover Thermodynamics.
- **Numerical Statistical Mechanics:** Chaos and low degrees of freedom statistical mechanics, Driven-dissipative systems and Entropy rate models, Introduction to Non-extensive systems.
- **Quantum statistical Mechanics:** Bose and Fermi statistics.

7. Numerical Methods and Advance Computing ;
(32 Lectures ; 4 credit)

Numerical methods:

- **Taylor series and its application**.
- **Eigenvalue problems**: Symmetric matrix - Jacobi method, Un-symmetric Matrix - LR method, QR method.
- **Modeling of Data:** Introduction, Qualitative discussion on:- Chi-square Fitting**,** Variances and co-variances of the parameters**,** Fitting data to a straight line**,** General linear least square.

- **Integration of Ordinary Differential equations:** Introduction, Taylor's series method, Euler's method, Runge-Kutta Methods, Predictor-correction method, Boundary value problems, Finite-Difference method.
- **Fast Fourier transform (FFT) and its applications:** Introduction to FFT, Discrete Fourier Transform**,** Leakage and windows**,** Box-Car window**,** Hanning window**,** Convolution and correlation**,** Auto power spectra, cross power spectra and coherence spectra**,** Data smoothing**,** Bi-spectral analysis.

Advance Computer programming:

- Programming for particle motion simulation considering large number of particles (MC or MD type).
- Programming for Fluid simulation.

8. Laboratory Practical II ; (32 hrs; 4 credit)

(To be carried out in different labs through student-group wise orientation)

- **Excitation of Ion Acoustic Waves in Plasma and ion acoustic speed measurement**.
  Design understanding of the experimental setup including vacuum, launcher, receiver, electronics etc. and data analysis.
- **Electric Probe diagnostic (Single Langmuir Probe)**

  Design understanding and construction of a Single Langmuir Probe (vacuum connectors, vacuum feed throughs, probe tip dimension and configuration, electric conductivity)/Probe calibration experiment (trouble shooting)/Obtaining Ampere-Voltage Characteristic of probe in plasma; Electron energy distribution in plasma.
- **Measurements of Space potential / Electric Field in Plasma using Emissive Probe**.
  Design understanding and construction of an Emissive Probe. Probe Calibration experiment, Understand different methods of plasma potential measurement using Emissive probe, Measure and interpret the experimental data.
- **B-dot probe measurement.**
  Design understanding and construction of a B-dot Probe and its measurement principle, Probe Calibration experiment, Measurement and data interpretation in an experimental.
- **Spectroscopic measurements (density, temperature measurement)**.
  Understanding of a spectrometer and its parts and accessories, Arrangement of an experimental setup and data interpretation after experiment.
- **Plasma density measurement by Microwave**.
  Understanding of the experimental setup and measurement principle, arrangement of an experimental setup and data interpretation after experiment.

Assessment – Practical report on experimental data and interpretation including description of the underlying theory and viva.

TRIMESTER – II ends

TRIMESTER – III

Total Credit – 15

1. Research Methodology (Total lecture – 8; Total credit – 1)
• **Meaning of Research:** Objectives of Research, Motivation in Research, Defining the Research Problem • **Documentation:** Documentation in doing Research; proposal writing, report writing, manuscript writing • **Data collection:** error in experimental/obtained data, analysis of errors Statistical analysis techniques: mean, median, mode, Chi-square , variance, curve fitting, confidence in obtained data, Presentation of data, analysis and meaningful conclusion
2. Introduction to Materials Science (Total lecture – 8; Total credit – 1)
Fundamentals of Material Science: - **Atomic Bonding and Crystal structure:** Metallic bond, unit cell, atomic packing, interstitial sites, Miller indices, crystal orientation, Crystal defects in metals viz. vacancy, interstitial, substitutional, dislocations etc., - **Physical Properties of materials** : Electrical, Thermal, Magnetic, Dielectric, optical and other properties of materials **Material Development Using Plasma:** - Thin film process - Material and surface modification **Common Material Characterisation Techniques :** Optical Microscope, Electron Microscope, X-ray diffraction
3. Mini Project - Credit – 4
4. Credit Seminar – Credit - 3

TRIMESTER – III ends

Duration: 1st August to 31st July (next year)
Course pattern: 3 trimester courses with 1 Project
Evaluation:

- Tests (Mid-term and Final) in each trimester
- Presentations/Seminar in each trimester, Assignment
- OGCE at the end of Trimester III

BACK TO MAIN

Ph.D. in Physical Science
(Program Code: PHYS04)

New one-year Pre-doc Course Structure at IOP

To be implemented in August 2017

1 Introduction

Institute of Physics is conducting the Pre-doc courses in the existing format for around 20 years with some modifications as and when required. It is now felt that a major restructuring of the courses is necessary in view of the current research interests and student backgrounds.

The major modifications proposed are
(i) the switch over from three trimesters to two Semesters (Aug-Dec and Jan-June/July), and
(ii) several optional courses every semester, instead of making all courses compulsory.

2 Course structure

1 Semester-I (Aug-Dec) - 2 core courses+ 3 optional courses ($5 \times 6 = 30$ credits)

101 Advanced Quantum Mechanics (Core)

102 Quantum Field theory-I (Optional)

103 Advanced Statistical Mechanics (Optional)

104 Advanced classical field theory (Optional)

105 Many body Physics (Optional)

106 Soft Condensed matter Physics (Optional)

107 Advanced Experimental Techniques (Optional)

108 Experimental Physics - Lab course (Core)

2 Semester-II (Jan-June) - 1 core, 2 optional courses, 1 project ($3 \times 6 + 12 = 30$ credits)

201 Mathematical methods, Numerical Methods and Research methodology (Core)

202 Advanced Condensed Matter Physics (Optional)

203 Advanced Nuclear Physics (Optional)

204 Quantum Field theory II (Optional)

205 High Energy Physics (Optional)

206 Quantum information and computation (Optional)

207 Nonlinear dynamics and Chaos (Optional)

208 Special topics in Condensed Matter Physics (Optional)

209 Special topics in High Energy Physics (Optional)

210 Special topics in Mathematical Methods (Optional)

211 Special topics in Quantum Mechanics (Optional)

212 Special topics in Nuclear Physics (Optional)

213 Special topics in Statistical Physics (Optional)

214 Project (Core)

Project may be submitted and defended in July, A grand viva in July.
Total: 60 credits

3 Syllabus

101 Advanced Quantum Mechanics

Review of basics through problem solving

Schrödinger equation, Heisenberg Picture, Scattering problem in one dimension, Time-independent perturbation theory, Hydrogen atom, Born Approximation. Ladder operators and coherent states.

Time-dependent perturbation theory

Interaction picture, Time ordered perturbation theory, Fermis Golden rule, Floquet.

Relativistic Quantum Mechanics

Dirac Equation, Gamma matrices and Lorentz transformation of Dirac wave function, Positive and negative energy solutions and hole theory, Coupling to electromagnetic field, magnetic moment, Klein Paradox. Dirac equation for massless particles, Helicity. Majorana representation, Dirac equation in various space-time dimensions.

Path-integral formulation

Derivation of Path-Integral representation, Time-ordered correlators in path-integral formulation, coupling to electromagnetic field, Aharonov-Bohm effect, Double well potential in path-integral formulation, Instantons, Tunneling in path-integral formulation. Path-Integral in non-simply connected configuration space.

Geometric phase

Abelian and non-Abelian Berry phase. Some examples (According to the taste of the instructor), Aharonov-Bohm effect.

Discrete Symmetries

Wigners theorem, Translation, Rotation, Lorentz Transformation (Group), Parity, charge conjugation and Time-reversal. Kramers degeneracy.

Second quantization

Indistinguishable particles, Bose and Fermi statistics, Many-body quantum mechanics in the second quantized form, Electromagnetic field in the second quantized formalism, Light Atom interaction.

Books :

1) Sakurai - Modern Quantum Mechanics
2) Landau-Lifschitz - Quantum Mechanics (Non-relativistic theory)
3) Gottfried-Yan - Quantum Mechanics : Fundamentals
4) Feynman-Hibbs - Quantum Mechanics and Path Integrals
5) Sidney Coleman - Aspects of Symmetry, (Chapter : Uses of Instantons)

102 Quantum Field Theory-I

Canonical quantization of free field theory

Canonical quantization of free (complex) scalar field. Retarded, Advanced and Feynman propagator. Causality. Normal-ordering of operators. Concept of (connected) multi-point correlation function. Wicks theorem. Canonical quantization of free Dirac field. Feynman Propagator. Wicks theorem for Dirac field. Canonical quantization of electromagnetic field. Feynman Propagator. Casimir effect.

Interacting scalar field

Interacting scalar field : Perturbative evaluation of correlation functions. Time-ordered perturbation theory. Feynman Diagrams. Calculation of some tree-level amplitudes in phi-4 theory.

Path-integral quantization of scalar field theory

Derivation of Feynman propagator and Wicks theorem. Path-integral quantization of Maxwell theory. Grassmann numbers and Path-integral quantization of Dirac field. Path integral quantization of interacting scalar field theory : Generating functional of connected correlators and derivation of time-ordered perturbation theory.

S-matrix

LSZ reduction. Sample calculations of tree-level S-matrix.

Symmetries

Noether's theorem and Ward identity.

Miscellaneous topics

Wick rotation. Relation between d-dimensional QFT and (d + 1)-dimensional statistical mechanical system. Introduction to Wilsonian-RG and the concept of effective low energy field theory description.

Books :

1) Peskin and Schroeder - An introduction quantum field theory
2) Ramond - Field theory : A modern primer .

103 Advanced Statistical Mechanics

Review of Thermodynamics and Statistical mechanics by problem solving

a) Quick review of Basic postulates, potentials, Legendre transformation
b) Basics of Statistical Mechanics: random walk/Probability, Basics of ensembles , Quantum statistics

Dynamics

Boltzmann H theorem, its use for transport properties Master equation, Langevin Equation, Fokker Planck equation Simple discussions on Detailed balance, fluctuation-dissipation theorem, Onsager relations, Work theorem, Basics of Monte Carlo

Classical Interacting systems

Phase equilibrium, chemical equilibrium, Saha ionization; variational principle, Debye-Huckel theory; Van der Waals, Virial expansion; equilibrium curves, phase diagrams

Phase transitions and critical phenomena

First order,continuous transitions; Ising and O(n) models; mean field theory; symmetry breaking, Order parameter; Landau theory (scalar and vector order parameter), Tricritical point, Alexander-McTauge theory; Gaussian model, Ginzburg criterion. Scaling near critical point.

Quantum systems

Bosons: Details of Bose condensation of an ideal gas and in a harmonic trap Fermions: Chandrasekhar limit, Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect

Books:

1. F. Reif - Fundamentals of Statistical and thermal physics
2. K. Huang - Statistical Mechanics 2nd ed
3. Chaikin-Lubenskly - Principles of condensed matter physics

Other books by (a) Pathria, (b) J K Bhattacharjee, (c) Riechl, (d) S.K.Ma, (e) Newman-Barkema

104 Advanced Classical Field Theory

Selected topics from the list

Review of Basics Classical Electrodynamics

Vector analysis, Electrostatics Boundary-value Problems, Magnetostatics, Electric and Magnetic Fields in matter, Maxwell's Equations, Electromagnetic waves, Retarded Potentials, Relativistic Formulation

Classical Electrodynamics

Covariant formulation, Dynamics of relativistic particles in electromagnetic fields, Field and radiation from oscillating sources, Scattering and Diffraction, Wave-guides, Radiation by moving charges, Bremsstrahlung, Cherenkov radiation, etc

General Relativity

Principles of equivalence and general covariance, curvilinear coordinates, affine connection, covariant derivatives, metric, curvature tensors, geodesic equations, Einstein equation, Schwarzschild solutions, black holes, tests of general relativity, big bang theory

Hydrodynamics

Conservation laws and hydrodynamic description; Navier-Stokes equation for simple fluids; hydrodynamic description of ferro and antiferro magnets.

Field theory, Symmetry and Symmetry breaking

Landau-Ginzburg theory, order parameter, mean field theory, fluctuations Goldstone theorem, topological defects, solitons in different theories, nonlinear equations, Abelian Higgs model

Continuum Mechanics

General stress tensor, strain tensor, continuum limit, Hooke's law, Elastic distortions, models for elastic solids, liquid crystals, phonons in continuum

Books :

1) J. D. Jackson - Classical Electrodynamics
2) L. D. Landau and E. M. Lifshitz - The Classical Field Theory
3) S. Carroll - Space-time and Geometry
4) R. Rajaraman - Solitons and Instantons
5) P. M. Chaikin and T. C. Lubensky, "Principles of condensed matter physics"

105 Many Body Physics

Preliminaries

a) First and Second Quantization: Quantum Mechanics with many particles; b) First quantization, many particle systems; Operators in first quantization; c) Second quantization, basic concepts The occupation number representation; d) The general form for second quantization operators; Basis change in second quantization; Examples -Operators for kinetic energy, spin, density, and current; The Coulomb interaction in second quantization.

Mean Field Theories

a) Non-interacting many particle system vs interacting many particle system. Examples; b) Concepts of mean field approximation. Idea of broken symmetry; c) Hartree-Fock approximation, Thomas Fermi approximation.; d) Hohenberg-Kohn Theorem: Self-consistent Kohn-Sham Hartree-like theory for exact ground state energy and density of electrons; potential for alternative path to include many-electron effects; e) Application: i) model of ferromagnets, Stoner model of metallic ferromagnets , ii) application to BCS theory of superconductivity, iii) application to nuclear physics. f)Short discussion on the limitations of meanfield theories.

Method of Green functions

a) Single-particle Greens functions of many-body systems: meaning and significance; Greens function of free electrons; The Lehmann representation; The spectral function; Broadening of the spectral function due to interactions; Measuring the single-particle spectral function – spectroscopy; Two-particle correlation functions of many-body systems. b)Linear response theory and Kubo formalism for response function. c)Imaginary time Greens functions: Matsubara Greens functions; Connection between Matsubara and retarded and advanced Green's functions; Examples: Single-particle Matsubara Greens function; Evaluation of Matsubara sums .Equation of motion for Matsubara Greens functions; Wicks theorem and example of polarizability of free electrons. d) Feynman diagrams and Dyson series e) Application: i) Random impurities in disordered metals. ii) Anderson model for magnetic impurities iii) Random phase approximation for interacting electron system. iv) Application to interacting phonons(i.e beyond the Einstein model of lattice vibrations)

Renormalization Group method

a) Basic concepts; b) Wilsonian Renormalization Group c) Perturbative Renormalization Group d) Functional(or Exact) Renormalization Group method e) Applications.

Books:

1. Many-body quantum theory in Condensed Matter Physics - Karsten Flensberg and Henrik Bruus
2.Condensed Matter Field Theory - Alexander Altland and Ben Simons
3. Introduction to Many Body Physics - Piers Coleman
4. Green functions for solid state physicist - S. Doniach and E. H. Sondheimer
5. Quantum Theory of Many-Particle system - Alexander L fetter and J d Walecka
6. Renormalization methods - W. D. McComb
7. Electronic Structure Calculations for Solids and Molecules-Theory and Computational Methods by Jorge Kohanoff

106 Soft Condensed matter Physics

Selection of topics from the list

Basic introduction

Structure, scattering and correlation functions

various structures and scattering: ordered systems, liquids (classical and quantum), polymers, fractals, glasses. Effective forces: van der Waals to various time-temperature dependent forces

Liquid crystals, Polymers, and glass

1) Liquid crystals and colloids: models, phases, and phase diagrams
2) Polymers: Gaussian (ideal), self-avoiding, semiflexible polymer; scaling and its use; theta point; solutions and melts; topological effects; Response functions (elastic, viscoelastic behaviour); Dynamics: single and many chain;
3) Gels, rubber, percolation.
4) Introduction to glass transition

Generalized elasticity

XY model, Liquid crystals, crystals;

Hydrodynamic description

Conserved quantities, broken symmetry variables, dynamics near phase transitions (critical dynamics, nucleation, spinodal decomposition, phase ordering)

Topological and geometrical problems

topological defects in ordered systems like liquid crystals Elementary analysis of BKT transition; Fluctuating surfaces, topological invariants

Books:
1. Chaikin-Lubensky: Principles of condensed matter physics
2. Doi-Edwards, Polymer dynamics
3. M Doi, Soft matter physics
4. Richard A. L. Jones, Soft Condensed Matter

Review Articles:
1. Gary L Hunter and Eric R Weeks: The physics of the colloidal glass transition Rep. Prog. Phys. 75 (2012) 066501
2. Daan Frenkel, Soft condensed matter, Physica A, Volume 313, Issues 12, 1 October 2002
3. A. Bray, Theory of Phase ordering kinetics, Adv.Phys. 43,357 (1994)
4.R. D. Kamien, Rev Mod Phys. 84, 497 (2012)

107 Advanced experimental Techniques

Introduction to material science from bulk to nano to thin films. A multidisciplinary approach to structure-property relation and overview of few advanced experimental techniques to explore them.This course involves theory and visits to various experimental facilities toprovide first hand experience.

Crystallography

X-ray Diffraction and scattering, X-ray reflection from interfaces and multilayers, Neutron scattering

Optical spectroscopy

Raman spectroscopy, Photoluminescence spectroscopy, Infrared spectroscopy

Electron spectroscopy

Reveling the electronic structure via. Synchrotron radiation, Angle integrated and angle resolved Photoemission spectroscopy, X-ray absorption spectroscopy (XAS)

Ion spectroscopy

Introduction to particle accelerator, Ion Implantation, Rutherford back scattering (RBS), particle induced x-ray emission (PIXE)

Nuclear spectroscopy

Basic principles of Resonance spectroscopy and its application: Nuclear magnetic resonance spectroscopy(NMR), electron spin resonance (ESR), muon spin spectroscopy (μSR)

Surface Science

Growth of thin films and characterization by Scanning tunneling spectroscopy (STM), Atomic force microscopy (AFM), Low energy electron diffraction (LEED),transmission electron microscopy (TEM) scanning electron microscopy (SEM)

Transport measurements

Understanding magnetic and electronic transport measurements throughSQUID-VSM magnetometer, 4 probe resistivity.

108 Experimental Physics: Lab course

5 experiments to be done.

1. Nuclear Radiation Detectors: Semiconductor/gas/scintillation/particle detectors. Their calibrations, identifying unknown source, Identification of spectral features, Attenuation and other experiments,Charged particle spectroscopy,
2. Vacuum Techniques: Working with vacuum pumps,Pressure and flow measurements, leak detection
3. Workshop training: using lathe machine for making holes, cutting, casting, drawings.
4. Transport measurements:Temperature dependence of resistivity,Hall effect, Band gap determination
5. Surface science experiments:Thin film deposition,Investigating surface atomic structure, Scanning tunneling spectroscopy, Scanning electron microscopy.
6. Electronic experiments,Solvingdifferential equations using Op Amps,Digital electronics using OP Amps, timer etc., Analog to digital conversion &vice versa
7. Experimental control through computers
8. X-ray investigation of crystal structure/Laue method
9. Muon life time measurements.
10. Possible innovative experiment

201 Mathematical Methods, Numerical Methods and Research Methodology

Topics to be chosen as per interest:
Part-I: Mathematical Methods

Review (Problem solving)

Contour integration, analytic continuation, asymptotic expansion, branch cuts and Riemann surfaces, ODE/Special functions/integral representation,distributions (generalized functions)

Integral equations, Partial differential equations

Classification of Integral equations: Fredholm (1st, 2nd kind), Volterra; Method of solution in special cases, including Wiener-Hopf method, Numerical methods; Ill-posed problems and regularization. Partial differential equations (beyond what is done in other physics courses): First and second order equations: Classification (hyperbolic, elliptic and parabolic), method of solutions, special equations like KdV, KPZ, Navier-Stokes and others.

Ref: M. Stone and P. Goldbart, Mathematics for Physics; Arfken;

Group theory

Introduction to Groups, representations, Lie groups; Applications in quantum mechanics, crystal symmetry, solid state physics.
Ref: Books By A. W. Joshi, M. Tinkham

Probability theory, measure theory and Lebesgue integration

Introduction to probability and statistics; Introduction to measure theory and probability as a measure; Integration - Lebesgue- Stieltjes, Lebsgue integrals; Discrete and continuous random variables; Various standard distributions; transformations of probability distributions; Characteristic functions; Law of large number, Tchebyshebv's inequality, central limit theorem, stable laws, large deviation theory; Bayesian inference;
Ref: P. Halmos: Measure theory; Feller: Probability theory and applications;
For Bayesian inference: Udo von Toussaint, Bayesian inference in physics, Rev. Mod. Phys. 83, 943 (2011).

Introduction to topology

Basic notions of topological space, fundamental and homotopic groups, homology and cohomology; Application in physics, like configuration and phase spaces, path integrals in QM, defects, textures, instantons, etc.
Ref: Nash and Sen, Topology for physicists; Nakahara: Geometry, topology and physics.

Part-II: Numerical Methods

1. Introduction to computer languages:
   (Fortran/C/C++/python etc..) Representation of numbers, Numerical precision and estimation of errors.

2. Numerical Interpolation and extrapolations

3. Sorting and searching
4. Linear Algebra, eigenvalue and eigenvectors
5. Root finding algorithms: Bisection method, Newton-Raphsons method, The Secant Method
6. Numerical Integration, Quadratures
7. Numerical solution to Ordinary and Partial differential equations
8. Random number generation, Monte Carlo Simulation
9. Data fitting, chi-square fitting, goodness of fit test, Kolmogorov-Smirnov test

Part-III : Research Methodology Article writing, communication skills, seminar presentation, review of research papers.

202 Advanced Condensed Matter Physics

Selection of topics

The Electron Gas and Liquid

a) The electron gas, Hartree-Fock, The fermi liquid and Landau Parameters, The Random phase approximations, strong interaction (Wigner crystals) b) Non fermi liquid c) interactions in the presence of lattice (Mott insulators) d) Electron-Phonon interaction.

Reduced Dimensionality

a) Quantum Dots, b) The special case of 1D, the Landauer formalism for transport, c) interactions in 1D: Luttinger liquids d) The 2D electron gas, the quantum Hall effect (integer and fractional) e) introduction to topological insulators.

Physics of Disordered System

a) Anderson localization, b) Weak localization, c) Hopping transport, d) The metal insulator transition e) interactions in the presence of disorder, f) many body localization.

Superconductivity

a) Preliminaries, conventional vs unconventional superconductivity. b) Microscopics of BCS theories, gauge symmetry breaking, Josephson effect. c) High temperature superconductivity, Cuprate and Pnictides superconductivity, introduction to simple models of High Tc superconductivity. d) distinction between s-wave, p-wave, d-wave superconductivity. e) heavy fermionic superconductivity.

Magnetism

a) Basics, b) Ferromagnetism and Anti ferromagnetism, spin waves. c) Stoner model, t-J Model d) Introduction to frustrated magnetism, e) Local moments, the Kondo effects and RKKY interactions. f) Introduction to heavy Fermionic system, the Kondo lattice.

Books:

1. Karsten Flensberg and Henrik Bruus, Many-body quantum theory in Condensed Matter Physics
2. Philip Philips, Advanced Solid State Physics
3. Majlis, The quantum theory of Magnetism
4. Michael P Murder, Condensed Matter Physics
5. G Mahan, Many Particle Physics
6. P de Gennes, Superconductivity in metal and Alloys
7. D Pines, Elementary Excitations in Solids
8. A. C Hewson, The Kondo Problem to heavy fermions

203 Nuclear Physics

Nuclear Physics General

NN interaction: symmetries, basics, low energy scattering and shape independence, meson theory and properties of NN interaction, Nuclear systematics: masses, radii, shapes, magnetic and quadrupole moments, shell structure, radioactivity, fission, halo nuclei.

Nuclear models

Liquid drop model, semi empirical mass formula, Fermi gas model, Basics of shell model, Hartree- Fock, pairing, Relativistic mean field formalism for finite and infinite nuclear many-body problem (intro.) rotational and vibrational spectra, giant resonances.

Nuclear reactions

Resonances and compound nucleus, direct reactions (inelastic, stripping, pickup etc.), extracting nuclear information from reactions.

Nuclear matter

Nuclear equation of state (Relativistic and Non-relativistic Formalisms), neutron stars, Quark models, quark equation of state, relativistic heavy ion collisions, signature of QGP,

Big bang and QCD phase transition, hadron and quark, phase transition in neutron stars.

Books :

1. W. Greiner and J. Eisenberg - Nuclear Models, Vol. I, II and III
2. A. Bohr and B. R. Mottelson - Nuclear Structure, Vol I and II
3. Blatt and Weisskopf - Theoretical Nuclear Physics
4. M. A. Preston and R.K. Bhaduri - Structure of Nucleus
5. B. Muller - Physics of Quark Gluon Plasma
6. Cheuk-Yin Wong - Introduction to High-Energy Heavy-Ion Collision

204 Quantum Field Theory - II

A selection of topics from the following list.

Loop calculations in scalar field theory

One-loop calculation of 2 and 4-point functions in interacting scalar field theory, Regularization and Renormalization, Renormalization group equation and beta function, Anomalous dimension, Renormalization of composite operators.

Renormalization group flow

Solution of Callan-Symanzik equation, Classification of fixed points, Multiple couplings and linearized RG-flow in the neighborhood of a fixed point, Various types of asymptotic behavior of QFT, Wilson-Fisher fixed point and introduction to ϵ-expansion in large-N vector model.

Non-Abelian gauge theory

Non-Abelian gauge theory, Path-Integral quantization of Non-Abelian gauge theories, BRST symmetry, One loop beta function of non-Abelian gauge theory and asymptotic freedom, Introduction to Wilson loop and confinement .

Effective action and global symmetry breaking

1PI effective action and Coleman-Weinberg potential, Spontaneous global symmetry breaking using 1PI effective potential, Goldstone Boson.

Gauge symmetry breaking

Spontaneous breaking of gauge symmetry and Higgs mechanism.

Anomalies

Introduction to anomalies in QFT.

Finite temperature field theory

Introduction to finite temperature field theory, Coleman-Weinberg effective potential at finite temperature, Symmetry restoration at high temperature.

Miscellaneous topics

Non-Perturbative techniques in field theory. Solitons and Instantons in field theory.

Books :

1) Peskin and Schroeder - An introduction quantum field theory
2) Ramond- Field theory - A modern primer
3) Matthew Schwartz - Quantum field theory and the standard model
4) Weinberg- The quantum theory of fields, Vol-1 and Vol-2.
5) Sidney Coleman - Aspects of symmetry

205 High Energy Physics

A selection of topics from the following list.

Introduction

Broad preview and overview, a bit of discussion of history and current status, basic ingredients of modern theories, colliders and detectors, LHC and main detectors

Symmetries and Lie Groups

Quantum numbers, conservation laws, discrete and continuous symmetries, Lie groups and algebras, SU(n) and SO(n) groups and representations, Young Tableau, hadron spectroscopy, eight-fold way, quark model

S-Matrix, Cross section and Decay rates

General discussion, relativistic kinematics, phase space, basic formulas for $2 \to 2$ scattering and decays into 2 or 3 particles, Feynman rules

Gauge Theories and Spontaneous symmetry breaking

Construction of gauge theories, discrete symmetry breaking, breaking of global and local continuous symmetries, Goldstone and Higgs phenomena

Electromagnetic Interactions

Quantum Electrodynamics, Simple processes like Moller Scattering, Bhabha Scattering, Compton scattering, pair annihilation

Weak Interaction

Fermi theory, V-A theory, C, P and CP violation, muon decay, pion, kaon and B/D-mesons decay, neutrino-electron, neutrino-muon, and neutrino-quark scattering, IVB theory, problems

Strong Interaction

Deep-inelastic scattering and structure of hadrons, Bjorken scaling, Quark-parton model, sum rules, scaling violation, splitting functions, DGLAP equation, $e^-e^+ \to$ hadrons, basic $2 \to 2$ processes involving quarks and gluons, glimpse of helicity methods

Standard Model

Motivation for $SU_c(3) \otimes SU_L(2) \otimes U_Y(1)$ symmetry and its breaking, construction of the action, masses of vector bosons and fermions, CKM matrix and CP violation

Basic processes in the Standard Model

W/Z boson decays, heavy quark production, neutral-current processes, basic Higgs boson production and decays

Beyond Standard Model Scenarios

Neutrino oscillations and neutrino mass, standard model shortcomings, effective field theories, anomalous interactions, GUTs, supersymmetry, large extra dimension, etc

Books :

1) F. Halzen and A. D. Martin - Quarks and Leptons
2) T-P Cheng and L-F li - Gauge Theory of Elementary Particle Physics
3) V. D. Barger and R. J. N. Phillips - Collider Physics
4) V. Barger, D. Marfatia, and K. Whisnant - The Physics of Neutrinos

206 Introduction to Quantum Information

A selection of topics from the following list.

Quantum Mechanics Formalism

Postulates, density matrix, generalized measurements, qubits, no-cloning theorem

Composite Systems

Entangled states, partial trace, Schmidt decomposition, purification

Quantum Entanglement

Detection and quantification of entanglement in bipartite and multipartite systems, monotones, majorization

Quantum Operations

quantum channels, Kraus representation, quantum noise, master equations, tomography

Quantum Nonlocality

EPR paradox, Bell inequality, CHSH inequality, Tsirelson bound, PR box, steering, quantum games

Quantum Communication

superdense coding, teleportation, entanglement swapping, secret sharing

Quantum Cryptography

One-time pad, BB84, B92, Ekert protocols

Quantum Algorithms

Universal quantum gates, Deutsch algorithm, Deutsch-Jozsa algorithms, Quantum Fourier transform

Books :

1) M. A. Nielsen and I. L. Chuang - Quantum Computation and Quantum Information

2) J. Preskill - Lecture notes on Quantum Information Theory, Online at Caltech Website
3) M. M. Wilde - Quantum Information Theory
4) A. Peres - Quantum Theory: Concepts and Methods

207 Non-Linear dynamics and Chaos

Introduction

One and two dimensional systems

Fixed points, bifurcation, limit cycles; phase plane analysis; Topological analysis

Interacting systems

Predator-Prey model/Lotka-Volterra system

Specific systems

(one or more of the following)
Enzyme Kinetics (Michaelis-Menten equation)
Neuron dynamics (Hodgkin-Huxley and FitzHugh-Nagumo models)
Kinematic waves (Belousov-Zabotinski reaction, traffic flow, Singular perturbation/shocks)
Travelling waves (Fisher-Kolmogorov problem, kdV equation)
noisy problems (Edwards-Wilkinson/KPZ problem of surface growth)

Chaos

Lyapunov exponent, Lorentz equation, Logistic map, fractals

Turbulrnce

Elementary introduction to Kolmogorov scaling.

Books :

1. S. Strogatz: Nonlinear dynamics and Chaos
2. J. Murray: Mathematical Biology I, II
3. J. K. Bhattacharjee -Staticial Physics

208-213: Special Topics

These are special courses as per research requirements, may even be research level topics not covered in other courses or topics of current interest.

214 Project (core)

Each student has to do a project (equivalent to 2 courses) and defend it at the end of the semester.

Harish-Chandra Research Institute

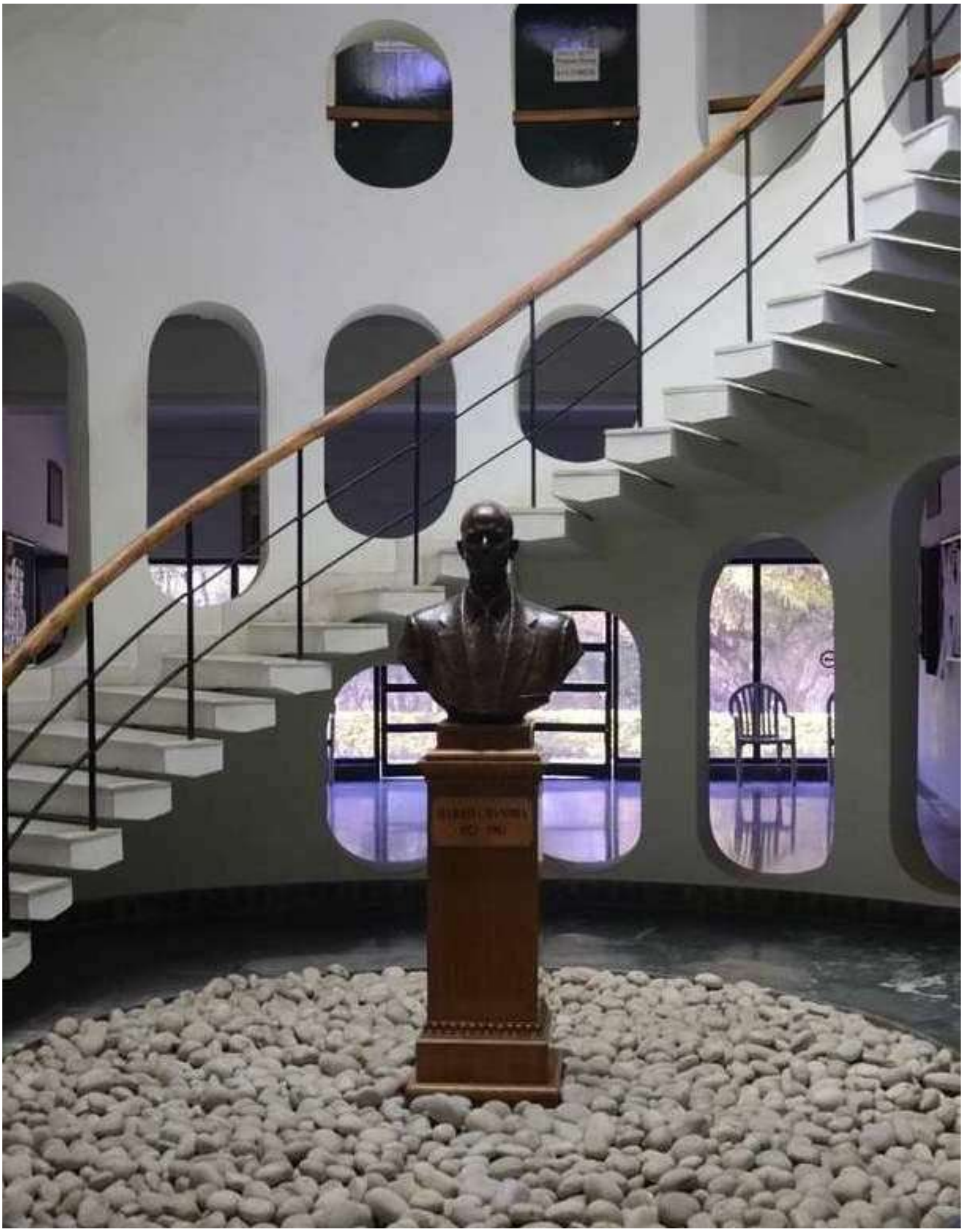
Doctoral Program in Physics

The Ph.D. program consists of course work and projects for the first three semesters, followed by research work leading to a Ph.D. degree.

Curriculum and detailed course content

SYLLABUS FOR

Ph.D. in Physical Science
(Program Code: PHYS04)



Degree granted by Homi Bhabha National Institute

Course Structure

The instructional part of the doctoral program consists of two semesters of pedagogical lectures followed by two projects in the third semester.

Semester I	Semester II	Semester II
Elective I	Elective II	Big Project
Project	Elective III	
Mathematical Methods II	Statistical Mechanics	Small Project
Quantum Field Theory I	Numerical Methods	

Elective I : Choose one from — Fluid Mechanics, General Relativity, Non-linear Dynamics, Quantum Information and Computation I, Quantum Mechanics III .

Elective II and III : Choose two from — Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure, Particle Physics, Quantum Field Theory II, Quantum Information and Computation II, Quantum Optics, Soft Matter, Ultra Cold Atoms.

Semester I

08PHYS04-001-C Quantum Field Theory I

Non-relativistic quantum field theory: quantum mechanics of many particle systems; second quantisation; Schrodinger equation as a classical field equation and its quantisation; inclusion of inter-particle interactions in the first and second quantised formalism

Irreducible representations of the Lorentz group, connection to quantum fields

Symmetries and conservation laws: examples in non-relativistic and relativistic field theories; translation, rotation, Lorentz boost/Galilean transformation and internal symmetry transformations; associated conserved charges

Free Klein-Gordon equation: classical action and its quantisation; spectrum; Feynman rules for computing n-point Green functions of elementary and composite operators.

Interacting Klein-Gordon field: Feynman rules for computing Green functions; physical mass of the particle from the analysis of two point Green functions; S-matrix and its computation from n-point Green functions; relating S-matrix to cross-section.

Quantisation of free Dirac fields: spectrum; Feynman rules

Quantisation of free electromagnetic field: role of gauge invariance; gauge fixing; physical state condition; spectrum; Feynman rules

Quantum electrodynamics: coupling Dirac field to electromagnetic field; gauge invariance; quantisation; Feynman rules for computing Green functions; Spectrum and S-matrix from the Green functions.

08PHYS04-002-C Mathematical Methods II

Integral transforms, Fourier transforms, inversion and convolution, Laplace transforms

Advanced topics in ODE, Partial differential equations: classification of second order PDEs, Laplace and Poisson equations, applications to electrostatics, Heat equation, Wave equation

Group theory, definitions and examples of groups. Homomorphism, isomorphism and automorphism, Permutation groups

Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group. Symmetries in physical systems, Young Tableau.

08PHYS04-003-C Project

In this semester, every student is supposed to do a project on a theoretical physics topic under the supervision of HRI faculty. Main fields in theoretical physics represented at HRI at the moment are, Astrophysics, Condensed Matter Physics, Particle Physics Phenomenology, Quantum Information and Computation, and String Theory.

Elective I

Choose any one of the following topics, Fluid Dynamics, General Theory of Relativity, Techniques in Nonlinear Dynamics, Quantum Information and Computation I and Quantum Mechanics III.

08PHYS04-001-E Fluid Mechanics

Ideal Fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity

Viscous Fluids: Viscosity, Navier-Stokes equation, Reynolds number, laminar flow, exact solution to the eq. of motion.

Turbulence: Stability of flows, instabilities, quasi-periodic flows, Strange attractors, turbulent flows, jets, free shear layers, wakes, boundary layers

Thermal Conduction in fluids: eq. of heat transfer, conduction in incompressible fluid, law of heat transfer, convection, convective instability in static fluid

Compressible flows

Relativistic Fluid dynamics: eq. of motion, energy-momentum tensor, eq. for flow with viscosity and thermal conduction.

08PHYS04-002-E General Theory of Relativity

Review of Lorentz transformations and special theory of relativity.

Tensors and their transformation laws; Christoffel symbol and Riemann tensor; geodesics; parallel transport along open lines and closed curves; general properties of the Riemann tensor.

Equivalence principle and its applications: gravity as a curvature of space-time; geodesics as trajectories under the influence of gravitational field; generalisation to massless particles; gravitational red-shift; motion of a charged particle in curved space-time in the presence of an electric field; Maxwells equation in curved space-time.

Einsteins equation, Lagrangian formulation, Einstein-Hilbert action.

Schwarzschild solution: construction of the metric and its symmetries; motion of a particle in the Schwarzschild metric; Schwarzschild black hole; white holes and Kruskal extension of the Schwarzschild solution: construction of the metric and its symmetries; Motion of a particle in the Schwarzschild metric; precession of the perihelion; bending of light; horizon, its properties and significance.

Precession of the perihelion; bending of light; radar echo delay.

Initial value problem; extrinsic curvature; Gauss-Codacci equations;

Linearised theory, gravitational waves, field far from a source, energy in gravitational waves, quadrupole formula

Elementary cosmology: principles of homogeneity and isotropy; Friedman-Robertson-Walker metric; open, closed and flat universes; Friedman equation and stress tensor conservation, equation of state, big bang hypothesis and its successes.

08PHYS04-003-E Nonlinear Dynamics

Long time behaviour of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.

Periodic orbit for conservative systems, periodic orbits for dissipative systems (limit cycles) and their stability, Bifurcations and centre manifolds.

Different kinds of perturbation theory for calculating periodic orbits, Renormalisation group aided perturbation theory, Poincare Bendixon theorem, chaos and strange attractors.

Maps, fixed points, cycles and stability, bifurcations , period doubling, intermittency and quasi periodicity, universal behavior at the onset of chaos , renormalization group and scaling behaviour.

Partial differential equations , patterns, Galerkin truncations and reduction to dynamical systems.

08PHYS04-004-E Quantum Information and Computation I

Quantum formalism: states, evolution, measurements.

Multipartite quantum systems: description and manipulation of bipartite systems and beyond.

Entanglement: quantification and detection in bipartite and multipartite systems.

Quantum communication: no-cloning theorem, quantum teleportation, quantum dense coding, multipartite communication protocols.

Quantum cryptography: essential classical cryptography, BB84, B92, Ekert, and secret sharing protocols.

Quantum computation: quantum algorithms, universal gates.

Interface of quantum information with other sciences.

Experimental realisations.

08PHYS04-005-E Quantum Mechanics III

Atomic physics: One electron atoms - spin-orbit interaction, fine structure, Lamb shift, Zeeman effect, Stark effect.

Two electron atoms: spin wave functions, approximate handling of electron-electron repulsion. Coupling of angular momenta, multiplet structure, gyromagnetic effects. Hyperfine and nuclear quadrupole interactions.

Many electron atoms: central field approximation, Thomas-Fermi and Hartree-Fock methods.

Molecular physics: Born-Oppenheimer approximation, molecular structure, rotation and vibration of diatomic molecules, hydrogen molecular ion, vibrational-rotational coupling, effect of vibration and rotation on molecular spectra. Electronic structure- molecular orbital and valence bond theories.

Atoms and light: transition rates, dipole approximation, Einstein coefficients, radiative damping, optical absorption, ac Stark effect.

Cold atoms: Doppler cooling, magneto-optical trap, ion traps, dipole force, evaporative cooling, optical lattice.

Collective effects: Feshbach tuning of interactions, Bose condensation of alkali atoms, BCS-BEC crossover, the unitary Fermi gas. Imaging cold atoms.

Computing with atoms: qubits and their properties, entanglement, quantum logic gates, decoherence and error correction.

Semester II

08PHYS04-004-C Statistical Mechanics

Basics: phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.

Non interacting classical systems: few level systems, ideal gases, oscillators.

Non interacting quantum systems: method of second quantisation, electrons in metals, relativistic electron systems, electrons in a strong magnetic field, lattice vibrations and phonon physics, photons, blackbody radiation, Bose condensation.

Interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.

Phase transitions: symmetry breaking and long range order, mean field approach, Landau theory, 2nd and 1st order transitions, Landau-Ginzburg functional, illustrative examples, estimate of fluctuations.

08PHYS04-005-C Research Methodology and Numerical Methods

Research Methodology including quantitative methods, communication skills, seminar presentation and review of research papers

Introduction to programming languages: F77, F90 or C

Errors in numerical calculations.

Numerical linear algebra, eigenvalue and eigenvectors.

Interpolation techniques.

Generation and use of random numbers.

Sorting and searching.

Differentiation and Integration (including Monte Carlo techniques)

Root finding algorithms

Optimisation, extrema of many variable functions.

ODEs and PDEs: including FFT and finite difference methods, integral equations.

Elective II and III

Choose any two of the following topics,

Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure Calculations, Particle Physics, Quantum Field Theory II, Quantum Information and Computation II, Quantum Optics, Soft Matter, Ultra cold Atoms.

08PHYS04-006-E Astrophysics

Introduction to celestial objects, coordinates and the concept of time. Radiation transfer. Equations of radiation transfer, Black-body/thermal radiation, Opacity and optical depth, solutions of the radiation transfer equations in limiting cases, Rosseland mean opacity.

Thermal Bremsstrahlung emission, synchrotron emission. Self absorption and the emergent spectrum. Thomson scattering. Compton and Inverse-Compton scattering. Scattering in a region with magnetic field, Faraday rotation Introduction to fluid dynamics. Convection instability and transfer of energy from cores of stars. Supersonic motion, shocks.

Introduction to Magneto-hydro dynamics, flux freezing, Generation and amplification of magnetic fields in astrophysical situations.

Stellar structure. Mass-radius relation for main sequence stars, Minimum and maximum mass for nucleosynthesis, Hertzsprung-Russell diagram, Evolution of a star on the HR diagram. Novae and Supernovae, End points of stellar evolution. Inter-stellar medium. Phases of interstellar medium. Thermal, photoionisation, chemical and pressure equilibrium, Star formation, feedback and the evolution of ISM.

Orbits around massive bodies, Tidal disruption, restricted 3 body problem, Roche limit. Orbits in external potentials, potential-density pairs. An overview of models for galaxies. Accretion of matter on to a point mass, spherical accretion, Eddington limit.

Introduction to Cosmology, Friedmann models, equations. Hubble's law. A brief overview of the thermal history of the universe.

08PHYS04-007-E Condensed Matter Physics II

The course will consist of any two of A-D:

Part A: Mesoscopics and spintronics:

Foundation: low dimensional systems: quantum Wells, wires and quantum dots, 1D and 2D heterostructures, coupled wells and superlattices.

Charge Transport: transmission and its relation to conductance, Landauer theory, transmission function, S matrix and Green functions. Non-equilibrium Green functions and Landauer-Buttiker theory. Noise in Charge transport, scattering theory of shot noise.

Spintronics: introduction to spintronics.(Datta-Das spin transistor) equilibrium and non-equilibrium spin currents, spin Hall effect, coupled charge and spin transport, TMR, spin shot noise, entanglement generation and its detection.

Part B: Electronic structure:

Physics in low dimensions: surface states, reconstructions, adsorption, atomic wires and clusters.

Electron-electron interactions: Hartree-Fock approximation, electron gas, density functional theory.

Anharmonic effects in crystals: thermal expansion, lattice thermal conductivity, umklapp processes.

Phonons in metals: Kohn anomaly, dielectric constant, temperature dependence of electrical resistivity.

Dielectric properties of insulators. Plasmons, magnons etc.

Part C: Mesoscopics and interacting systems:

Quantum Hall effect

Quantum dots and quantum wires, Kondo effect

Fermi liquid theory and non Fermi liquids

Bosonization and Luttinger liquids.

Quantum spin systems

Part D: Correlated electrons:

Mott physics: electron localisation, magnetic order, doped phase, physics in the cuprates.

Kondo systems: physics of the single impurity, dense systems Kondo and Anderson lattice, heavy fermions, quantum criticality.

Metallic magnets: ferromagnetism in strongly repulsive systems, the transition metals, spin-fermion systems, the double exchange model, the classical Kondo lattice.

Electron-phonon coupling: the classical theory, polaron formation, many electron systems, polaron ordering, physics in the manganites.

Superconductivity: the BCS-BEC crossover, superconductivity in repulsive systems, competition with magnetism, effect of disorder.

08PHYS04-008-E Cosmology

Friedman-Robertson-Walker metric, Friedman equation and stress tensor conservation, equation of state: matter, radiation, cosmological constant, experimental evidence for dark matter and dark energy.

Age of the universe, cosmological horizon, expansion rate.

Thermal history of the universe, formation of hydrogen and origin of CMBR, decoupling of neutrinos, nucleosynthesis, recombination.

The horizon problem, possible resolution via inflation, slow roll condition and slow roll parameters, reheating, inflationary origin of density perturbation.

Early history, electroweak baryogenesis via leptogenesis, dark matter.

Theory of cosmological perturbations: gauge invariant scalar and tensor perturbations, spectral index, ratio of tensor to scalar fluctuation and Lyth bound, transition from quantum to classical perturbation: horizon exit and reentry, from density fluctuation to CMB fluctuations via Boltzmann transport equation, origin of the acoustic peak, origin of CMB polarisation, E and B modes.

08PHYS04-009-E Introduction to Electronic Structure

Review of QM: variational method, identical particles, many fermion wave functions.

First-principles Hamiltonian and Born-Oppenheimer approximation.

Treating electron-electron interactions: Hartree-Fock approximation, exchange energy, correlation energy.

Density functional theory: Thomas-Fermi method, Hohenberg-Kohn theorems, Levy constrained search formulation, Kohn-Sham formulation, exchange-correlation energy, LDA and GGA functionals, spin density functional theory.

Solution of the Kohn-Sham equations, basis sets - LCAO: STO-NG, 4-31G, 6-31G etc, quality of basis sets, polarisation functions, spin-restricted calculations, Roothan equations.

Spin unrestricted calculations. Plane wave basis set.

Pseudopotentials and PAW in conjunction with plane waves.

Structure optimisation, Hellman-Feynman theorem.

Simple practical applications: band structure of standard solids, metals and semiconductors, optimisation of lattice constants, cohesive energies and other simple properties.

Possible advanced topics: hybrid functionals, van der Waals interactions, density functional perturbation theory, phonon band structure, electron-phonon coupling. CI, CCSD methods, QMC.

08PHYS04-010-E Particle Physics

Experimental methods: fixed target and collider experiments, particle detectors.

Role of symmetries: charge conjugation, parity, time reversal, isospin and SU(2), quark model and SU(3).

Introduction to relativistic kinematics: Mandelstam variables, phase space, calculation of cross-sections and decay widths.

Basics of quantum electrodynamics: electron-positron annihilation, electron-muon scattering, Bhabha scattering, Compton scattering.

Deep inelastic scattering: Bjorken scaling, parton model, scaling violation, introduction to quantum chromodynamics and tree level processes.

Introduction to weak interactions: parity violation, V-A theory, pion and muon decay, neutrino scattering.

Standard Model: Glashow-Salam-Weinberg model, neutral current, physics of W, Z and Higgs, CKM mixing and CP violation.

Neutrino physics, neutrino oscillation

08PHYS04-011-E Quantum Field Theory II

Path integrals for scalar and fermionic fields: generating functional, Feynman rules, loop diagrams.

Renormalisation of scalar and Yukawa theories: power counting, regularisation, renormalisable and non-renormalisable theories, Green functions at 1 loop of some prototypical theories, basics of renormalisation group (running coupling), 1PI effective actions.

Spontaneous symmetry breaking and Goldstone's theorem.

Path integrals for the Maxwell field, gauge fixing.

Renormalisation of QED: 1 loop diagrams, Landau pole.

Non-abelian Gauge Theories: Classical theory of non-abelian gauge theories, Quantization of non-abelian gauge theories by path integral methods, Non-abelian gauge theories at one loop and asymptotic freedom, Spontaneous symmetry breaking in non-abelian gauge theories.

08PHYS04-012-E Quantum Information and Computation II

General evolution and Decoherence theory.

Master equations (Markovian and Non-Markovian, Various measure of nonmarkovianity).

Advanced entanglement theory (GM, GGM, newly proposed measures etc).

Quantum Correlation Beyond Entanglement (Quantum Discord, Geometric discord, Work-Deficit etc).

Resource theory in QI (Entanglement, Quantum Coherence, Reference Frame, Asymmetry etc).

Quantum Thermodynamics.

Advanced topics in quantum channels.

Quantum information and condensed matter systems.

08PHYS04-013-E Quantum Optics

Introduction: Quantization of the electromagnetic field, Fock states, coherent states, squeezed states, basic atom-photon interaction, density-matrix formalism.

Theory of coherence; Semiclassical theory of atom-photon interaction.

Quantum theory of atom-photon interaction.

Quantum theory of dissipation.

Quantum information in continuous variable systems; Quantum state engineering.

Quantum operations based on beam splitters, mirrors, squeezing and homodyne and heterodyne measurements and nonlinear operations such as parametric down converters.

Photon addition and subtraction operations; Elements of cavity QED.

08PHYS04-014-E Soft Matter

Forces, energies and timescales in soft matter, van der Waals force, hydrophobic and hydrophilic interactions. Basic phenomenology of liquid crystals, polymers, membranes, colloidal systems. Phase behaviour, diffusion and flow, viscoelasticity.

Order parameter, phase transitions: mean-field theory and phase diagrams, elasticity, stability, metastability, interfaces.

Colloidal systems: Poisson-Boltzmann theory, DLVO theory, sheared colloids, stability of colloidal systems, measurement of interaction.

Polymers: model systems, chain statistics, polymers in solutions and in melts, flexibility and semi-flexibility, distribution functions, self-avoidance, rubber elasticity, viscoelasticity, reptation ideas.

Membranes: fluid vs. solid membranes, energy and elasticity, surface tension, curvature, de Gennes-Taupin length, brief introduction to shape transitions.

Experimental tools and numerical approaches: Stokes limit, Rouse and Zimm Model for polymers, membranes, relaxation, computational studies, multiscale modelling.

08PHYS04-015-E Ultra Cold Atoms

Spatial, time, and energy scales in cold atom physics.

Experimental background: trapping and cooling, Feshbach resonance, optical lattices, cold atom spectroscopies.

Basic theory: many particle physics, mean field theory, phase transitions, perturbation theory.

Continuum bosons: bosons in free space, weak interactions, Bogoliubov theory, BEC in trapped systems, Gross-Pitaevski equation.

Continuum fermions: fermions in free space, trapped fermions, Fermi liquid theory, weak attraction - BCS instability, strong attraction - BEC of pairs, the unitary Fermi gas, Stoner instability.

Optical lattices: Hubbard model - Bose/Fermi cases, superfluid-Mott transition for repulsive bosons, BCS-BEC crossover for attractive fermions, Mott transition in repulsive fermions.

Spin systems: quantum, S = 1/2, magnetism on unfrustrated and frustrated lattices.
Entanglement in many body systems: pure states, mixed states, area laws, tensor network states.

Special topics: population imbalance, Anderson localisation, gauge fields, quench dynamics.

Semester III

By this time students would have already chosen their field of research. In this semester they are supposed to do two projects, a small project carrying 6 grade points and a big project with 12 grade points, preferably in their field of interest

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BACK TO MAIN

Doctoral Programmes in Physics at IMSc

Ph.D. in Physical Science
(Program Code: PHYS04)

There are two streams leading to the Doctoral degree in Physics at IMSc: the one available to students who have completed their Master's degree prior to joining IMSc (Ph.D.) and the one available to students who join after their Bachelor's degree (Integrated Ph.D.). The Ph.D. program has *two semester compulsory course work* while the integrated Ph.D. has *four semester compulsory course work*. The third and fourth semester course work of the integrated Ph.D. program is the same as the two semester course work of the Ph.D. program.

The courses together with the pre-requisites and reference material, are given below. Integrated Ph.D. students begin with the *rst* semester courses while Ph.D. students begin with the *third* semester courses.

No.	Semester I	No.	Semester II	No.	Semester III
(11)	Classical Mechanics	(21)	Quantum Mechanics II	(31)	Quantum Field Theory I
(12)	Quantum Mechanics I	(22)	Classical Field Theory	(32)	Mathematical Methods II
(13)	Electromagnetic Theory	(23)	Condensed Matter Physics I	(33)	Statistical Mechanics II
(14)	Mathematical Methods I	(24)	Statistical Mechanics	(34)	Particle Physics I

The Fourth semester has *two core courses* (18 credits) and a *project* (12 credits). The core courses di er for students desirous of research in High Energy Physics (HEP) or Low Energy Physics (LEP). These are to be decided in consultation with the monitoring committee.

No.	HEP students	No.	LEP students
(41)	Quantum Field Theory II	(43)	Advanced Condensed Matter Physics
(42a) (42b)	Cosmology-and-Gravitation *or* Particle Physics II	(44a) (44b) (44c)	Nonlinear Dynamics *or* Quantum Information-and-Computation *or* Statistical Field Theory,

The integrated Ph.D. program students earn 123 credits while those of Ph.D. program earn 60 credits at the end of the course work.

Detailed syllabi of the proposed course

The course contents are indicative and will be ne tuned with experience.

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11) Classical Mechanics (four-and-half hours classwork per week, **9 credits**)

- *Lagrangian formulation and the action principle:*

  Configuration space, generalized coordinates Constrained systems, holonomic constraints as coordinate transformations, motion in a central field, including Kepler problem, Rutherford scattering, Small oscillations, normal modes, total time derivatives, non-uniqueness of Lagrangian, Noether's theorem, Conservation laws;

- *Rigid body kinematics and dynamics:*

  Kinematics, rotational kinetic energy, moments of inertia, inertia tensor, Euler angles, angular momentum, Free rigid body motion, axisymmetric tops;

- *Hamiltonian formulation:*

  The Legendre transformation, canonical momentum Poisson brackets, Phase space reduction, cyclic coordinates, Phase space description and evolution, surfaces of section, periodically driven systems, Liouville's theorem, Poincaré recurrence;

- *Canonical transformations, Hamilton-Jacobi theory, perturbation theory:*

  Definition; point transformations; time-independent transformations; symplectic transformations and time-dependent transformations, Invariants of canonical transformations, Generating functions Hamilton-Jacobi equation, action-angle variables, Perturbation theory as a sequence of canonical transformations of a perturbed integrable system;

- *Relativistic mechanics (including Lagrangian formulation):*

  Space-time, 4-vectors, Lorentz transformations, basic relativistic kinematics and dynamics.

Textbooks:

1. L. Landau and E. Lifshitz, *Mechanics : Course of Theoretical Physics*, Vol.1, Pergamon, 1974.
2. W. D. McComb, *Dynamics and Relativity*, Oxford University Press, 1999.
3. V. I. Arnold, *Mathematical Theory of Classical Mechanics*, Springer, 1977.
4. M. Tabor, *Chaos and Integrability in Nonlinear Dynamics*, Wiley, 1989.
5. H. Goldstein, *Classical Mechanics*, Narosa, 1990.
6. I. Percival and D. Richards, *Introduction to Dynamics*, Cambridge, 1991
7. J.V. Jose and E.J. Saletan, *Classical dynamics: A contemporary approach*, Cambridge, 1998.

12) Quantum Mechanics I: (four-and-half hours classwork per week, **9 credits**)

- *Fundamentals of Quantum Theory:*

  The breakdown of classical physics, the polarization of photons, Wave-particle duality: Particle properties of photons and wave properties of electrons, Schrodinger evolution, Hamiltonian, examples: free particle, one-dimensional potential well, potential barrier, harmonic oscillator, etc., Hilbert space formulation of Quantum Mechanics: states, observables, measurement, evolution, collapse of wave function, uncertainty relation and its interpretation, Discrete and continuous spectra, canonically conjugate observables, Schrodinger, Heisenberg and interaction pictures, Virial theorem, Ehrenfest's theorem, semi-classical quantization;

- *Theory of spin-1/2 systems:*

  Stern-Gerlach experiment for the existence of spin Quantum Mechanics of two-level systems

- *Spherically symmetric potentials:*

  Schrodinger equation for spherically symmetric potentials, Orbital angular momentum and spherical harmonics, Hydrogen atom problem and three dimensional harmonic oscillator;

- *Symmetries and conservation laws:*

  What is a symmetry, Wigner's theorem, Continuous transformations, Rotation, Euclidean and Galilean groups, Transformations and invariances;

- *Angular momentum theory in Quantum Mechanics:*

  Orbital and spin angular momenta, Raising and lowering operators, Addition of angular momenta, Clebsch-Gordon coefficients, Schwinger oscillator model, Spherical tensors and Wigner-Eckart Theorem, Spin-orbit coupling,

- *Exactly solvable models:*

  Charged particle in a magnetic field, Landau levels, Quantum Hall e ect;

- *Time-independent perturbation theory:*

  Non-degenerate and degenerate cases, An-harmonic oscillator, Van der Waal's force, Dipole interactions for spin-1/2 systems, Stark e ect, Zeemann e ect;

- *Time-dependent perturbation theory:*

  Approximate solution of Schrodinger equation, Sinusoidal perturbation of two-level system: resonance phenomenon, Coupling with states of continuous spectrum, Fermi's golden rule, Interaction of atom with electromagnetic wave,

Textbooks:

1. C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics*, Vols. I and II, Wiley, 1970.
2. J. J. Sakurai, *Modern Quantum Mechanics*, Addisson Wesley, 1995.
3. Leslie E. Ballentine, *Quantum Mechanics: A Modern Development*, World Scientific, 1998.

13) Classical Electromagnetism: (three hours classwork per week, **6 credits**)

1. *Electrostatics and Magneto-statics :*

   Mathematical preliminaries, boundary value problems using Green function techniques, special techniques for calculating potentials, electrostatics of dielectric media, magnetic vector potential and the gauge problem, Biot-Savart law, magnetic dipole moment and the Larmor precession, magnetic susceptibility and permeability, ferromagnetism;

2. *Maxwell Electrodynamics :*

   Motion of charges in external fields, electromagnetic waves in vacua and propagation through continuous media, gauge transformations, Lorentz covariant formulation of electrodynamics, energy-momentum of electromagnetic field and Poynting's theorem, Lagrangian and Hamiltonian formulation of electrodynamics;

3. *Radiation Theory :*

   Advanced and retarded Green functions, Lienard-Wiechert potentials, dipole radiation and Larmor's formula, spectral resolution and angular distribution of radiation from a relativistic point charge, synchrotron radiation, Rayleigh and Thomson scattering;

4. *Classical Electron Theory :*

   Radiation reaction, acausality and preacceleration, incompleteness of Maxwell electrodynamics;

Textbooks :

1. D. J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall, 1981.
2. L. Landau and E. Lifshitz, *The Classical Theory of Fields*, Pergamon, 1979.
3. J. D. Jackson, *Classical Electrodynamics*, Wiley Eastern, 1986.

14) Mathematical Methods I (three hours classwork per week, **6 credits**)

- *Linear Algebra:*

  Linear Vector spaces, Determinants & Matrices, Special matrices: orthogonal, hermitian, unitary, Eigenvalue problem: matrix diagonalization, Canonical Forms, Infinite-dimensional vector spaces: Hilbert space & Hermitian operators, Numerical solution of linear equations;

- *Complex Analysis:*

  Complex algebra, analytic functions, infinite sequences and series, tests of convergence, Weierstrass theorem, Taylor and Laurent series, classification of isolated singularities, poles & calculus of residues, contour integration, residue theorem and applications;

- *Di erential and Integral Equations:*

  Ordinary di erential equations, linear di erential equations up to second order, orthogonal polynomials and functions, Integral transforms: Laplace and Fourier transforms, partial di erential equations, classification of PDEs, Laplace and wave equations, boundary value problems, Special functions, Integral equations and Green functions, Ideas about nonlinear equations, Approximation methods: WKB approximation (at the level of Mathews-Walker);

Textbooks:

1. J Mathews and R L Walker, Mathematical Methods for Physicists, Benjamin, 1964;
2. G Arfken, Mathematical Methods for Physicists, Academic Press, 1995.

21) Quantum Mechanics II (four-and-half hours classwork per week, **9 credits**)

- *Quantum theory of identical particles:*

  Symmetrization of wave functions, Pauli's exclusion principle, Bosons and fermions, Spin-statistics theorem, Second quantization formalism, Quantum theory of many-electron atoms, Electron gas: application to solids;

- *Approximation methods:*

  WKB approximation, Variational methods, Absorption and stimulated emission of radiation;

- *Scattering theory:*

  Lipmann-Schwinger equation, Born approximation, Partial waves, The optical theorem, Determination of phase-shifts, Hard sphere scattering, Low energy scattering, Resonances;

- *Path integral approach to Quantum Mechanics:*

  Kernel of wave-packet evolution, Feynmann's approach, Examples of free particle and harmonic oscillator, Path-integral approach to spin systems, Aharonov-Bohm e ect, The adiabatic theorem, Berry's phase;

- *Relativistic Quantum Mechanics:*

  Dirac and Klein-Gordon equations and their solutions, Relativistic invariance, Space reflection and time reversal, Idea of spin, Helicity, Hydrogen atom, fine structure of spectral lines;

- *Phase-space description of Quantum Mechanics:*

  Coherent states, squeezed states and thermal states, Wigner's phase-space quasi-probability distribution, Glauber-Sudarshan's P-representation, Husimi distribution, Symplectic transformation and covariance matrix, Non-classical states of light;

- *Foundations of Quantum Mechanics:*

  Density operators formalism, Contradiction of Quantum Theory with local realism, The causality issue.

Textbooks:

1. C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics*, Vols. I and II, Wiley, 1970.
2. J. J. Sakurai, *Modern Quantum Mechanics*, Addisson Wesley, 1995.
3. Marlan O. Scully and M. Suhail Zubairy, *Quantum Optics*, Cambridge University Press, 1997.
4. W. Greiner, *Relativistic Quantum Mechanics: Wave Equations*, Springer, 1997.
5. Leslie E. Ballentine, *Quantum Mechanics: A Modern Development*, World Scientific, 1998.
6. S. D. Bjorken and J. D. Drell, *Relativistic Quantum Mechanics*,
   McGraw-Hill Science/Engineering/Math, 1998.

22) Classical Field Theory (three hours classwork per week, **6 credits**)

1. *Continuum Mechanics:*

   Coarse graining and continuum limit, The displacement field and strain tensor, The stress tensor and constitutive relations. Hooke's Law, The energy functional, Deformation of thin rods: Stretching, bending and torsion, Equations of motion. Elastic waves, Conservative systems, Lagrangian and Hamiltonian formalisms;

2. *Hydrodynamics:*

   The velocity and density fields. Continuity equation, Pascals Law and the stress tensor, Bernoullis principle, Euler equations. Gravity waves, Viscosity, Navier-Stokes equations. Boundary conditions, examples of flow, low Reynolds number flows, Stokes limit;

3. *Electrodynamics:*

   The electromagnetic field tensor and Bianchi identity, covariant charge density and current, action formalism for electrodynamics, Maxwell's equations and relativistic covariance, Wave solutions. Gauge invariance, Lagrangian and Hamiltonian formalism; [7 Lectures]

4. *Landau-Ginzburg theories:*

   Order parameter field, symmetry breaking, Noether theorem, mean-field theory, Gaussian fluctuations, Goldstone modes, generalized sti ness, topological defects, solitons, vortices, O(N) model, Abelian Higgs model (superconductivity);

5. *Gravitation:*

   Principle of equivalence, curvilinear coordinates, metric, connection, curvature tensor, energy-momentum tensor, Einstein equations;

Textbooks:

1. L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields*, Pergamon Press, 4th Edition, 1980.

2. G. Giachetta, L. Mangiarotti and G. Sardanashvily, *Advanced Classical Field Theory*, World Scientific, 2009.

23) Condensed Matter Physics I (four-and-half hours classwork per week, **9 credits**)

- *Introduction:*

  Length, time and energy scales in condensed matter, soft and hard condensed matter, examples of materials properties, bonding and interactions, van der Waals interaction, hydrogen bonding;

- *Condensed matter systems:*

  Crystals: Lattice, basis, 2-d and 3-d crystals, point and space groups, symmetries, experimental determination of structure, scattering, lattice with basis, Miller indices, structure factor, form factors, defects in crystals;

  Liquids and glasses, Liquid crystals, Polymers, Quasicrystals;

- *Electronic Properties:*

  Jhelium model: Single electron model, density of states, Fermi surface and quasiparticles;

  Thermodynamic properties: Review of thermodynamics, statistical mechanics of non-interacting electrons, Sommerfeld expansion, specific heat, magnetic susceptibility;

  Transport properties: Drude Model, electrical conductivity, thermal conductivity thermoelectric phenomena. Band theory;

  Electrons in periodic potentials, Bloch's theorem, Kronig-Penney model, Brillouin zones, nearly free and tightly bound electrons, Fermi surfaces, band theory, e ective mass, Wannier functions and tight binding, survey of the periodic table;

- *Lattice vibrations:*

  Cohesion of solids, mechanical properties, elasticity, constitutive relations;

  Modes of lattice vibrations. Quantization and phonons. Statistical mechanics of phonon gas, Einstein and Debye models, umklapp processes, thermal expansion, Kohn anomalies, charge-density waves;

  Electron phonon interactions;

- *Semiconductor Physics:*

  Introduction: Valence and conduction bands. Doping and the Fermi level;

  Band diagrams, metal interfaces, work functions, Schottky barrier, diodes and transistors;

  Nano-electronics: heterostructures, quantum wells, quantum wires and quantum dots;

- *Optical Properties:*

  Optical properties of metals, optical properties of semiconductors, direct and indirect band gaps, polarization, Clausius-Mosotti relation, polarons, point defects and color centres, metals at low frequencies, anomalous skin e ect, plasmons, Brillouin and Raman scattering;

- *Superfluidity and Superconductivity:*

  Superfluidity of Helium, BEC, Landau argument, two-fluid model, BEC in atomic gases, superconductivity, phenomenology including Meissner e ect, type-I and type-II superconductors;

- *Magnetism:*

  Atomic magnetism, Hunds rules, Curie's law, Pauli paramagnetism, Landau diamagnetism, quantum mechanics of interacting moments, Heisenberg model, spin waves;

Textbooks:

1. N. Ashcroft and N. Mermin, *Solid State Physics*, Holt, Rinehart and Winston, 1976.

24) Statistical Mechanics I (four-and-half hours classwork per week, **9 credits**)

1. *Fundamental principles :*

   Elements of probability theory, algebra and calculus of random variables, binomial, Poisson and Gaussian distributions, moments and cumulants of probability densities, the central limit theorem, the basic postulate of statistical mechanics, first discussion of ergodicity and mixing;

2. *Thermodynamics:*

   Macroscopic definition of thermodynamic variables, temperature, pressure, work and heat, the Carnot cycle and empirical definition of entropy, free energy and other thermodynamic potentials, convexity of entropy and thermodynamic potentials, thermodynamic potentials as Legendre transforms of the entropy, thermodynamic relations of Maxwell, Gibbs and Duhem, Clausius and Clapeyron, and Clausius and Mosotti, the third law of thermodynamics;

3. *The Gibbs distribution:*

   Gibbs definition of entropy, the Gibbs distribution as maximisation of entropy subject to constraints, connection with Legendre transforms, connection to thermodynamics, the three canonical distributions, the Maxwell-Boltzmann distribution, the probability distribution of a classical and quantum harmonic oscillator;

4. *Non-interacting systems I:*

   Classical ideal gas, the Boltzmann distribution and classical statistics, the counting approach to the Boltzmann distribution, free energy and equation of state of the ideal gas, the law of equipartition, ideal gases with internal degrees of freedom, diatomic and polyatomic gases, the magnetism of an ideal gas;

5. *Non-interacting systems II:*

   Fermi distribution, Bose distribution, counting approach to Fermi and Bose distributions, Fermi and Bose gases of elementary particles, the degenerate electron gas, the specific heat of the degenerate electron gas, magnetism of an electron gas, the degenerate Bose gas, black body radiation;

6. *Non-interacting systems III:*

   Solids at high temperature and the Dulong-Petit law, solids at low temperatures and Einstein's theory of specific heat, the Debye interpolation formula, thermal expansion of solids;

7. *Interacting systems I :*

   Deviations of gases from ideality, van der Waals equation, the conditions of phase equilibrium, the Clausius-Clapeyron equation, the critical point, law of corresponding states, virial and cluster expansions, the method of correlation functions, the Ornstein-Zernike relation;

Textbooks:

1. L. D. Landau and E. M. Lifshitz, *Statistical Physics*, 3rd Edition, Butterworth-Heinmann, 1980.
2. H. B. Callen, *Thermodynamics and an Introduction to Thermo-statistics*, 2nd Edition, Wiley, 1985.
3. D. Chandler, *Introduction to Modern Statistical Mechanics*, Oxford Univ. Press, 1987.
4. M. Plischke and B. Bergersen, *Equilibrium Statistical Mechanics*, World Scientific, 1994.
5. R. K. Pathria, *Statistical Mechanics*, Butterworth-Heinmann, 1996.
6. M. Kardar, *Statistical Mechanics of Particles*, Cambridge Univ. Press, 2007.
7. F. Reif, *Fundamentals of Statistical and Thermal Physics*, Waveland Pr. Inc., 2008.

31) Quantum Field Theory I (four-and-half hours classwork per week, **9 credits**)

First two-third portion of the course is meant for all students, while a bifurcation is made at the end of this for separately orienting students towards HEP and LEP, during the remaining one-third portion of the course. Thus the common section has 32 lectures, the other two parts have 16 to 18 lectures.

1. *QFT I part I:*

   (Common to all students. Knowledge of Relativistic Quantum Mechanics, *i.e.*, Dirac equation and KG equation is expected. Some basic notions of the Lorentz group and Poincare group are also expected)

   - *Elements of Classical Field theory:*
     Lagrangian and Hamiltonian densities, quantization of KG and Dirac and electromagnetic fields, propagators for KG, Dirac and vector (photons) ;
   - *Perturbation theory:*
     Wick's theorem and Wick expansion, Feynman diagrams, cross sections and S matrix. Feynman rules for scalars, spinors and gauge fields (Abelian) ;
   - *Elementary processes in QED:*
     electron positron annihilation, Compton scattering, Bhabha scattering, crossing symmetry etc. ;
   - *Radiative corrections for scalar theory:*
     loop corrections, regularization and renormalization, dimensional regularization. elementary ideas of the systematics of renormalization ;
   - *Functional method techniques:*
     Scalar field theory quantization (with, if time permits, some discussion of critical phenomena in this approach) ;
     The last two lectures below while not relativistic QFT is included because i would be useful for HEP students too and hence is placed in the common section
   - *Non-interacting electrons:*
     Tight binding models, the many body ground state, quasi-particle and quasi-hole excitations. Partially filled bands and Fermi surface kinematics ;

2. *QFT 1 part II:* (For HEP students)

   - *LSZ formalism:*
     one loop diagrams in QED, Ward Takahashi identities, regularization in QED ;
   - *Path integral/Functional method*
     Quantization in spinor and vector (gauge) theories ;
   - *Systematics of renormalization:*
     Power counting, idea of counter terms, structure of one loop and beyond in scalar and QED. (no explicit 2 loop calculations etc.) ;

3. *QFT I part III:* (Many Body Theory for Condensed Matter/LEP students)

   - *Second quantization in operator formalism (non-relativistic):*
     Diagrammatic perturbation theory, Retarded Greens functions, Spectral function, quasi-particle lifetimes, Angle resolved photoemission spectroscopy (ARPES) ;
   - *Linear response theory and Kubo formulae ;*
   - *Interacting bosons:*
     Symmetry breaking, semi-classical spectrum. Applications to cold atoms and superfluids ;
   - *Mean field theory:*
     BCS hamiltonian and superconductivity ;
   - *Magnetism:*
     Heisenberg models. Spin waves. Coherent states and path integrals for spin systems. Non-linear sigma models ;

Part II and part III will run concurrently, however, to allow the more enterprising and interested students to attend both parts (if they so wish), lectures for these two parts are intended to be arranged at non-overlapping times.

Textbooks:

1. M. E. Peskin and D. V. Schroyder, *Quantum Field Theory*, Sarat Book House, 2005.
2. G. D. Mahan, *Many-Particle Physics*, Springer, 2010.

32) Mathematical Methods II (three hours classwork per week, **6 credits**)

- *Numerical interpolation techniques (including Lagrange method)*
- *Advanced Complex Analysis:*

  Analytic continuation, branch cuts, Multivalued functions, Riemann surfaces, Conformal Mapping, Method of steepest descent;
- *Group theory:*

  Discrete and continuous groups;
- *Numerical methods:*

  Numerical solution of integrals, Numerical solution of ODEs, Numerical solution of PDEs: finite di erence Monte Carlo method (especially solving integrals), Spectral techniques (including FFT) Numerical minimization techniques;
- *Probability and statistics:*

  Brief survey of probability theory and statistical distributions, Bayesian probability Data analysis;

Textbooks:

1. C. M. Bender and S. A. Orszag, *Advanced Mathematical Methods for Scientists and Engineers: Asymptotic Methods and Perturbation Theory* (vol. 1), Springer, 1999.
2. T. W. Gamelin, *Complex Analysis*, Springer, 2001.
3. E. T. Jaynes and G. L. Bretthorst, *Probability Theory: The Logic of Science* (vol. 1), Cambridge Univ. Press, 2003.
4. M. Tinkham, *Group Theory and Quantum Mechanics*, Dover, 2003.
5. R. Gilmore, *Lie Groups, Lie Algebras, and Some of Their Applications*, Dover, 2006.
6. J. H. Mathews and R. W. Howell, *Complex Analysis for Mathematics and Engineers*, Jones and Bartlett, 2006.
7. N. G. Van Kampen, *Stochastic Process in Physics and Chemistry*, 3rd Edition, North Holland, 2007.

33) Statistical Mechanics II (four-and-half hours classwork per week, **9 credits**)

- *Introduction to critical phenomena:*

  Survey of experimental results, scaling hypothesis and empirical scaling relations, self-similarity and fractals;

- *Interacting systems:*

  Critical phenomena and continuous phase transitions, symmetry and the order parameter, Landau theory, introduction to the Ising model, Curie-Weiss mean field theory, the absence of phase transitions in one dimension;

- *Criticality in spin systems:*

  The Ising model in one dimensions, solution using transfer matrices, the lack of phase transitions in one dimensions, the Landau-Peirls argument. The Ising model in two dimensions, Wannier's calculation of the critical temperature, mean field solutions of the Ising model, survey of principle results of Onsager's exact solution;

- *Criticality in classical field theories:*

  Landau-Ginzburg theory, the Landau-Ginzburg functional as an e ective Hamiltonian, calculation of correlation functions, exponents and thermodynamic quantities, mean field and RPA closures, the problem of divergences;

- *Introduction to the renormalisation group:*

  Historical survey, integration of short-wavelength degrees of freedom, classification of fixed points, flow equations, illustration with Kadano block spins in the 1d Ising model;

- *perturbative renormalisation in momentum space:*

  Philosophy of the perturbative RG scheme, significance of the upper critical dimension, diagrammatic expansion in momentum space, the expansion, exponents and thermodynamic quantities in powers of , comparison with mean field approximations;

- *Non-perturbative renormalisation in real space:*

  Kadano block spins, techniques of approximate non-perturbative renormalisation, numerical renormalisation in the Ising model;

- *Broken Symmetry:*

  Continuous symmetry groups and e ective Hamiltonians, the consequences of broken symmetry, Goldstone modes and fluctuations, elastic variables, topological defects, fluctuation destruction of long-range order, the Mermin-Wagner and Landau-Peirles arguments, the disclination and dislocation unbinding transitions;

- *Disorder:*

  Disorder in physical systems, quenched and annealed disorder, the Parisi solution for quenched disorder, illustrative examples;

- *Dynamics of fluctuations:*

  Linear response in physical systems, the regression of fluctuations and Onsager's hypothesis, symmetry of kinetic coefficients, the Fokker-Planck and Langevin descriptions of fluctuations, the fluctuation-dissipation theorem;

Textbooks:

1. L. D. Landau and E. M. Lifshitz, *Statistical Physics*, 3rd Edition, Butterworth-Heinmann, 1980.
2. H. E. Stanley, *Introduction to Phase Transitions and Critical Phenomena*, Oxford Univ. Press, 1987.
3. D. Chandler, *Introduction to Modern Statistical Mechanics*, Oxford Univ. Press, 1987.
4. M. Plischke and B. Bergersen, *Equilibrium Statistical Mechanics*, World Scientific, 1994.
5. R. K. Pathria, *Statistical Mechanics*, Butterworth-Heinmann, 1996.
6. S.-k. Ma, *Modern Theory of Critical Phenomena*, Westview Press, 2000.
7. P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics*, Cambridge Univ. Press, 2000.

34) Particle Physics I (three hours classwork per week, **6 credits**)

Standard Model, Part I:

- *Symmetries and Quarks*:

  Discrete symmetries, isospin-SU(2), G-parity, SU(3)-classification of mesons and baryons, mass formula, magnetic moments, motivation for colour as an internal symmetry;

- *Scattering Processes*:

  Relativistic kinematics, phase space, lifetimes and cross-sections, Golden rule; scattering of a spinless charged particle by electromagnetic field, scattering of electrons by electromagnetic field, $e \quad \mu$ scattering, Moller scattering, electron-proton scattering and form factors, higher order corrections, vacuum polarization, charge renormalization, Lamb shift, $g \quad 2$;

- *Parton Model and QCD*:

  Deep inelastic scattering (DIS) of electrons on nucleons, structure functions and scale invariance, parton model; quantum chromodynamics : Lagrangian, symmetries;

Standard Model, Part II:

- *Early Developments*:

  Beta-decay, μ-decay, parity violation, $V \quad A$ theory of weak interactions, conserved vector current (CVC) hypothesis;

- Strange particle decay, mixing of neutral K-mesons, Cabibbo theory, current-current interaction, PCAC and current algebra;

- *CP Problem*:

  C,P,T transformations, CP violation;

- *Electro-Weak Unified Theory*:

  Spontaneous symmetry breaking, Higgs mechanism, $SU(2) \times U(1)$ theory, electroweak unification, neutral current phenomena, W,Z bosons;

- *Current Phenomenology*:

  New flavours, KM-matrix and associated phenomenology, neutrinos, masses and mixing, neutrino oscillations.

Textbooks:

1. T. D. Lee, *Particle Physics and Field Theory*, Harwood, 1981.
2. F. Halzen, A.D. Martin, *Quarks and Leptons*, Wiley, 1984.

41) Quantum Field Theory II (four-and-half hours classwork per week, **9 credits**)

- *Functional Methods in Quantum Field Theory*:

  Quantization of the Klein-Gordon and Dirac fields and their interactions, derivation of the Feynman rules of covariant perturbation theory, quantization of the Maxwell field, issues of gauge fixing, BRST invariance and QED Ward identities;

- *Functional Integral Quantization of Non-abelian Gauge fields*:

  Faddeev-Popov method of gauge fixing, BRST invariance and Slavnov-Taylor identities, Gribov ambiguities, loop computations in non-abelian gauge theories and renormalizability;

- *Renormalization Group and its Applications*:

  The Gell-Mann, Low and Wilson approaches to the renormalization group, Callan-Symanzik equations and fixed points of the beta function, asymptotic freedom of non-abelian gauge theories, applications to perturbative QCD;

- *Anomalies in Abelian and Non-abelian Gauge Theories*:

  The axial vector anomaly in QED and its implications, non-abelian anomalies, anomaly freedom vs renormalizability and unitarity, Fujikawa's approach to anomalies;

- *Topological Solutions*:

  Soliton solutions and their implications, Polyakov-'t Hooft magnetic monopole and the BPS limit, instantons and tunneling in quantum field theory;

Textbooks:

1. S. Coleman, *Aspects of Symmetry*, Cambridge University Press, 1985.

2. R. Rajaraman, *Solitons and Instantons*, Elsevier, 1986.

3. M. Peskin and D. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley, New York, 1995.

4. S. Weinberg, *Quantum Theory of Fields*, Vols. I and II, Cambridge University Press, 1996.

42a) Cosmology and Gravitation (four-and-half hours classwork per week, **9 credits**)

- Principle of relativity, principle of equivalence, tensors, tensor calculus on Riemannian manifolds, symmetries of Riemannian manifolds, hypersurfaces, extrinsic curvatures, Gauss-Codazzi equations;
- *Einstein's field equations:*

  Newtonian limit, tests of general relativity, gravitational radiation;
- *Solutions of Einstein's equations :*

  Schwarzschild solution, Kerr solution, black holes;
- Tetrad formulation of gravity, generalizations to arbitrary dimensions;
- *Hamiltonian formulation :*

  For metric gravity, for tetrad formulation, canonical quantization and path integral quantization;
- Cosmology : Robertson-Walker model, early universe;
- Singularity theorems;

Textbooks:

1. S. Weinberg, *Gravitation and Cosmology*, Wiley, 1972.
2. R. Wald, *General Relativity*, Chicago, 1987.

42b) Particle Physics II (four-and-half hours classwork per week, **9 credits**)

- *Basic Ingredients of the Standard Model*:

  Yang-Mills fields, Higgs mechanism, asymptotic freedom;

- *Electroweak Sector*:

  Weinberg-Salam Model, phenomenological consequences, families and flavours, anomaly cancellations, radiative corrections and precession tests;

- *Quantum Chromodynamics (QCD)*:

  Lagrangian, perturbative QCD, Altarelli-Parisi equations, nonperturbative QCD and colour confinement models, strong CP problem, chiral perturbation theory, heavy quark e ective theory, Skyrme model;

- *Neutrino Physics*:

  Solar neutrinos, double beta decay, neutrino masses and mixing models;

- *CP Violation*:

  CP violation in $K \quad \bar{K}$ system, $B \quad \bar{B}$ system, models of CP violation;

- *Supersymmetry*:

  Hierarchy problem, construction of the supersymmetric standard model, search for SUSY signals;

- *Other Approaches beyond the Standard Model*:

  Grand unified theories;

Textbooks:

1. T Cheng and L. Li, *Gauge Theory of Elementary Particles*, Oxford University Press, 1984.

43) Advanced Condensed Matter Physics (four-and-half hours classwork per week, **9 credits**)

- *Correlated Electron Physics:* Second quantization review, Hubbard model, Heisenberg model;

  Materials phenomenology, magnetic phases, CDW states;

  Quantum magnetism, Stoner criterion, double exchange;

  Superconductivity, Cooper argument, BCS, gap equation, Bogoliubov-de Gennes equations, strong coupling theory, RVB and modern approaches to superconductivity in correlated systems;

  Quantum Hall e ect, integer and fractional, edge states, Laughlin and Jain wave functions, topological defects; Luttinger liquids, Bethe ansatz;

  Mesoscopic physics;

  Disordered electronic systems and metal insulator transitions;

- *Soft Condensed Matter Physics* Interactions in soft matter, entropic interactions, fluctuation-induced interactions, hard sphere statistical mechanics and crystallization;

  Self-assembly of amphiphiles, phases, theoretical approaches;

  Colloids, self-assembly, the freezing transition;

  Polymers, polymer structure, self-avoidance, Edwards model, osmotic pressure, Flory-Huggins theory, screening, semi-flexibility, persistence length;

  Membranes, biological membranes, lipid bilayers, physical properties, de Gennes-Taupin length, tethered membranes;

  Liquid crystals, nematic, cholesteric and smectic, order parameters, Frank free energy, Landau-de Gennes model defects, defect phases;

  Survey of hydrodynamics, hydrodynamic approaches to soft matter physics, dynamical properties of polymers, membranes, colloids;

  Soft matter away from equilibrium, shear-induced phases;

  Optional: Granular media and Glasses;

Textbooks: <u>For Strongly Correlated Systems:-</u>

1. M. P. Marder, *Condensed Matter Physics*, Wiley-Interscience, 2000.
2. A. Altland and B. Simons, *Condensed Matter Field Theory*, Cambridge University Press, 2006.
3. G. D. Mahan, *Many-Particle Physics*, Springer, 2010.

<u>For Soft Condensed Matter:-</u>

1. P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics*, 1st Edition, Cambridge University Press, 2000.

44a) Quantum Information and Computation (four-and-half hours classwork per week, **9 credits**)

- *Resume of Quantum Mechanics:*

  Composite quantum systems and tensor product Hilbert spaces, Subsystems and density operators, From Schrödinger to Liouville evolution; completely positive maps as quantum channels; From projective measurements to POVMs; State estimation;

- *Entanglement and its applications:*

  EPR argument and Bell inequalities; Separability vs. entanglement; Positive unphysical maps witnessing entanglement; Partial transpose criterion for checking separability; Other entanglement detection criteria; Multi-partite entanglement; Quantum teleportation, dense coding, entanglement swapping;

- *Connection with Shannon information theory:*

  Shannon's noiseless coding theorem and Schumacher's quantum counterpart; Accessible information and Holevo's bound; Shannon's noisy channel coding theorem and HSW theorem; Quantum channel capacities; Decoherence and quantum error correction;

- *Measures of entanglement:*

  Thermodynamic considerations of entanglement under LOCC; Entanglement concentration and dilution; Several measures of entanglement; Majorization;

- *Quantum Cryptography:*

  Basics of classical cryptography; RSA cryptosystem; Quantum key distribution; Security of quantum key distribution;

- *Entanglement in continuous variable systems:*

  Gaussian states; Role of Wingner description and symplectic transformations; Quantum information processing with continuous variable systems;

- *Quantum computation:*

  Classical and quantum computers; Circuit complexity; One- and two-qubit gates; Universality of gates; Deutsch-Jozsa algorithm; Grover's search algorithm; Quantum Fourier transform and Shor's factorization algorithm;

- *Implementations:*

  Quantum key distribution experiments; Unconditional quantum teleportation using continuous variable systems; Implementations of quantum computers using NMR, trapped ions, Josephson junctions, linear optical devices, etc.;

Recommended readings:

1. *Quantum Computation and Information*, Michael A. Nielsen and Issac L. Chuang (Cambridge University Press, 2000);

2. John Preskill's Lectures on Quantum Information and Computation, available at: http://theory.caltech.edu/people/preskill/ph229/♯lecture;

3. David Mermin's Lectures on Quantum Computation, available at: http://people.ccmr.cornell.edu/ mermin/qcomp/CS483.html;

4. *The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation*, Dik Bouwmeester, Artur Ekert, Anton Zeilinger (eds.) (Springer, 2000);

5. *Elements of Information Theory*, Thomas M. Cover and Joy A. Thomas (John Wiley & Sons, 1999);

6. Contemporary review articles available at:- http://xxx.imsc.res.in/archive/quant-ph

44b) Nonlinear Dynamics (four-and-half hours classwork per week, **9 credits**)

- *Hamiltonian formulation*:

  Iterative maps, fixed points, Lyapunov exponents, Integrable systems, Perturbed integrable systems, Poincaré-Birkho construction (illustration with driven pendulum);

- *Deterministic Nonlinear Dynamics*:

  Discrete dynamics and maps, di erentiable dynamics: dissipative systems, non-dissipative systems, Hamiltonian systems;

- *Integrability Aspects of Hamiltonian Dynamics*:

  Liouville-Arnold theorem, KAM theory;

- *Chaos*:

  In discrete dynamical systems, in Hamiltonian systems, in dissipative systems;

- *Semiclassical Analysis*:

  Berry-Tabor theory, Gutzwiller Theory;

- *Quantum Aspects.*

Textbook:

1. M. Tabor, *Chaos and Integrability in Nonlinear Dynamics*, Wiley, 1989.
2. M. C. Gutzwiller, *Chaos in Classical and QUantum Mechanics*, Springer, 1990.
3. I. Percival and D. Richards, *Introduction to Dynamics*, Cambridge, 1991.
4. L. Reichl, *A Modern Course in Statistical Physics*, Wiley, 1998.
5. S.H. Strogatz, *Nonlinear dynamics and Chaos: Applications to Physics, Biology, Chemistry and Engineering*, Cambridge, 2001.
6. M. Lakshmanan and S. Rajasekar, *Nonlinear Dynamics*, Springer, 2003.
7. L. Reichl, *The transition to Chaos*, Springer, 2004.

44c) Statistical Field Theory (four-and-half hours classwork per week, **9 credits**)

- Review of quantum statistical mechanics, functional integration representation of partition function, scalar field, charged scalars and Bose-Einstein condensation, Fermions, interactions and diagrammatic techniques, self-coupled scalar field theory, Yukawa theory, QED, renormalization and loop corrections to $\ln Z$.
- Spontaneous symmetry breaking and Higgs model QCD, deconfinement phase transitions.
- Salem-Weinberg model and symmetry restoration, early universe, nuclear matter and pion condensates, neutron stars.

Textbook:

1. P. Kapusta, *Finite Temperature Field Theory*, Cambridge University Press, 1989.

Courses of Study
For PhD Program

SCHOOL OF PHYSICAL SCIENCES

Ph.D. in Physical Science
(Program Code: PHYS04)

National Institute of Science Education and Research Bhubaneswar

(An Off-Campus Center

Of

Homi Bhabha National Institute – a deemed to be University, Anushkati Nagar, Mumbai)

With effect from the Academic Year 2018

School of Physical Sciences Ph. D course structure (60 credits)

Core courses				
Sl. No	Course code	Course title/Description	Contact hours/week (Lectures + Tutorial + Lab)	Credits
		Courses in odd semester		
1	P601	Classical Mechanics	3+1+0	6
2	P602	Mathematical Methods	3+1+0	6
3	P603	Electromagnetism	3+1+0	6
4	P698	Self Study/Mini project/credit seminar (One part of this will involve attending lectures of an elective course)		12
		Courses in even semester		
5	P614	Statistical Mechanics	3+1+0	6
6	P615	Quantum Mechanics	3+1+0	6
7		Any elective course from list below	3+1+0	6
8	P699	Mini Project		12

Elective courses				
Sl. No	Course code	Course title/Description	Contact hours/week (Lectures + Tutorial + Lab)	Credits
1	P648	Nuclei and Particle Physics	3+1+0	6
2	P649	Atoms Molecules and Radiation	3+1+0	6
3	P650	Introduction to Condensed Matter Physics	3+1+0	6
4	P651	Advanced Solid State Physics	3+1+0	6
5	P652	Computational Physics	3+1+0	6
6	P653	Quantum Field Theory I	3+1+0	6
7	P654	Particle Physics	3+1+0	6

8	P655	Introduction to Phase transitions and Critical phenomena	3+1+0	6
9	P656	Nonlinear Optics and Lasers	3+1+0	6
10	P657	General Relativity and Cosmology	3+1+0	6
11	P658	Soft Condensed Matter	3+1+0	6
12	P659	Applied Nuclear Physics	3+1+0	6
13	P660	Many Particle Physics	3+1+0	6
14	P661	Physics of Mesoscopic Systems	3+1+0	6
15	P662	Introduction to Quantum Optics	3+1+0	6
16	P663	Astronomy and Astrophysics	3+1+0	6
17	P664	Plasma Physics and Magnetohydrodynamics	3+1+0	6
18	P665	Biophysics	3+1+0	6
19	P666	Quantum Nanoelectronics	3+1+0	6
20	P667	Nonlinear Physics, Chaos and Turbulence	3+1+0	6
21	P668	Magnetism and Superconductivity	3+1+0	6
22	P669	Density Functional Theory of Atoms, Molecules and Solids	3+1+0	6
23	P670	Quantum Field Theory II	3+1+0	6
24	P671	Quantum Information and Quantum computation	3+1+0	6
25	P672	Experimental High Energy Physics	3+1+0	6
26	P673	Experimental Techniques	3+1+0	6
27	P674	Introduction to Cosmology	3+1+0	6

1 Core courses

P601: Classical Mechanics

1. Generalized coordinates, velocities and momenta, Lagranges formulation
2. Principle of least action, formulation by Maupertuis, Euler, Hamilton. Liouville's theorem
3. Two-body central force problem (reduced mass), planet orbits, Virial theorem
4. Collisions and scattering, CM and Lab frames, scattering cross section
5. Motion in non-inertial frames, Coriolis force
6. Hamilton's equations, Poisson brackets
7. Canonical transformations, Hamilton-Jacobi equation, Generating functions, Symmetries and conservation laws
8. Small oscillations, Normal modes.
9. Rigid body dynamics, Euler angles, Euler equations, rotation of a top
10. Special topics : nonlinear oscillators, non-linear dynamics, Lyapunov exponents, Introduction to chaos.

References:

1. Classical Mechanics, H. Goldstein
2. Mecanics - Landau and Lifshitz
3. Classical Mechanics - John R Taylor
4. Classical dynamics of particles and systems - Marion and Thornton
5. Introduction to dynamics - Percival and Richards

P602: Mathematical Methods

1. Vectors and Tensors (index notation, vector analysis in curvilinear coordinates, Cartersian tensors and four vectors, General tensors)
2. Review of Linear Algebra with emphasis on applications to physical problems (linear transformations + Matrix representations, Eigenvalues, Eigenvectors, Inner product spaces
3. Review of complex analysis with applications (Cauchy-Riemann equations, Complex integration, Cauchy theorems, Contour integration, Branch points and branch cuts, Applications to integrals, series etc)
4. Hilbert space methods, special functions (Hilbert space, Orthonormal series expansions in Hilbert space especially Fourier series, Special functions)
5. Ordinary and Partial differential equations (Analysis of second order OFEs Sturm-Liouville system, Boundary value problems for Laplace, Diffusion(Heat) and wave equations)
6. Integral Transforms, its applications and Generalized functions (Laplace and Fourier transform, Dirac delta and other generalized functions, Greens functions of ODE and PDE)
7. Group theory (introduction using various groups occurring in physics, its algebra, Representation of groups, Characters)

References:

1. Mathematical Methods in the Physical Sciences, M. L. Boas
2. Mathematical Methods for Physicists, Arfken and Weber
3. Mathematical methods, C. Harper
4. Mathematical method for physicists, T. L. Chow
5. Mathematical methods in science and engineering (2books) - Seluk Bayin
6. Mathematical Methods in Physics and Engineering :Riley, Hobson
7. Mathematical Physics I and II: S.D. Joglekar
8. Mathematical Methods for Engineers and Physicists (3 books) -K. T. Tang
9. Graduate Mathematical Physics - James J. Kelly
10. Mathematical Methods In Classical And Quantum Physics : Tulsi Dass

P603: Electromagnetism

1. Electrostatics in vacuum, force, field, potentials and energy
2. Electrostatic boundary conditions and conductors
3. Solution of Laplace's equation in one, two and three dimensions, uniqueness theorem, methods of images, separation of variables, multipole expansion
4. Dielectrics
5. Current distributions, magnetic fields and magnetostatic boundary conditions
6. Motion of charges in electric and magnetic fields, energy and momentum of electromagnetic fields
7. Maxwell's equations, EM waves and their propagation in free space and in media
8. Potential formulation, Coulomb and Lorentz gauge, radiation from an accelerated charge, dipole radiation Special topics : Diffraction theory, polarization.

References:

1. Introduction to electrodynamics - David Griffiths
2. Foundations of electromagnetic theory - Reitz, Milford, Christy
3. Classical electrodynamics - J. D. Jackson
4. Electricity and Magnetism - M. H. Nayfeh, M. K. Brussel

P614: Statistical Mechanics

1. Review of thermodynamics, thermodynamic potentials, thermodynamic equilibrium and stability
2. Probability theory: Probability densities, cumulants and correlations, central limit theorem, laws of large numbers
3. Gibbs distribution : Ensembles, classical and quantum free particles, systems with continuous and discrete spectrum, degenerate Fermi systems, Bose condensation
4. Interacting systems: Cluster and Virial expansions, radial distribution function
5. Introduction to response, fluctuation and noise, Einstein formula
6. Phase transition : phenomenology of first order and continuous phase transitions, order parameters, 1D Ising model, universality and scaling, Ginzburg- Landau- Wilson theory, spontaneous symmetry breaking
7. Fundamentals of statistical mechanics: phase space, Liouville theorem, statistical distribution theorem
8. Brownian motion, Langevin equation, Markov processes and Fokker Planck equation

References:

1. Introduction to Statistical Mechanics - Kerson Huang
2. Statistical Physics - Reif
3. Statistical Physics of particles - M. Kardar
4. Introduction to Phase transitions and critical phenomena - H. E. Stanley

P615: Quantum Mechanics

1. Hilbert space (states, operators, evolution)
2. Review of one dimensional problems, delta and periodic potentials, Bound states vs scattering states, Simple harmonic oscillator
3. The central force problem, review of the hydrogen atom, hard and soft sphere
4. Angular momentum, rotation operators and the rotation group, spin, spherical harmmonics, addition of angular momentum.
5. Symmetries in quantum mechanics
6. Introduction to path integrals
7. Time independent perturbation theory, WKB approximation, variational method, Zeeman and Stark effects
8. Identical particles and exchange statistics
9. Time dependent perturbation theory, Heisenberg and interaction representations, Rabi Oscillations
10. Basic aspects of scattering theory : Born approximation and partial waves and phase shifts

    Special topics: Dirac equation/semi classical theory of radiation/geometric phase (a subset of these topics depending on available time)

References:

1. Principles of Quantum Mechanics - R. Shankar
2. Quantum Mechanics I and II - Cohen-Tannoudji, Diu and Laloe
3. Modern Quantum Mechanics - J. J. Sakurai
4. Introduction to Quantum Mechanics - David Griffiths
5. Quantum Physics - S. Gasiorowicz
6. Quantum Mechanics - E. Merzbacher
7. Quantum Mechanics - Bransden and Joachain
8. Introductory Quantum Mechanics - R. Liboff

2 Elective Courses

P648: Nuclei and Particle Physics

1. Nuclear systematics and stability (masses, sizes, spins, magnetic moments, quadrupole moments, energetics and stability against particle emission, beta decay).
2. Nucleon-Nucleon interaction, space-time symmetries, conservation laws, isospin symmetry, low energy (effective range, shape independence, meson exchange picture (qualitative).
3. Liquid drop model, compound nucleus and fission, nuclear vibrations and rotations.
4. Shell model, introduction to Hartree-Fock, spins and magnetic moments.
5. Direct nuclear reactions.
6. Mesons and baryons, resonances, SU(3) classification, isospin and strangeness, quark model, colour.
7. Weak interactions (nuclear and particle decays, neutrinos etc).

References:

1. Introduction to Nuclear Physics - Roy and Nigam
2. Nuclear Physics - Preston and Bhaduri
3. Introduction to particle physics - Griffith
4. Introduction to particle physics - Perkins

P649: Atoms, Molecules and Radiation

1. Hydrogen atom including l.s coupling and hyperfine interaction.
2. Helium atom introduction to exchange and correlation; variational calculation of ground and excited-states.
3. Introduction to the idea of effective potentials for electrons in many-electron atoms (Hartree theory and idea of self-consistency); use of Clementi-Roetti wave-functions.
4. One-electron atomic systems in an electromagnetic field; dipole approximation and associated selection rules; Stark and Zeeman effect (Note: Instructor will have to introduce the students to time-dependent perturbation theory here).
5. Einsteins A and B coefficients, population inversion, laser action, derivation of A and B coefficients from semi-classical treatment of light-atom interaction.
6. Molecular formation: Discussion of atom-atom interaction, van der Waals force, ionic interaction and covalent bond.
7. Molecular structure: Hydrogen molecule MO and VB pictures; Importance of correlations.
8. Molecular spectra (restricted to two atom molecules) electronic, rotational and vibrational.
9. Some lectures left for interesting current topics.

References:

1. Elementary Atomic Structure - G.K. Woodgate
2. Atomic Physics: C.J. Foot
3. Atoms, molecules and Photons: W. Demtroder
4. The Theory of Atomic Spectra: Condon and Shortley
5. Topics in Atomic Physics: C.E. Butkhardt and J.L. Leventhal
6. Physics of Atoms and Molecules - B.H. Bransden and C.J. Joachain

P650: Introduction to Condensed Matter Physics

1. General introduction, Drude and Sommerfeld model.
2. Crystal structure; x-ray diffraction.
3. Cohesive energy.
4. Blochs theorem; Band theory nearly free electrons; tight binding approximation; semi-classical dynamics of electrons in a band, definition of metals and insulators.
5. Basic properties of Semiconductors.
6. Thermal properties of insulators, phonons.
7. Landau levels - de Hass van Alphen effect and Integer quantum hall effect.
8. Introduction to Magnetism.
9. Introduction to Superconductivity.

References:

1. Introduction to Solid-state Physics, C. Kittel
2. Solid-state physics, N. Ashcroft and N.D. Mermin,
3. Solid-state physics, Rosenberg
4. Solid sate physics, Burn
5. Oxford Series in Condensed Matter [Oxford university press]

P651: Advanced Solid State Physics

1. Introduction to physics of metals and insulators. Electrical, thermal and optical properties of metals and insulators, and need to study excitation spectrum in detail.
2. Electrons, phonons and Magnons, Screening and Plasma Oscillations
3. Charge impurity in a metal: Friedel Oscillation, Magnetic impurity in a metal,
4. moment formation and suppression in metals.
5. Electron gas in Low dimension: impurity and interaction effects.
6. Quantum Hall Effect
7. Metal-Insulator transition
8. Electron - phonon interaction, Frohlich Hamiltonian and Superconductivity.

References:

1. Advanced Solid State Physics: Philip Phillips
2. Elementary Excitations in Solids: D. Pines
3. Solid State Physics: Marder
4. Concepts in Solids: P.W. Anderson
5. Basic Notions in Condensed Matter: P.W. Anderson

P652: Computational Physics

1. Monte Carlo: Markov chain, Metropolis algorithm, Ising Model, Quantum Monte Carlo
2. Molecular Dynamics: Integration methods, extended ensembles, molecular systems
3. Variational methods for SchrodingerdEquation: Hartree and Hartee-Fock methods, Post HF methods
4. Density Functional Theory: Fundamental theorem, XC-potentials
5. Quantum Molecular dynamics: Carr-Parinello approach, hybrid QM/MM method
6. Computational methods for lattice field theories

References:

1. Computational Physics, Joseph Marie Thijssen, Cambridge University Press
2. An Introduction to Computational Physics, Tao Pang, Cambridge University Press
3. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids, Clarendon Press
4. D. P. Landau and K. Binder, A Guide to Monte Carlo Simulations in Statistical Physics, Cambridge University Press
5. M. Suzuki, editor, Quantum Monte Carlo Methods, Springer-Verlag
6. I. Prigogine and Stuart A. Rice, New Methods in Computational Quantum Mechanics, Wiley.
7. D. Frankel and B. Smit, Understanding Molecular Simulation, second edition, Academic Press.
8. Computational Methods in Field Theory, H. Gausterer and C.B. Lang, Ed.s, Lecture Notes in Physics 409
9. R. G. Parr and W. Yang, Density Functional theory of atoms and molecules
10. F. Jensen, Introduction to Computational Chemistry
11. C. J. Crammer, Essentials of computational chemistry

P653: Quantum Field Theory I

1. Relativistic quantum mechanics - Klein-Gordon equation, Dirac equation, free-particle solutions
2. Lagrangian formulation of Klein-Gordon, Dirac and Maxwell eqns, Symmetries (Noethers theorem), Gauge field, Actions
3. Canonical quantization of scalar and Dirac fields
4. Interacting fields - Heisenberg picture, perturbation theory, Wicks theorem, Feynman diagram
5. Cross-section and S-matrix
6. Quantization of gauge field, gauge fixing
7. QED and QED processes
8. Radiative corrections - self-energy, vacuum polarization, vertex correction
9. LSZ and optical theorem
10. Introduction to renormalization

References:

1. An Introduction to Quantum Field Theory - Peskin and Schroeder
2. Quantum Field theory: K. Huang
3. Quantum Field Theory: Mandl and Shaw
4. Quantum Field Theory: Itzykson and Zuber

P654: Particle Physics

1. Elementary particles, discrete symmetries and conservation laws.
2. Symmetries and Quarks.
3. Klein-Gordon equation, concept of antiparticle.
4. Lorentz symmetry and scalar / vector / spinor fields.
5. Dirac equation
6. Scattering processes of spin-1/2 particles (Feynmans rules as thumb rule QFT course), propagators.
7. Current-current interactions, weak interaction, Fermi theory.
8. Gauge symmetries, spontaneous symmetry breaking, Higgs mechanism
9. Electroweak interaction, Glashow-Salam-Weinberg model.
10. Intoduction to QCD, structure of hadrons (form factors, structure functions), parton model, Deep inelastic sattering.

References:

1. Quarks and Leptons: An Introductory Course in Modern Particle Physics - Francis Halzen, Alan D. Martin
2. Introduction to Elementary Particles, David Griffiths
3. An Introduction to Quantum Field Theory - Peskin and Schroeder

P655: Introduction to Phase transitions and Critical phenomena

Experimental evidences of classical and quantum critical phenomena, thermodynamic potentials. heat capacity, magnetic susceptibility, phases, phenomenol-ogy of 1st order phase transitions, continuous transitions, order parameters and models: Ising, XY, Heisenberg, uni-versality and scaling, Ginzburg-Landau-Wilson theory, spontaneous symmetry breaking. Bose-Einstein condensation,expansion around upper critical dimension, domain walls and surface tension, 1D Ising model and instantons, critical behavior, critical exponents, relations between critical exponents, Kadanoff scaling, universality conjecture, calculation of critical exponents: real space RG methods, Phi- 4 theory, 4- epsilon expansion.?RG of Wilson and Fisher, contin-uous symmetry: Mermin-Wagner theorem. Goldstone modes, non-linear sigma-model, vortices, Kosterlitz-Thouless phase transition, topology and duality, surface roughening and Sine-Gordon models, quantum critical phenomena,dissipative quantum tunneling, quantum phase transitions, Bose-Hubbard model.

References:

1. Introduction to Phase Transitions and Critical Phenomena by H. Eugene Stanley
2. A Modern Approach to Critical Phenomena by Igor Herbut
3. Statistical Physics: Statics, Dynamics and Renormalization by Leo P. Kadanoff
4. The Theory of Critical Phenomena by J. J. Binney, A. J. Fisher, M. E. J. Newman
5. Modern Theory of Critical Phenomena by Shang-keng Ma
6. Statistical Mechanics of Phase Transitions by J. Yeomans
7. Field Theory, the Renormalisation Group and Critical Phenomena by Daniel J. Amit

P656: Nonlinear Optics and Lasers

Introduction to general lasers and their types, emission, absorption processes and rate equations, Population inver- sion, gain, optical cavities, three- and four- level lasers, CW and pulsed lasers, Q-switching and mode-locking, Physics of gas discharge, Atomic, Ionic, molecular, liquid, and excimer lasers, optical pumping, Holography, overview of non- linear Optics, nonlinear polarization, Nonlinear optical susceptibility, Symmetry considerations, Wave Propagation in nonlinear media, electro optical and magneto optical effects, higher harmonic generations, Phase matching and quasi phase matching, Sum and difference frequency generation, Optical parametric amplification and oscillation, Kerr ef- fect, Cross-Phase Modulation, Self phase modulation, Multiphoton Processes , Self focusing, Four-Wave Mixing, Laser Spectroscopy, wavefront conjugation Stimulated Raman Scattering, Stimulated Brillouin Scattering, Optical solitons and Optical Pulse Compression

References:

1. Lasers by P.W. Milonni and J.H. Eberly, John Wiley and Sons
2. Lasers by A. E. Siegman, University Science Books
3. Principles of Lasers by Orazio Svelto, Springer Verlag
4. The principles of nonlinear optics by Y. R. Shen, John Wiley and Sons
5. Nonlinear Optics by Robert W. Boyd, Academic Press
6. Nonlinear Optics: Basic Concepts by D.L. Mills, Springer Verlag
7. Optical waves in crystals by Amnon Yariv and Pochi Yeh, Wiley-Interscience
8. Laser Spectroscopy by Wolfgang Demtrder, Springer Verlag

P657: General Relativity and Cosmology

1. Review of Newtonian Mechanics. Special theory of relativity. Prelude to General relativity, historical developments
2. 4-Vectors and 4-tensors, examples from physics
3. Principle of Equivalence, Equations of motion, Gravitational force
4. Tensor Analysis in Riemannian space, Effects of Gravitation, Riemann-Christoffel curvature tensor, Ricci Tensor, Curvature Scalar
5. Einstein Field Equations, Experimental tests of GT
6. Scwartzchild Solution, Gravitational lensing
7. Gravitational waves: generation and detection
8. Energy, momentum and angular momentum in Gravitation
9. Cosmological principle, Robertson-Walker metric, Redshifts
10. Big-Bang Hypothesis, CMB.
11. Issues in Quantum Gravity

References:

1. A first course in General Relativity- B. Schutz
2. Gravity: HJ. Hartle
3. The Classical Theory of Fields: Landau and Lifshitz
4. Gravitation and Cosmology: S. Weinberg
5. Introducing Einstein's Relativity: D'Inverno

P658: Soft Condensed Matter

1. Prerequisite: Introduction to condensed Matter Physics, Statistical Physics
2. What is Soft Condensed Matter: forces, energies and time scales.
3. Phase transition in soft matter, Radial distribution function and description of liquids.
4. Colloids Polymers Gels Liquid Crystals
5. Soft matter in nature

References:

1. Chaikin Lubensky Condensed Matter Physics
2. D. Goldstein: States of Matter
3. Chandler: Statistical Physics (OUP 1987)
4. R A L Jones: Soft Condensed Matter (O U P 2002)
5. Soft Matter Physics: Daoud and Williams (Springer 1999)

P659: Applied Nuclear Physics

1. Basis of Nuclear Structure and reactions
2. Radioactivity and radioactive decays
3. Passage of charged particle through matter
4. Detectors and Accelerators
5. Applications: Effects of radiation on biological systems and nuclear medicine, Industrial applications
6. Power from fission and fusion: Characteristics of fission, Nuclear reactors, Thermonuclear fusion

References:

1. Nuclear Physics : Principles and Applications, John Lilley
2. The Atomic Nucleus, R. D. Evans
3. Fundamentals of Nuclear Reactor Physics, Elmer Lewis, Academic Press
4. An introduction to the passage of energetic particles through matter, N. J. Caron
5. Accelerator Physics, Shyh-Yuan Lee, World Scientific

P660: Many Particle Physics

1. Prerequisite: Statistical Physics, Quantum Mechanics, Introduction to Condensed Matter Physics
2. Second Quantization, One and two body operators
3. Observables and their relationship to one and two body Greens functions
4. Thermodynamic potential, Spectral functions, Analytic properties of Green's functions
5. Linear Response, correlation function, sum rules
6. Canonical Transformation: Bogoliubov Valetin, Schrieffer Wolf, etc.
7. Equation of motion,
8. Diagrammatic Perturbation theory for Green function and thethermodynamic potential, Luttinger Ward Identities.
9. Mean field theory
10. Functional Integration Methods

References:

1. Lifshitz Pitaeviski (Landau Lifshitz Stat Phys Part II)
2. Rickeyzen Greens function for condensed Matter
3. Doniach and Sondhaimer Greens function for condensed Matter
4. Fetter Walecka: Quantum Theory of Man body Particle systems:
5. Ben Simon: Many Particle Physics
6. Basic Notions in Condensed Matter: P.W. Anderson
7. Techniques and application of Path-integration Plan: S. Schulman

P661: Physics of Mesoscopic Systems

1. Prerequisite: Quantum Mechanics1; Statistical Mechanics; Introduction to Condensed Matter Physics
2. Effects of magnetic fields: The AharonovBohm effect; 2D electron gas; Landau levels; Transverse modes in 2D quantum wire; Shubnikovde Haas oscillations; Magnetic edge states; Integer Quantum Hall effect, Fractional Quantum Hall effect
3. Electron transport: Boltzmann semiclassical transport; Onsager reciprocity relations; Conventional Hall effect; Drude conductivity; Einstein relation; Electronic states in quantum confined systems; Conductance from transmission; Ballistic transport; Quantum of conductance; Landauer formula; Quantum point contact; T .matrices; Smatrix and Green functions; Current operator; LandauerButtiker formalism; Linear response and Kubo formula; Nonequilibrium Green's function approach to transport; Scattering: BreitWigner resonance and Fano resonance; Delay time for resonances; Friedel sum rule; Levinson.s theorem; Singleelectron tunneling: Coulomb blockade and Kondo effect
4. Quantum Information: Josephson Junctions and Cubits; Metastable states and escape dynamics
5. Disordered conductors: Weak localization; Mesoscopic fluctuations; Random Matrices; Anderson localization; Quantum Chaos; Dephasing; Decoherence

References:

1. Electronic Transport in Mesoscopic Systems, S. Datta, Cambridge University press.
2. Introduction to Mesoscopic Physics, Y. Imry, Oxford University Press.
3. Mesoscopic Electronics in Solid State Nanostructures, T. Heinzel, WileyVCH.
4. Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations, P. Mello and N. kumar, Oxford University Press.

P662: Introduction to Quantum Optics

1. Prerequisite: Quantum Mechanics I & 2; Electromagnetism I
2. Electro-magnetic field quantization: Quantum fluctuation and Quadrature operators of a single mode field, Thermal fields, Vacuum fluctuation and zero point energy, Quantum phase
3. Coherent and squeezed states of radiation field: Properties and phase space picture of coherent state, Generation of a coherent state, Squeezed state physics, Generation and Detection of squeezed light, Schrodinger cat states, Multi-mode squeezing, Broadband squeezed light, Squeezing via non-linear process
4. Atom-field interaction: Rabi model (Semi-classical model for atom-field interaction), Jaynes-Cummings model (fully quantum mechanical model for atom-field interaction), Dressed states, Density operator approach, Hanle effect, Coherent trapping, electromagnetically induced transparency, Four wave mixing
5. Quantum coherence function: Photon detection and quantum coherence functions, First order coherence and Young.s type double source experiment, Second order coherence, Physics of Hanbury-Brown-Twiss effect, Experiments with single photon, Quantum mechanics of beam splitter, Interferometry with single photon
6. Optical test of quantum mechanics: Photon sources: spontaneous parametric down-conversion, Hong-Ou-Mandel Interferometer, Superluminal tunneling of photons, EPR paradox and optical test of Bell.s theorem
7. Atom Optics: Mechanical effects of light, Laser cooling, Atom interferometry, Atoms in cavity, Experimental realization of Jaynes-Cummings model
8. Heisenberg-limited interferometry and quantum information: Entanglement and interferometric measurements, Quantum teleportation, Quantum cryptography, An optical realization of some quantum gates.

References:

1. Introductory Quantum Optics, C. C. Gerry and P. L. Knight, Cambridge University Press
2. Quantum Optics, M. O. Scully and M. S. Zubairy, Cambridge University Press
3. Quantum Optics, M. Fox, Oxford Master series in Atomic, Optical and Laser physics
4. Quantum Theory of Light, R. Loudon, Oxford science publication

P663: Astronomy and Astrophysics

1. Introduction and Tools :
   Tools - astronomical objects, scales, distance ladder, astrometry, magnitude scale
   Gravity - Keplers law, Virial theorem
   Radiation physics - radiative flux, transfer function, absorption, scattering and emission
2. Stars:
   Stars and stellar structures - stellar spectra, HR diagram
   Equilibrium in stars
   Star formation and Protostars
   Stellar evolution
   Supernovae
   black holes and gravitational waves
3. Interstellar medium
4. Galaxies
   The Milky way Galaxy - distribution of matter, differential rotation, formation of the spiral arms Elliptical and Spiral Galaxies
   Evidence for dark matter Active Galaxies - Active Galactic Nuclei, Seyfert Galaxies, Quasars, Blazers
5. Magnetic fields
   Astrophysical phenomena where magnetic fields are critical
   Galactic magnetic fields - dust and synchrotron polarization, Faraday rotation, Zeeman measurements
6. Gravitational Lensing (optional)
7. Clusters and Superclusters (optional)
8. Cosmology (optional)
   Cosmological Observations and the Cosmological Principle
   Newtonian Cosmology and Cosmological Models
   Cosmic Microwave Background

References/Textbooks: *References*:

1. Fundamental Astronomy - H. Karttunen, P. Krger, H. Oja, M. Poutanen, K. J. Donner
2. Introduction to Modern Astrophysics - B. W. Carroll and D. A. Ostlie
3. An invitation to Astrophysics - T. Padmanabhan

4. Astrophysical Concepts - Martin Harwit
5. Introductory Astronomy and Astrophysics - Zelike and Gregory
6. Universe - Roger Freedman
7. Physical Universe - F. Shu
8. Astrophysics Processes - Hale Bradt
9. Radiative processes in Astrophysics - Rybicki and Lightman
10. An introduction to Astronomy and Astrophysics - Pankaj Jain
11. Quasars and Active Galactic Nuclei - Kembhavi and Narlikar

P664: Plasma Physics and Magnetohydrodynamics

Introduction to plasmas, applications: in fusion, space and astrophysics, semiconductor etching, microwave generation: characterization of the plasma state, Debye shielding, plasma and cyclotron frequencies, collision rates and mean-free paths, atomic processes, adiabatic invariance, orbit theory, magnetic confinement of single-charged particles, two-fluid description, magneto hydrodynamic waves and instabilities, heat flow, diffusion, kinetic description, and Landau damping, ideal magnetohydrodynamic (MHD) equilibrium, MHD energy principle, ideal and resistive MHD stability, drift-kinetic equation, collisions, classical and neoclassical transport, drift waves and low-frequency instabilities, high-frequency micro instabilities, and quasilinear theory.

References:

1. Plasma Physics by Peter Andrew Sturrock
2. Principles of Magnetohydrodynamics by J. P. Hans Goedbloed , Stefaan Poedts
3. Hydrodynamic and Hydromagnetic Stability by S. Chandrasekhar
4. The Physics of Plasmas by T. J. M. Boyd, J. J. Sanderson
5. Fundamentals of Plasma Physics by Paul M. Bellan,
6. Introduction to Plasma Physics by R.J Goldston , P.H Rutherford
7. An Introduction to Magnetohydrodynamics by P. A. Davidson
8. An Introduction to Plasma Astrophysics and Magnetohydrodynamics by M. Goossens

P665: Biophysics

Under development.

P666: Quantum Nanoelectronics

Introduction and Review of Electronic Technology, From Electronics to Nanoelectronics: particles, waves and Schrodinger Equation, Quantum Description of atoms and molecules Quantum Description of metals, semiconductors, junction devices, Some newer building blocks for nanoelectronic devices, Fabrication and Characterization Methods for nanoelectronics, The field effect transistor FET: size limits and alternative forms, Devices based on electron tunneling, resonant tunnel diodes, Single electron transistors, molecular electronics, hybrid electronics, Devices based on electron spin and ferromagnetism, Qubits vs. binary bits in a Quantum Computer, Applications of nanoelectronic technology to energy issues, Summary and brief comment on the future of nanoelectronic techniques

References:

1. Quantum Nanoelectronics: An Introduction to Electronic Nanotechnology and Quantum Computing by Edward L. Wolf
2. Quantum Electronics - by Amnon Yariv
3. Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience - by Edward L. Wolf
4. Fundamentals of Nanoelectronics - by George Hanson
5. Introduction to Nanoelectronics: Science, Nanotechnology, Engineering and Applications - by Vladimir Mitin, Viatcheslav A. Kochelap, Michael A. Stroscio

P667: Nonlinear Physics, Chaos, Turbulence

1. General introduction and motivation : examples of linearity and nonlinearity in physics and the other sciences; modelling systems using iterated maps or differential equations, nonautonomous systems
2. General features of dynamical systems : Systems of differential equations with examples; control parameters; fixed points and their stability; phase space; linear stability analysis; numerical methods for nonlinear systems; properties of limit cycles; nonlinear oscillators and their applications; the impossibility of chaos in the phase plane; bifurcations: their classification and physical examples; spatial systems, pattern formation and the Turing mechanism; strange attractors and chaotic behaviour.
3. The logistic map: Linear and quadratic maps; graphical analysis of the logistic map; linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; chaotic behaviour and the determination of the Lyapunov exponent; universality and the Feigenbaum numbers; other examples of iterated maps.
4. Hamiltonian Sysytems: Phase space; Constants of motion and integrable Hamiltonians; Nonintegrable systems, the KAM theorem and period-doubling; applications.
5. Fractal geometry: dimension of an object, Mandelbrot set, Julia set, iterated function systems.
6. Spatio-temporal dynamics: Spatio-temporal chaos
7. Quantum Chaos: Quantum analogies to Chaotic behaviour, Correalations in wave functions, chaos and semiclassical approaches to Quantum mechanics

References:

1. S. H. Strogatz, Nonlinear Dynamics and Chaos: With Applications in Physics, Biology, Chemistry and Engineering.
2. Robert C. Hilborn, Chaos and Nonlinear Dynamics.
3. Brian Davies, Exploring Chaos: Theory and Experiment.
4. K. T. Alligood, T. D. Sauer and J. A. Yorke, Chaos: An Introduction to Dynamical Systems.
5. Edward Ott, Chaos in Dynamical Systems.
6. 6. M.Tabor, Chaos and Integrability in Nonlinear Dynamics: An Introduction.

P668: Magnetism and Superconductivity

1. Prerequisite: Solid State Physics, Quantum Mechanics, Statistical Physics
2. Review of atomic/ionic magnetism.
3. Diamagnetism Paramagnetism Ferromagnetism characteristics, Occurrence.
4. Orbital magnetism, de Haas van Alfen effect.
5. Heisenberg Model: Ground state, Spin waves.
6. Hubbard Model and Itinerant exchange.
7. Magnetic domains and hysteresis.
8. The phenomenon of Superconductivity: historical perspective, characteristics, occurrence.
9. London Equations, Thermodynamics, Meissner Effect.
10. Ginzburg Landau Theory, Abrikosov Vortices.
11. Josephson Effect.
12. Cooper Instability, BCS wave function, Gap equation, thermodynamics and magnetic response.
13. Conventional and non-conventional superconductors.

References:

1. Solid State Physics, Neil W. Ashcroft and N. David Mermin
2. Interacting Electrons and Quantum Magnetism , A. Auerbach
3. Magnetism D.C. Mattis
4. Magnetism: R.M. White
5. Superconductivity - Schrieffer
6. Superconductivity - de Gennes
7. Superconductivity - Tinkham

P669: Density Functional Theory of Atoms, Molecules and Solids

Many-body problem: QM of electrons and nuclei, approximation methods for many electron systems, Born-Oppenheimer approximation, Hartree and HF theory, tight binding method, greens functions, electron correlation, CI & many-body and Moller-Plesset theory, complete active space methods, coupled cluster theory, density matrices, time-dependent approach to all the above formalism

Foundations of Density Functional Theory(DFT): Hohenberg-Kohn (HK) theorem, degenerate ground states, variational DFT, $N-$ and $v-$ representability problem, Levy-Lieb constrained search, fractional particle number & derivative discontinuity, spin polarized systems, Exited states part I: Effective Single Particle Picture: Kohn-Sham (KS) construction, non-interacting $v-$ representability, degenerate KS DFT, KS equations for spin polarized systems, interpretation of KS eigenvalues

Exchange-Correlation (XC) Energy Functional: exact exchange formalism within DFT, exact representations of the energy functional, LDA, GGA, meta-GGA, weighted density approximation, self interaction correction (SIC), virial theorems, exact exchange formalism (OPM, KLI, HS), where DFT goes wrong, strengths of DFT, strong correlation: DFT+U, RPA, GW, DFPT, DMFT, orbital free DFT, DFT-hybrid

Crossover to Excited-States: time-dependent DFT: Runge-Gross theorem, time-dependent KS equations, adiabatic LDA & TD XC potentials, linear response TDDFT, Excited states part II, spin polarized TDDFT, frequency dependent XC kernel, TDCDFT, TDOEP, relativistic DFT, molecular orbital theories

References:

1. Density Functional Theory of Atoms and Molecules by Robert G. Parr, Weitao Yang
2. Density functional Theory by R.M. Dreizler, E.K.U. Gross
3. Density Functional Theory by Eberhard Engel
4. Primer in Density Functional Theory by C. Fiolhais, F. Nogueira, Miguel A.L. Marques
5. Fundamentals of TDDFT by Miguel A.L. Marques et al.
6. Time-dependent Density Functional Theory by Miguel A.L. Marques et al.
7. Time-dependent Density Functional Theory by Carsten Ullrich
8. Quantal Density Functional Theory I & II by Viraht Shani

9. Recent Advances in Density Functional Methods (Part I, II & III) by Delano P Chong
10. Atomic and Electronic Structure of Solids - by Ethimios Kaxiras
11. Electronic Structure: basic theory and practical methods by Richard M. Martin
12. Many-Body Quantum Theory in Condensed Matter Physics by H. Bruus, K. Flensberg
13. Quantum Theory of the Electron Liquid by Gabriele Giuliani, Giovanni Vignale
14. Molecular Electronic Structure Theory by T.U. Helgaker, P. Jorgensen, and J. Olsen
15. Electronic Structure Calculations for Solids and Molecules by J. Kohanoff
16. Methods of Electronic Structure Calculations by M. Springborg
17. Self Consistent Fields in Atoms by Norman March
18. Computational Materials Science by J. G. Lee
19. Density Functional Theory in Quantum Chemistry by Takao Tsuneda
20. Material Modeling using DFT by Feliciano Giustino

P670: Quantum Field Theory II

1. Path-integral formulation of quantum mechanics
2. Path-integral for scalar fields, generating functional, connected Greens functions, Feynman rules, 1 loop diagrams
3. Grassmann variable, path-integral for Dirac field
4. Path-integral for Electromagnetic field, gauge fixing
5. QED, symmetries and Ward identity
6. Renormalization divergences and power counting, 4 theory, QED, spontaneous symmetry breaking, Renormalization Group basics (running of coupling).
7. Yang-Mills theory, gauge fixing and ghosts, BRST, asymptotic freedom

P671: Quantum Information and Quantum computation

1. Introduction to Classical information: Shannon entropy, Mutual Information
2. Quantum Information I: Hilbert space, density matrices, quantum entropy and Holevo bound
3. Quantum Information II: Entanglement, Teleportation, super dense coding and Bell inequalities
4. Quantum dynamics:Two level systems, decoherence and Rabi oscillations
5. Quantum computation: single qubit gates-phase, swap, Hadamard; two qubit gates-CNOT
6. Quantum algorithms: Deutsch, Grover, Introduction to Shor's algorithm
7. Quantum error correction
8. Applications: Quantum simulation and Adiabatic quantum computation
9. Solid state quantum information and computation: Introduction to entanglement in nanostructures, quantum computation with superconducting devices and topological quantum computation.

References:

1. V. Vedral, Introduction to Quantum Information Science (Oxford U. Press)
2. Nielsen and Chuang, Quantum Information and Computation (Cambridge U. Press)
3. Kaye, Laflamme, Mosca, An Introduction to quantum computing. (Oxford U. press)

P672: Experimental High Energy Physics

The interaction of high-energy particles with matter: specific applications related to EHEP.

1. Relativistic kinematics: Detailed derivation of kinematic variables and their transformations whenever needed. Decay kinematics. Rapidity, pseudo-rapidity, spacelike and time-like. Some examples where relativistic kinematics play important role for understanding of data.
2. Detectors in High Energy Physics: General concept of building a HEP experiment, coverage and options, Gas detectors; Semiconductor detector; Scintillator and Cerenkov detectors Specific to EHEP, Calorimeter and Preshower detectors: principle of electromagnetic and hadronic shower generation.
3. Detector Simulation: Need of simulation, various techniques, MC, some general Concepts.
4. Data Analysis in HEP: General approach of data cleanup, calibration, track reconstruction, reconstruction of events
5. Error analysis in EHEP.
6. Computing in EHEP: Basics of OO programming using C++, few applications in EHEPdata analysis.

References:

1. Relativistic Kinematics; A guide to the kinematic problems of High Energy Physics: R. Hagedorn
2. The Experimental Foundations of Particle Physics: R. N. Cahn, G. Goldhaber
3. Techniques for Nuclear and Particle Physics experiments: A How to Approach: W.R. Leo (Springer)
4. Experimental Techniques in Hugh Energy Nuclear and Particle physics: T. Ferbel (World Scientific)
5. Introduction to Experimental Particle Physics : R.C. Fernow
6. Data Reduction and Error analysis for the physical sciences: P. Bevington and D. K.Robinson
7. Data Analysis Techniques for High Energy Physics: R. Frunwirth, M. Regler, R. K. Bock and H. Grote

P673: Experimental Techniques

1. Mechanical drawing and designs: Basics tools: hand tools, machines for making holes, the lathe, milling machines, grinders, casting; Mechanical drawing, drawing tools, basic principles of mechanical drawing, dimensions, tolerances, from design to working drawings
2. Vacuum technology: gases, gas flow, pressure and flow measurement, vacuum pumps, pumping mechanisms, ultrahigh vacuum, leak detection
3. Optical systems: optical components, optical materials, optical sources Charge particle optics: electrostatic lenses, charged-particle sources, energy and mass analyzer
4. Detectors: optical detectors, photoemission detectors, particle and ionizing radiation detectors, signal to noise ration detection, surface barrier detector.
5. Particle detectors and radioactive Decay: Interactions of charged particles and photons with matter; gaseous ionization detectors, scintillation counter, solid state detectors
6. Electronics: electronic noise, survey of analog and digital I/Cs, signal processing, data acquisition and control systems, data analysis evaluation
7. Nano- and micro-fabrication: various lithography techniques such as photolithography, nanoimprint lithography, e-beam lithography, ion-ball milling
8. Some experiments: SEM, TEM, X-ray diffraction, SQUID Magnetometry, Magnetotransport, PL/CL time resolved spectroscopy, Rutherford Backscattering spectrometry (RBS), RBS-Channeling, UV-VIS-IR spectrometry.

References:

1. The art of Measurement, by Bernhard Kramer, VCH publication
2. Building Scientific apparatus by J. H. Moore et al.
3. Experiments in Modern Physics, Second Edition by Adrian C. Melissinos, Jim Napolitano
4. The art of experimental Physics by Daryl W. Preston,
5. Vacuum Technology, A. Roth North-Holland Publisher
6. Charge Particle Beams, by Stanley Humphries, John Wiley and Sons
7. Principles of charged Particles Acceleration, by Stanley Humphries, John Wiley and Sons
8. Radiation detection and Measurements, G. Knoll, 3rd Edition
9. Techniques for Nuclear and particles physics experiments, W. R. Leo, 2nd edition, Springer

P674: Introduction to Cosmology

1. The cosmic history and inventory.
2. A sketch of General Relativity.
3. The expanding Universe
4. Friedmann Equations and Cosmological Models
5. The Standard cosmological model.
6. The inflationary Universe.
7. Primordial nucleosynthesis and the thermal history of the Universe.
8. Perturbations in an expanding Universe.
9. Growth of perturbations
10. Dark Matter Halos.
11. Statistical description of gravitational clustering
12. Special Topics:
    Fluctuations in the CMB, Lensing, Cluster Cosmology, The Lyman-Alpha Forest, Reionization, Halo Model, Redshift Space Distortions.

References:

1. Introducing Einstein's General Relativity - Ray D'Inverno
2. The Early Universe - Kolb and Turner
3. Introduction to Cosmology - Barbara Ryden
4. Modern Cosmology - Scott Dodelson
5. Principles of Physical Cosmology - P.J.E. Peebles
6. Large Scale Structure of the Universe - P.J.E. Peebles
7. Structure Formation in the Universe - T. Padmanabhan

P675: Quark-Gluon-Plasma and Nucleus-Nucleus Collisions

1. Introduction to high energy heavy ion collisions and Quark-Gluon-Plasma, comparison of big bang and the little bang.
2. Thermodynamics:relativistic gas (hadrons, quarks and gluons) and its statistical and thermodynamical properties, MIT Bag model,Hagedorn gas, phase diagram of QCD.
3. Relativistic Kinematics: four vectors notation, rapidity variables, pseudorapidity varibales, light cone variables, relativistic invariants, Dalitz plot, cross sections .
4. Collision Dynamics: initial state of nuclear collisions, fluid dynamical evolution, kinetic transport model, freeze-out and particle production.
5. Experiments: a general overview of different experimental setup related to search for QGP and relevant observables.
6. Signatures of QGP: collective flow, J/Ψ suppression, strangeness enhancement, jet quenching, electromagnetic probes, Hanbury-Brown-Twiss measurement.
7. Recent progresses.

References:

1. Hadrons and QGP by Letterssier and Rafelski
2. Introduction to High Energy Heavy Ion Collissions by C. Y. Wong.
3. Phenomenology of Ultra Relativistic Heavy Ion Collissions by W Florkowski.
4. Ultrarelativistic heavy ion collisions by R. Vogt.
5. Introduction to relativistic heavy ion collisions, by L. P. Csernai.
6. A Short Course On Relativistic Heavy Ion Collission by A. K. Chaudhuri.
7. Extreme states of matter in strong interaction physics by Helmut Satz.
8. Relativistic Hydrodynamics by L. Rezzolla and O. Zanotti.
9. Finite Temperature Field Theory by J. I. Kapusta and C. Gale.
10. The Early Universe by Kolb and Turner.
11. Fantastic Realities by Frank Wilczek.

Courses of Study

For PhD Program: Health Sciences

@

Tata Memorial Centre

Under the aegis of

Homi Bhabha National Institute

(For Academic year 2019 onwards)

Syllabus for Courses of Study for PhD Program: Health Sciences

Contents

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Standing Committee for PhD in Health Sciences at TMC:

1.	Prof.Shripad. Banavali	-	Chairperson
2.	Prof.Sudeep Gupta	-	Member
3.	Prof. Rajiv Sarin	-	Member
4.	Prof. Kumar Prabhash	-	Member
5.	Prof.TanujaSheth	-	Member
6.	Prof. Rajesh Kinhikar	-	Member

Academic Committee for PhD in Health Sciences at TMC:

1.	Prof. RajivSarin	-	Chairperson
2.	Prof.Sorab Dalal	-	Member
3.	Prof. V. Prasanna	-	Member
4.	Prof.Abhijit Dey	-	Member
5.	Prof. Kumar Prabhash	-	Member
6.	Prof. Rajesh Dikshit	-	Member
7.	Prof. V. Rangarajan	-	Member
8.	Prof. Rajesh Kinhikar	-	Member

Board of Studies (BoS) in Health Sciences at TMC:

1.	Prof. S.D. Banavali, TMH	-	Convener
2.	Prof. Sandeep Basu, RMC	-	Co-convener
3.	Prof. S.V. Chiplunkar, ACTREC	-	Member
4.	Dr.Nithya Gogtay, KEM Hospital, Mumbai (Outside Expert)	-	Member
5.	Dr. Ashutosh Agarwal, PGIMER, Chandigarh (Outside Expert)	-	Member
6.	Prof. Kailash Sharma, TMC	-	Member
7.	Prof.Siddharth Laskar, TMC	-	Member
8.	Prof. Ajay Puri, TMC	-	Member
9.	Prof. J.P. Agarwal, TMC	-	Member
10.	Prof. Suyash Kulkarni, TMC	-	Member

Balancing Members

1.	Prof. Rajesh Kinhikar, TMC	-	Balancing Member
2.	Prof. A.K. Dureja, HBNI	-	Balancing Member

SOP for Approval of Course Work for Ph.D. in Health Sciences:

1. Each Ph.D., student will have to do 60 credit course work per year.
2. Semester I: August to November.
3. Semester II: January to April.
4. 3 lectures will be taken per week (consisting of 4 contact hours each).
5. There will be Tutorials/Assignments in addition to lectures.
6. 1st Year:
    a. There will be 8 courses in 1st year (Approx. 7.5 Credits each)
    b. There will be 4 courses per semester
    c. The core course is to be completed in the first year
7. 2nd Year:
    a. There will be 2 self-study courses consisting of 6 credits each in the second year.
8. There will be 8 “Core” course modules in total, which will be offered to all Ph.D. students.
9. Additionally, there will be “Elective” Modules to be completed by each student. There are many “Elective” modules submitted to HBNI for approval. Each student will select Elective modules from the approved modules as per their Ph.D. topic.
10. All the “Core” and “Elective” modules will be evaluated and Okayed by the Academic & Standing Committee of Ph.D. programme in Health Sciences & then sent to HBNI for final approval.
11. The students will have to choose a total of 8 Courses (Core + Elective) only from all the courses already approved by HBNI.

SOP for Advertising Ph.D. seats for that year:

1. Clinicians interested in becoming Ph.D. Guides should be at least 15 years post completion of M.D.
2. They should be well versed with conducting research and have funded projects to support students enrolled in Ph.D. programme under them.
3. The applications of those interested in becoming Ph.D. guide, after thorough review by Academic Director, will be sent to HBNI.

4. Once cleared by HBNI, these applications will be forwarded to BOS (Health Sciences) for recommendation.
5. The recommended applications will be then resent to HBNI for approval.

6. Once approved by HBNI, the Ph.D. guide will be sent intimation of the same.

7. The Academic Office will have a list of all approved Ph.D. guides. At the start of the year, The Academic Office will intimate the guide to submit to Academic Office If they have projects to support Ph.D. students.

8. The projects will then be submitted to Academic Committee & the Standing Committee of Ph.D. in Health Sciences & number of Ph.D. students to be taken for that year will be decided by April of that year & Advertisements made.

9. A PhD Guide in Health Sciences can get maximum of 2 New PhD Students in a year. Each PhD Guide in Health Sciences can have maximum of 4 PhD Students at any given time.

SOP for Enrolment of Ph.D. Students (Health Sciences) under HBNI:

1. Ph.D. Health Science Standing Committee will approve projects to be given to Ph.D. students for the batch.

2. Advertisement for Entrance Examination for Ph.D. in Health Sciences will be made.

3. Examination and Interviews will be done and the list of eligible candidates will be displayed at TMH website.

4. Students will join after medical fitness.

5. Enrollment Form – ‘A’ will be sent to HBNI with D/D of Rs. 10,000/- with their documents like
    a. All Mark sheets and appropriate degree certificates of B.Sc., M.Sc., MD
    b. Copy of AADHAR Card
    c. Copy of Award Letter
    d. Fellowship documents if any

6. HBNI will send Enrollment numbers for the batch.

7. JRF will be assigned to the Ph.D. guide as per their chosen field of work.

8. Lab rotation in first month declared

9. 1st Year course work will be of around 9 to 10 months. (Marks to be included of Main Course + Electives+ Open Seminar)

10. 1st DC will be held at around end of 1st year.

11. The Doctoral Committee of the staff (as per new ordinance) will be as follows:
    a. A Professor or an Associate Professor shall be the Chairman of the Committee,
    b. The Guide shall be the Convener and where applicable, the co-guide shall be a member.
    c. Two faculty members of the Institute specializing in a domain encompassing the topic of research.
    d. One faculty member preferably from any other CI or any other University/Academic Institute in an allied domain as the topic of research.
    e. A Technology Adviser, if any, shall be a Permanent Invitee.

12. HBNI will then send a letter approving DC committee.

13. 1st DC report will consists of documents mentioned below

14. (Set is to be submitted to HBNI):-
    a. Oral General Comprehensive Examination Report (OGCE)
    b. Annual Progress Report
    c. Mark sheet of Course work
    d. B & C part of Enrollment form

15. Request for synopsis: In total at least 4 DC reports will be needed for synopsis submission + one 1st author publication+ at least 1 conference to be attended.

Annexure - I

Details of Assessment for Course of PhD in Health Science at TMC:

1. Salient features of core course and electives:

Students at TMC are required to do a core course and take elective courses, which are determined by them in consultation with their thesis supervisor.

A] The core course is for 1000 marks which are equal to 500 contact Hrs (30 Credits) and is configured in the following manner:

a. There are 8 Core Course modules which are all compulsory as below:

b. The students are evaluated in a written exam for each course and have take-home assignments for each course.

c. The students also have to present two assigned papers over the period of the core course.

d. The courses also include lectures on advanced techniques that introduce the students to new methodologies.

B] Multiple electives are offered at TMC and the students will have to pick 4 for a total of 400 marks which are equal to 200 contact Hrs (12 Credits) Each elective has a course co-ordinator/co-ordinators who designs the course and determines the process by which the students are examined over the course.

C] Core course includes Special Lectures on Epidemiology and Bioinformatics (5 lectures), Intellectual Property rights (1 lecture) and Research Methodology (6 lectures). All these lectures have no separate credit points.

D] Research Methodology (6 lectures) is a separate module with no separate credit points. Laboratory Work all through the year carries 200 marks which are equal to 100 contact Hrs (6 Credit). Scientific writing assessed at the final seminar is for 100 marks which are equal to 50 contact Hrs (3 Credit)

E] Final Seminar presentation on the topic of Ph.D. dissertation carries 200 marks which are equal to 100 contact Hrs (6 Credit) and

F] Oral General Comprehensive Examination (OGCE) is for 100 marks which are equal to 50 contact Hrs (3 Credit)

Total course work is of 2000 marks which are equal to 1000 contact Hrs (60 Credits).

2. Choice based credit system:

TMC follows the HBNI guidelines on how many academic hours correspond to how many marks. While the core course is mandatory for all students, the students do have a choice of electives. Similarly, the credits for the Final seminar, lab work and scientific writing are based on the choice of project that will be pursued by the student. The courses were initially developed for Ph.D. in Life Sciences program and are formulated as per HBNI guidelines.

HBNI Orientation Course on Basic and Cancer Biology for Junior Research Fellows, Ph.D. Health Sciences

Proposed Lectures / Marks of Coursework: 1st year of the Ph.D. program

[Total: 2000 marks]

Sr. No	Orientation	No. of Lectures	Marks
1	Laboratory Safety Lectures	3	-
2	Visits to Library, Common Instrument Room and Laboratory Animal Facility	3	-
3	Orientation to the Cancer Clinic	4	-

A]Core Course **200 Contact hrs / 1000 marks**

Lectures

Course code	Core Course Topics	Lectures		Marks
		Contact Hrs	F/N Practicals	
09HLTH04-001-C	Cell Biology & Cancer Biology	32	20	Written Test 140 marks Home Assignments: 150 marks
09HLTH04-002-C	Cell Proliferation and Cell death	16		
09HLTH04-003-C	Oncogenes and Tumor Suppressors	20		
09HLTH04-004-C	Metastasis and Angiogenesis	16	20	Written Test 140 marks Home Assignments: 150 marks
09HLTH04-005-C	Cancer Epigenetics and Genetics	28		
09HLTH04-006-C	Carcinogenesis	20		
09HLTH04-007-C	Tumor Immunology	20	10	Written Test 120 marks Home Assignments: 100 marks
09HLTH04-008-C	Structural Biology and Biophysics	20		
	Presentations 1 & 2	28		200 Marks
		200		1000 marks = 30 credits

B] Electives

Each Elective 20 Contact hrs + FW/Practical 5 Contact hrs + 3 Credits each.

Course code	Core Course Topics	Lectures		Marks
		Contact Hrs	F/N Practicals	
09HLTH04-001-E	Biostatistics	20	5	Exam 100 marks
09HLTH04-002-E	Animal Models in Cancer Research	20	5	Exam 100 marks
09HLTH04-003-E	Cancer Therapeutics	20	5	Presentations 100 marks
09HLTH04-004-E	Carcinogenesis, Chemoprevention and DNA Repair	20	5	Presentations 100 marks
09HLTH04-005-E	Deregulation of Cell Growth in Cancer	20	5	Presentations 50 marks Assignment 50 marks
09HLTH04-006-E	Structural Bioinformatics, Biophysics & Structural Biology	20	5	Exam 100 marks
09HLTH04-007-E	Tumor Immunology	20	5	Presentations 100 marks
09HLTH04-008-E	Metastasis	20	5	Presentations 100 marks
09HLTH04-009-E	Bioinformatics	20	5	Presentations 100 marks
09HLTH04-010-E	Epidemiology & Preventive Oncology	20	5	Presentations 100 marks
09HLTH04-011-E	Medical Physics	20	5	Presentations 100 marks
09HLTH04-012-E	Nutrition	20	5	Presentations 100 marks
				400 marks = 12 credits

C] Special Lectures:

Course Code	Core Course Topics	No. of Lectures	Marks
09-HLTH04-001-S	Epidemiology & Bioinformatics	5 lectures	No marks
09-HLTH04-002-S	Intellectual Property Rights	1 lectures	No marks

09-HLTH04-009-C **Research Methodology**

Sr. No.	Core Course Topics	No. of Lectures	Marks
a)	Lectures	6 lectures	**No marks**
b)	Laboratory work	All through the year	**200 marks = 100 Contact hrs = 6 Credits**
c)	Scientific Writing	Assessed at final seminar	**100 marks = 50 Contact hrs = 3 Credits**

E] Seminar Presentation on the topic of their Ph.D. dissertation

No. of Lectures	Marks
10	**200 marks = 100 Contact Hrs = 6 Credits**

F] First Thesis Committee Meeting / Comprehensive Examination

No. of Lectures	Marks
10	**100 marks=50 Contact Hrs = 3 Credits**

Grand Total:	**2000 marks = 1000 Contact Hrs = 60 credits**

Syllabus Ph.D. (Health Sciences) For various Courses: Cell Biology; Clinical Research; Medical Physics; Cancer Biology; Epidemiology)

Core Course: 200 Contact hrs + 50 Field Work / Practical hours / 1000 marks

Sr. No	Core Course Topics	Lectures Contact hrs		Marks
		Contact Hrs	FN/ Practical	
Cancer Biology				
Module 1	Cell biology & Cancer Biology	32	20	Written test 140 marks Home Assignments : 150 Marks
Module 2	Cell Proliferation and Cell death	16		
Module 3	Oncogenes and Tumour Suppressors	20		
Module 4	Metastasis and Angiogenesis	16	20	Written Test 140 marks Home Assignments : 150 marks
Module 5	Cancer Epigenetics and Genetics	28		
Module 6	Carcinogenesis	20		
Module 7	Tumour Immunology	20	10	Written Test 120 marks Home Assignments : 100 marks
Module 8	Structural Biology and Biophysics	20		
	Presentation 1 & 2	28		200 Marks
		200		**1000 Marks = = 30 credits**
Clinical Research				
Module A	Cell cycle, DNA Repair, Carcinogenesis & metastases			400
Module B	Genetics, Epigenetics & Next Gen Sequencing			400
Module C	Cancer Immunology, molecular imaging and pathology & drug resistance			400
Module D	Clinical Genetics & cancer prevention			400

<table>
<tr><td colspan="5">Medical Physics</td></tr>
<tr><td>Module 1</td><td>Teletherapy – Accelerators & Telecobalt – Advances</td><td>24</td><td rowspan="7">20</td><td>100</td></tr>
<tr><td>Module 2</td><td>Brachytherapy – advances</td><td>20</td><td>50</td></tr>
<tr><td>Module 3</td><td>Dosimetry</td><td>20</td><td>50</td></tr>
<tr><td>Module 4</td><td>Clinical perspective</td><td>32</td><td rowspan="3">100
50
100</td></tr>
<tr><td>Module 5</td><td>Imaging Techniques</td><td>16</td></tr>
<tr><td>Module 6</td><td>Treatment Planning System</td><td>32</td></tr>
<tr><td>Module 7</td><td>Statistics</td><td>16</td><td>50</td></tr>
<tr><td></td><td></td><td colspan="2">160</td><td>500 marks = 250 Contact Hrs =15 credits</td></tr>
<tr><td colspan="5">Cancer Biology / Epidemiology</td></tr>
<tr><td>Module 1</td><td>Bioanalytical Methods</td><td></td><td></td><td>250</td></tr>
<tr><td>Module 2</td><td>Biomarkers</td><td></td><td></td><td>250</td></tr>
<tr><td>Module 3</td><td>Tobacco Carcinogenesis</td><td></td><td></td><td>250</td></tr>
<tr><td>Module 4</td><td>Basics of epidemiology</td><td></td><td></td><td>250</td></tr>
<tr><td>Module 5</td><td>Hands on training in tobacco constituents and biomarker analysis using LC – MS/MS</td><td></td><td></td><td>300</td></tr>
</table>

HBNI Health Science Ph.D. Course Structure

COURSE SUMMARY

	Course	Course Title	Lecture (H)	Credit
Trimester I	Core Courses	**Cancer Biology :-**		
		Cell biology & Cancer Biology	**32**	Written test 140 marks Home Assignments : 150 Marks
		Cell Proliferation and Cell death	**16**	
		Oncogenes and Tumour Suppressors	**20**	
		Metastasis and Angiogenesis	**16**	Written Test 140 marks Home Assignments : 150 marks
		Cancer Epigenetics and Genetics	**28**	
		Carcinogenesis	**20**	
		Tumour Immunology	**20**	Written Test 120 marks Home Assignments : 100 marks
		Structural Biology and Biophysics	**20**	
				Marks
		Cell cycle, DNA Repair, Carcinogenesis & metastases		**400**
		Genetics, Epigenetics & Next Gen Sequencing		**400**
		Cancer Immunology, molecular imaging and pathology & drug resistance		**400**
		Clinical Genetics & cancer prevention		**400**
		Medical Physics:-		
		Teletherapy – Accelerators & Telecobalt – Advances		**100**
		Brachytherapy – advances		**50**
		Dosimetry		**50**
		Clinical perspective		**100** **50** **100**

Trimester I	Core Courses	Imaging Techniques		
		Treatment Planning System		**50**
		Statistics		**50**
		Cancer Biology/ Epidemiology:-		
		Bioanalytical Methods		**250**
		Biomarkers		**250**
		Tobacco Carcinogenesis		**250**
		Basics of epidemiology		**250**
		Hands on training in tobacco constituents and biomarker analysis using LC – MS/MS		**300**
Trimester II	Electives	Biostatistics		**100**
		Cancer Therapeutics		**100**
		Carcinogenesis, Chemoprevention and DNA repair		**100**
		Biostatistics		**100**
		Animal models in cancer research		**100**
		Cancer Therapeutics		**100**
		Carcinogenesis, Chemoprevention and DNA repair		**100**
		Biostatistics		**100**
		Animal models in cancer research		**100**
		Cancer Therapeutics		**100**
		Deregulation of Cell Growth in cancer		**100**
		Bioinformatics		**100**
		Basic tools of research		**100**
		Tumour Immunology & Stem Cell biology		**100**
		Basic Epidemiology		**100**

		Molecular Epidemiology		**100**
		Clinical trial methodology		**100**
		Human genetics & Pathological anatomy of cancer		**100**
		Cancer registries & Biological sample collection and storage		**100**
	Mandatory	Research Methodology		

Annexure - II

Core Course

Core Course **Course I: BASIC CANCER BIOLOGY – I** **[Modules 1 – 3]**			
Module 1: Cell Biology and Cancer Cell Biology			
1	Lecture 1	Hallmarks of Cancer: Overview, Biological characteristics of cancer cells	Dr. SorabDalal Dr. NeelamShirsat
2	Lecture 2	Cell organelles in normal and cancer cells: Introduction to different organelles and their biogenesis, Intracellular protein	Dr. Dibyendu Bhattacharyya
3	Lecture 3	Differentiation, Development and Cancer	Dr. SanjeevWaghmare
4	Lecture 4	Stem cells & Cancer stem cells, Embryonic stem cells, Reprogramming &pluripotency, Adult stem cells	Dr. SanjeevWaghmare
5	Lecture 5	Advanced Technology: Lecture & Demo: Microscopy	Dr. D. Bhattacharyya / Ms. VaishaliKailaje
6	Lecture 6	Advanced Technology: Lecture & Demo: Electron Microscopy	Ms. SharadaSawant
7	Lecture 7	Advanced Technology: Lecture & Demo: *In vivo* imaging (Luminescence)	Dr. Abhijit De
8	Lecture 8	Advanced Technology: Lecture & Demo: In vivo imaging (microPET-CT)	Dr. PradipChaudhari

Module 2: Cell Proliferation and Cell Death			
9	Lecture 1	Deregulation of Proliferation: Cell cycle phases, Why is a cyclin called a cyclin?, Post-translational regulation of cdks: evidence from genetics, Biochemistry and structural biology, Regulation of cellular localization of cyclins	Dr. SorabDalal
10	Lecture 2	Deregulation of Proliferation: Regulation of cyclin turnover, How do cyclin - cdk complexes recognize substrates?, Phenotypes of cyclin / cdk knockout mice: What do they teach	Dr. SorabDalal
11	Lecture 3	Mechanisms of Cell Death: History, Methods of detection, Proteins that regulate cell death, Mitochondrial pathway of apoptosis	Dr. Pritha Ray
12	Lecture 4	Apoptosis, necrosis, autophagy: Death receptor pathway, Inhibitor of apoptosis family, Caspase-independent pathways	Dr. Pritha Ray
13	Lecture 5	Cancer Cell Metabolism - Basics	Dr.SanjeevWaghmare
14	Lecture 6	Cancer Cell Metabolism – Clinical and Therapeutics	Dr. VikramGota

Module 3: Oncogenes and Tumor Suppressors			
15	Lecture 1	Oncogenes: Definition, history, types Growth factors and receptors; Cytoplasmic tyrosine kinases	Dr. Amit Dutt
16	Lecture 2	Oncogenes: Serine-threonine kinases, G-proteins, Transcription factors	Dr. RukminiGovekar
17	Lecture 3	Tumour suppressor genes: Definition, History, Knudson's hypothesis, pRB signaling pathway	Dr. TanujaTeni
18	Lecture 4	Tumour suppressor genes: p53 signaling, Other tumour suppressor genes (PTEN, p16, etc)	Dr. TanujaTeni
19	Lecture 5	Telomerase: What is a telomere and telomerase, how does telomere stability affect cellular lifespan and tumorigenesis	Dr. SorabDalal
Written Test (Modules 1-3) - 140 marks			
Home Assignments (HAs) - 150 marks		**Assignment deadline:**	

Reading material:

1.Pawley, James (2013-04-11). Handbook of Biological Confocal Microscopy (Page iii). Springer.

2. A. Yildiz, R.D. Vale, Total Internal Reflection Fluorescence Microscopy, Cold Spring HarbProtoc. 2015 vol9 pdb. top086348–11. doi:10.1101/pdb.top086348.

3. Fundamentals of Physics Resnick.

4. Molecular Biology of the Cell – Alberts.

5. Principles and Techniques of Electron Microscopy Biological Applications by M. A Hayat. 6. The Molecular Basis of Cancer by Mendelson, Gray, Howley, Israel and Thompson.

In addition to these basic text books, the instructors also provide review articles and primary research papers that are relevant to the topic being covered.

Core Course

Course II: BASIC CANCER BIOLOGY – II

[Modules 4 – 6]

Module 4: Metastasis and Angiogenesis

20	Lecture 1	Mechanisms of contact inhibition and evasion: Cell-cell adhesion, junctional complexes, Cell-ECM interaction, epithelial mesenchymal transition	Dr.UjjwalaWarawdekar
21	Lecture 2	Migration and Invasion: Cytoskeletal elements: Role in cell architecture and motility	Dr. Milind Vaidya
22	Lecture 3	Metastasis: Introduction: Metastatic cascade mechanisms involved in different steps of metastasis, Degradation of matrix, Its complex regulation, Enzyme systems involved, Ways by which it aids metastasis, Receptors and cues used for cellular	Dr. SorabDalal
23	Lecture 4	Hypoxia and angiogenesis: Angiogenesis and vasculogenesis, Tumor angiogenesis and angiogenic switch, Models to study angiogenesis	Dr. Abhijit De

Module 5: Cancer Epigenetics and Genetics			
24	Lecture 1	Epigenetics and Cancer: Overview of epigenetics, Chromatin structure, Histone variants & modification, Histones & cancer	Dr. Sanjay Gupta
25	Lecture 2	Epigenetics and Cancer: Chromatin remodeling, Chromatin and gene regulation, DNA methylation, Methodologies related to chromatin biology	Dr. Sanjay Gupta
26	Lecture 3	Inherited cancer syndromes, Genetics, Genetic predisposition to cancer, Low & high penetrance genes, Multifactorial & polygenic inheritance, Non-traditional inheritance	Dr. Rajiv Sarin
27	Lecture 4	Advanced Technology: Lecture & Demo: Proteomics	Dr. RukminiGovekar
28	Lecture 5	Advanced Technology: Lecture & Demo: Genomics (Sanger sequencing, Real time PCR; Fragment analysis, etc)	Dr. PradnyaKowtal
29	Lecture 6	Advanced Technology: Lecture & Demo: Genomics (Expression profiling, Next Gen Sequencing, Copy Number Variation Analysis)	Dr. Amit Dutt
30	Lecture 7	Demo- NGS (Gr. Fl.-109)	Dr. Rajiv Sarin / Dr. PradnyaKowtal
Presentation I (Modules 1-4) - 100 marks			

Module 6: Carcinogenesis			
31	Lecture 1	Carcinogenesis - I: Overview of carcinogenesis, Carcinogen metabolism, Activation of cellular oncogenes, Experimental carcinogenesis, Initiation, promotion and progression stages of carcinogenesis, Theories of carcinogenesis	Dr. GB Maru / Dr. Manoj Mahimkar Dr. Sanjay Gupta
32	Lecture 2	Carcinogenesis – II: Animal models for carcinogenesis, Bioassays, Carcinogenesis and biomarkers; Environmental mutagens, carcinogens, initiators, promoters	Dr. ManojMahimkar
33	Lecture 3	Human tumor viruses: Human pathogenic viruses: Salient features of selective viruses, Phagenesis and its molecular determinants, Viral latency	Dr. Abhijit De
34	Lecture 4	DNA repair pathways: Mismatch repair, Base excision repair, Nucleotide excision repair	Dr. Shilpee Dutt

35	Lecture 5	DNA repair pathways: Non homologous end joining and Double strand break repair, Genomic instability	Dr. ShilpeeDutt
Written Test (Modules 4-6) - 140 marks			
Home Assignments (HAs) - 150 marks			
Reading Material: 1. Cancer Epigenetics by Gupta S, Khade B, VermaMukesh and Verma M. 2. DNA repair and mutagenesis by Freidberg, Walter and Seide. 3, Molecular Biology of the Cell by Alberts. 4. Introduction to Genetic Analysis by Griffiths, Wessler, Lewontin, Gelbart, Suzuki, Miller. 5. Molecular Mechanisms of HPV-induced Carcinogenesis. IARC MONOGRAPHS VOLUME 90:432-463. In addition to these basic text books, the instructors also provide review articles and primary research papers that are relevant to the topic being covered.			

Core Course **Course III: TUMOUR IMMUNOLOGY, STRUCTURAL** **[Modules 7-8]** **BIOLOGY & BIOPHYSICS**			
Module 7: Tumour Immunology			
36	Lecture 1	Tumour Immunology – I : Basic Concepts in Immunology, Immune evasion strategies; Cell types participating in Tumor Immunity, Immunotherapy	Dr. Shubhada Chiplunkar
37	Lecture 2	Tumour Immunology - II: Monoclonal Antibodies: Applications in cancer diagnosis/ therapy, Vaccines, Cell-based therapies	Dr. JyotiKode
38	Lecture 3	Tumour Immunology - III: Tumor Microenvironment, Role of cytokines/ chemokines, Role of Tumor-Associated Macrophages, Role of Myeloid Derived Suppressor cells, Role of T reg cells	Dr. Rushikesh Patil
39	Lecture 4	Advanced Technology: Lecture & Demo: Flow Cytometry	Dr. Rushikesh Patil / Ms. Shamal Vetale
40	Lecture 5	Nude / SCID Mice: Origin of Nude/SCID mice, Immune scenario/Immune defects; Models for tumor development, Newer strains, Applications in cancer research	Dr. Shubhada Chiplunkar

Module 8: Structural Biology and Biophysics			
41	Lecture 1	An overview of macromolecular crystallography; Crystal to X-ray diffraction; Different protein structures from primary to quaternary structure, Structure and Function of Biological Macromolecules	Dr. Ashok Varma
42	Lecture 2	Basics of Spectroscopy (Lecture + Demo): Application in studying structure & functions of macromolecules, UV / Vis, FTIR, Raman spectroscopy & fluorescence spectroscopy	Dr. Murali Chilakapati
43	Lecture 3	Interaction between Biomolecules: Structural and biophysical principles of protein-protein, protein-nucleic acid, protein-small molecule interaction and their relevance to function	Dr. Prasanna Venkatraman
44	Lecture 4	Advanced Technology: Biophysical tools for characterizing biomolecular interactions and protein oligomerization: Technique and Application of SPR and ITC in characterizing interactions (lecture xx module); Theory and Application of DLS for characterizing protein homogeneity and oligomerization.	Dr. Prasanna Venkatraman
45	Lecture 5	Protein Folding: Forces that determine the structure; The thermodynamic and kinetic concepts of folding; Folding in intracellular milieu; Tools to study protein folding in vitro	Dr. Kakoli Bose
46	Lecture 6	Enzymes: Classes of enzymes; Active site and Catalysis; Kinetics; Concept of initial rate, Vmax, Km and kcat; Enzyme Inhibition; Different type of inhibitions; Competitive, noncompetitive allostery. Applications…	Dr. Kakoli Bose
Written Test (Modules 7-8) - 120 marks			
Home Assignments (HAs) - 100 marks			
Presentation II (Modules 5-8) - 100 marks			

Reading material:

1. ‘Tumor Immunology’ Kuby

2. ‘Cancer Immunology’ by Hans Schreiber (chapter) from Fundamentals of Immunology.

3. Proteins second edition Structures and Molecular properties Thomas E Creighton.

In addition to these basic text books, the instructors also provide review articles and primary research papers that are relevant to the topic being covered.

MEDICAL PHYSICS

Module 1:- Teletherapy – Accelerator &telecobalt – Advances

Lectures	Topic
Lecture 1	Telecobalt& Linear Accelerators
Lecture 2	Advance Techniques 3DCRT,IMRT,SRS/SRT
Lecture 3	IGRT
Lecture 4	Tomotherapy
Lecture 5	QA in Telecobalt& LINAC
Lecture 6	Different phantoms for dosimetry of advance technology

Module 2:- Brachytherapy – Advances

Lectures	Topic
Lecture 1	Intracavitary and interstitial techniques and advances
Lecture 2	3D Brachytherapy guidelines
Lecture 3	3D Brachytherapy planning various optimization methods
Lecture 4	Inverse Brachytherapy planning
Lecture 5	Quality Assurance & Quality Control

Module 3:- Dosimetry

Lectures	Topic
Lecture 1	Dosimetry of X and gamma rays beams
Lecture 2	Details of IAEA and other protocols
Lecture 3	MOSFET and other advance dosimetryequipment
Lecture 4	In- vivo dosimetry for external and brachytherapy procedures
Lecture 5	Dosimetry of special procedures

Module 4:- Clinical Perspective

Lecture	Topic
Lecture 1	Introduction to Clinical Radiotherapy and Oncology
Lecture 2	Imaging modalities and methods in Oncology
Lecture 3	Effects of radiation on normal tissues
Lecture 4	Fractionation and multimodality treatment
Lecture 5	Genetic issues
Lecture 6	IGRT in H & N cancers
Lecture 7	IGRT in Gynecological cancers
Lecture 8	IGRT in Breast and lung cancers

Module 5:- Imaging Techniques

Lecture	Topic
Lecture 1	Modern Trends in Imaging techniques
Lecture 2	Magnetic Resonance Imaging (MRI)
Lecture 3	Clinical radioisotope laboratory and its organization, Cyclotron produces radionuclides, Cyclotron produced radionuclides
Lecture 4	PET, PET-CT, SPECT, Clinical Merits, Applications, Cases

Module 6:- Treatment Planning System

Lecture	Topic
Lecture 1	Computes in treatment planning, Factors to be incorporated in computational algorithms- Hardware and software requirements
Lecture 2	Review of algorithms for photon & electron beams
Lecture 3	Beam data requirements and acquisition
Lecture 4	Commissioning and QA of TPS, Role of Networking, Import/Export
Lecture 5	Concept of forward and Inverse planning
Lecture 6	Treatment planning for 3DCRT, evaluation tools (DVH,TCP/NTCP)
Lecture 7	Treatment planning for IMRT/IGRT Review of Literature and the AAPM task Groups, IAEA TECDOCS
Lecture 8	Treatment planning for Tomotherapy

Module 7: - Statistics

Lecture	Topic
Lecture 1	Introduction to probability, statistics and frequency distribution, Chi-square test, specificity, sensitivity, +ve predictive value, -ve predictive value
Lecture 2	Probability theory, sampling theory, correlation & regression
Lecture 3	Hypothesis testing, error types, follow-up indices
Lecture 4	Cancer registry, goodness of fit, Epidemiology

Mandatory Courses without Marks

Research Methodology		
RM1	Dr. SorabDalal Dr. P. Venkatraman	The flow and structure of a paragraph - case study. Grammar, common unscientific terms used in writing, the common pitfalls seen - direct translation of words from mother tongue to English
RM2	Dr. SorabDalal Dr. P. Venkatraman	Literature review - where to get material, the quality and quantity of content. Establishing a background for a research project
RM3	Dr. SorabDalal Dr. P. Venkatraman	Laboratory notebook maintenance - Do's and don'ts, Good research practice, ethics, plagiarism
RM4	Dr. SorabDalal Dr. P. Venkatraman	The art and science behind manuscript writing and successful research proposal Ideas, their formulations, what are aims and objectives, What constitutes results and discussions
RM5	Dr. SorabDalal Dr. P. Venkatraman	The fine art of power point presentation
RM6	Dr. Abhijit De	Preparing figures for manuscripts and grants

An abstract written by the students is corrected in class. There is no examination.

Reading material:

1. The Science of Scientific Writing. George D. Gopen and Judith A. Swan American Scientist, Volume 78

2. Guidelines on style for scientific writing by Will G Hopkins PhD

Annexure – III

ELECTIVES OFFERED AT TMC:

A total of twelve electives are being offered this year (this number will keep on changing as we start adding newer electives as per the needs of various PhD topics under the PhD guideship of a vast number of Guides with varied backgrounds)

The total marks for the electives are 400.

The Elective on Statistics (100 marks) is compulsory for all.

From the remaining options, the students have to choose any two or three electives for additional 300 marks.

JRFs must finalize their choice of electives in consultation with their Ph.D. guide, before sending an email to Academics Office.

The Course Coordinator would be the nodal person responsible for conducting the course and administering the tests.

The lectures may be taken by a number of faculty members, including those from institutions other than ACTREC / TMH.

Sr. No.	Elective Topics	Coordinator/s
1	**Biostatistics** ***Compulsory***	**Dr. Rajiv Sarin& Ms. Kannan**
2	**Animal Models in Cancer Research**	**Dr. Arvind Ingle**
3	**Cancer Therapeutics**	**Dr. Rukmini Govekar**
4	**Carcinogenesis, Chemoprevention and DNA Repair**	**Dr. Girish Maru & Dr. Manoj Mahimkar**
5	**Deregulation of Cell Growth in Cancer**	**Dr. Shilpee Dutt**
6	**Structural Bioinformatics, Biophysics & Structural Biology**	**Dr. Ashok Varma& Dr. Kakoli Bose**
7	**Tumor Immunology**	**Dr. Shubhada Chiplunkar**
8	**Metastasis**	**Dr. Pritha Ray**
9	**Nutrition**	**Dr. G. Chinnaswamy**
10	**Medical Physics**	**Dr. R. Kinhikar**
11	**Clinical Research**	**Dr. R. Sarin**
12	**Epidemiology & Preventive Oncology**	**Dr. R. Dikshit / Dr. S.A. Pimple**

Elective 1: Biostatistics

Coordinators: Dr. Rajiv Sarin& Mrs. SadhanaKannan

Sr. No.	Lecturer	Topic
1	Dr. Rajiv Sarin	An overview of Biostatistics
2	Mrs. SadhanaKannan	Probability distribution (normal, Poisson, t, F, Chi-square)
3	Mrs. SadhanaKannan	Problem solving - 1
4	Mrs. SadhanaKannan	Sample size determination and justification of power estimates in a research protocol - observational studies, clinical trials (superiority, non-inferiority / equivalence), animal studies
5	Mrs. SadhanaKannan	Problem solving - 2
6	Mrs. SadhanaKannan	Hypothesis testing: analysis of categorical data
7	Mrs. SadhanaKannan	Problem solving - 3
8	Dr. Sudeep Gupta	Biostatistics pertaining to survival analysis
9	Mrs. SadhanaKannan	Hypothesis testing: analysis of continuous data - parametric & non parametric tests (t-test, ANOVA, repeated measures ANOVA, ANCOVA, correlation, regression - linear and logistic)
10	Mrs. SadhanaKannan	Problem solving - 4
11	Mrs. SadhanaKannan	Hypothesis testing: analysis of time to event (survival data - Kaplan Meier analysis, log rank test and Cox regression analysis)
12	Mrs. SadhanaKannan	Problem solving - 5
	Mrs. SadhanaKannan	EXTRA – if needed
		Exam (100 marks)

Overall 100 Marks =

50 Lecture Contact Hours + 5 hours of Field Work / Practical = 3 Credits

Elective 2: Animal Models in Cancer Research

Coordinator: Dr. A.D. Ingle

Sr. No.	Lecturer	Topic
L1	Dr. Arvind Ingle	Introduction to laboratory animals
L2	Dr. Rahul Thorat	Anatomy of the laboratory rodents from cancer research aspect
L3	Dr. Arvind Ingle	Biology of commonly used laboratory animals
L4	Dr. SanjeevWaghmare	Generation of transgenic and knock-out mice and their application in cancer research
L5	Dr. GirishMaru	Animal models for carcinogenesis and chemoprevention
L6	Dr. VikramGota	PK/PD modelling in preclinical drug development
L7	Dr. Pritha Ray	Molecular imaging overview – tools and practices
L8	Dr. Abhijit De	Preclinical modelling of cancer – functional imaging techniques
L9	Dr. PradipChaudhari	Radio-isotopic techniques in cancer research
L10	Dr. PradipChaudhari	Spontaneous canine cancer and its application in cancer research
		Exam (100 marks)

Elective 3: Cancer Therapeutics

Coordinator: Dr. R. Govekar

Sr. No.	Lecturer	Topic
L1	Dr. Sudeep Gupta	Cancer chemotherapy; past , present and future
L2	Dr. Pritha Ray	Mechanisms of chemoresistance
L3	Dr. Rajiv Sarin	Cancer Radiotherapy
L4	Dr. RukminiGovekar	Identification of novel therapeutic targets
L5	Dr. ShilpeeDutt	Mechanisms of radioresistance
L6	Dr. Kumar Prabhash	Targeted therapy: clinical experience
L7	Dr. Ashok Varma	in silico tools for drug designing
L8	Dr. JyotiKode	Anticancer drug screening- in vitro and in vivo
L9	Dr. VikramGota	Drug development
L10	Dr. Abhijit De	Nanotherapeutics, theragnostics, cell therapeutic
L11	Dr. NeelamShirsat	Gene therapy and RNAi technology
L12	Dr. S.V. Chiplunkar	Cancer Immunotherapy
P	Presentations-1	
	Presentations-2	
	Presentations-3	
	Presentations-4	

Presentations (100 Marks)

Elective 4: Carcinogenesis, Chemoprevention and DNA Repair (100 marks)

Course Coordinators: Dr. Girish Maru& Dr. Manoj Mahimkar

Sr. No.	Lecturer	Topic
1	Dr. Girish Maru	Carcinogenesis overview and concepts of initiation, promotion and progression, Chemical carcinogenesis
2	Dr. Girish Maru	Biomarkers of carcinogen exposure, biologically effective dose. Markers of early response, late effects and disease
3	Dr. Manoj Mahimkar	Biomarkers of carcinogen exposure, biologically effective dose. Markers of early response, late effects and disease
4	Dr. Manoj Mahimkar	Short term and long term assays; Model test systems for detection of environmental mutagens/ carcinogens/ initiators/ promoters
5	Dr. Manoj Mahimkar	Short term and long term assays; Model test systems for detection of environmental mutagens/ carcinogens/ initiators/ promoters
6	Dr. Manoj Mahimkar	Role of DNA damage and repair in carcinogenesis
7	Dr. Sanjay Gupta	Epigenetics and Carcinogenesis
8	Dr. Abhijit De	Viral carcinogenesis with major focus on HPV
9	Dr. Girish Maru	Chemoprevention: Why chemoprevention, what is chemoprevention, Environmental chemopreventive agents
10	Dr. Girish Maru	Chemoprevention: Why chemoprevention, what is chemoprevention, Environmental chemopreventive agents
P	Presentations-1	
	Presentations-2	
	Presentations-3	
	Presentations-4	

Presentations (100 marks)

Electives 5: Deregulation of Cell Growth in Cancer

Coordinators: Dr. Shilpee Dutt

Sr. No.	Lecturer	Topic
L 1	Dr. S. Dalal	Orientation and Rb family of proteins in regulation of cell growth
L 2	Dr. A. Dutt	Role of Ras family in regulating cell growth
L 3	Dr. N. Shirsat	Role of the P13K-AKT-mTOR pathway in cancer
L 4	Dr. A. Dutt	Myc and tumor progression
L 5	Dr. S. Dalal	Cell cycle checkpoints and cancer
L 6	Dr. S. Dutt	The p53 family: regulation of cell growth and cell death
L 7	Dr. S. Dutt	Senescence and cancer
L8	Dr. N. Shirsat	Wnt signaling and cancer
P	Presentations-1	On Lecture 1 & 2
	Presentations-2	On Lecture 3 & 4
	Presentations-3	On Lecture 5 & 6
	Presentations-4	On Lecture 7 & 8
A	**Will be informed in the class**	**Assignment deadline**
Presentations (50 marks) & Home Assignments (50 marks)		

Electives 6: Structural Bioinformatics, Biophysics & Structural Biology

Coordinators: Dr. Ashok Varma& Dr. Kakoli Bose

Venue: Seminar Room (3rd Fl. KS-331B) Time: Lecture -10 am& Presentations - 10 am

Sr. No.	Lecturer	Topic
L1	Dr. Kakoli Bose	Spectroscopic techniques Absorption spectroscopy; Fluorescence spectroscopy: Basic and various applications (quenching, FRET, etc.)
L2	Dr. Murali Krishna Chilakapati	Spectroscopic techniques Raman spectroscopy
L3	Dr. Prasanna Venkatraman	Biophysical methods: Protein conformation, interactions and oligomeric properties
L4	Dr. MV Hosur	X-ray crystallography
L5	Dr. Ashok Varma	X-ray crystallography (Hands-on)
L6	Dr. Kakoli Bose	NMR spectroscopy -- 1
L7	Dr. Kakoli Bose	NMR spectroscopy -- 2
L8	Dr. M.S. Madhusudhan (IISER, Pune)	Structural Bioinformatics Molecular Modeling (homology, threading, ab initio); Small molecule/ peptide design; MDS: Different tools available for these insilico studies
L9	Mr. Nikhil Gadewal	Molecular Docking (protein-protein, protein-ligand/ small molecules)
L10	Ms. Alpana Gupte Bastikar, Elphinstone College	Drug Designing - challenges, in-silico drug design – advantages - steps and tools (QSAR, 3D-QSAR etc); Application - How drug design-ning leads to clinical trial - with examples.
L11	Mr. Nikhil Gadewal	Hands-on-session on Bioinformatics
100 Marks (Exam)		
Bioinformatics MCQ: 20 marks, Bioinformatics hands-on: 10 marks, other subjects: 10 marks each (MCQ, subjective and problems)		

Elective 7 - TUMOR IMMUNOLOGY Co-coordinator - Dr. Shubhada Chiplunkar(5 lectures, 100 marks - Presentations)		
Sr. No.	**Topic of Lecture**	**Faculty**
1	Immune cells & their role in tumor immunity	Dr. Shubhada Chiplunkar
2	Tumor Antigens and anti-tumor effector functions of immune cells	Dr. JyotiKode
3	Immunosuppressive networks in cancer	Dr. Rushikesh Patil
4	Cancer Immunotherapy	Dr. Shubhada Chiplunkar
5	Cellular and molecular techniques for studying tumor immunity	Dr. JyotiKode
	Presentations	On all lectures
Presentations - 100 marks		

Electives 8: Metastasis Coordinator: Dr. Pritha Ray		
Sr. No.	**Lecturer**	**Topic**
L1	Dr. Sorab Dalal	Molecular basis of detachment & migration of Cancer Cell Regulation of cell-cell adhesion, Regulation of cell-matrix adhesion, Regulation of cytoskeletal dynamics and how they affect migration
L2	Dr. Sorab Dalal	Molecular basis of invasion & intravasation Formation of invadopodia, Dissolution of cell matrix, Migration through narrow spaces
L3	Dr. Pritha Ray	Molecular basis of survival in bloodstream, arrest & extravasion Haematogenous & Lymphatic spread of metastatic tumor cells, Survival in intravascular environment, Extravasation & MET
L4	Dr. Manoj Mahimkar	Molecular basis of metastatic colonization Seed & soli hypothesis, Effect of microenvironment
L5	Dr. Sonam Mehrotra	EMT, Anoikis& MET during metastasis EMT-MET in phenotypic plasticity, Mechanisms that link

		oncogenic EMT and suppression of anoikis, How EMT programs may lead to anoikis resistance, The role of cell polarity in anoikis, Insights in to the role of Hippo, Wnt and TGF-b signalling in EMT and anoikis
L6	Dr. Sonam Mehrotra	Role of Hippo, Notch and Wnt signaling Cross talk between signalling pathways in cancer metastasis, Therapeutic potential of Hippo signalling and other signalling pathways in cancer
L7	Dr. Pritha Ray	CSCs, CTCs in metastasis Role of Cancer stem cell in metastatic spreading, Circulating tumor cells and their relation to metastatic progression
L8	Dr. Syed Hasan	Targeted therapy in metastasis Biological effects of the fusion proteins and genetic alterations in cancer metastasis, Molecular basis of the targeted therapy, Clinical applications
L9	Dr. Shubhada Chiplunkar	Immunotherapy Immune system in cancer metastasis, Tumor microenvironment in metastasis, Immunotherapy for metastasis
L10	Dr. Abhijit De	Models of metastasis & Imaging metastasis Challenges in in vivo metastasis experiments, In vivo metastatic models – chemically induced, transplantable and genetically modified model, Applications of imaging guidance in monitoring and quantitation of metastatic loads
P	Presentations -	On Lecture 1 & 2 On Lecture 3 & 4 On Lecture 5 & 6 On Lecture 7&8 On Lecture 9 & 10
Presentations 100 marks		

ELECTIVE 9: Bioinformatics

a. DNA data resources (EMBL, Gen Bank, DDBJ), Genome Browsers (UCSC, Ensembl, NCBI)
b. Data and sequence alignment, Protein scoring systems (PAM, BLOSUM), Phylogenetic trees
c. Transcriptomics (RNA and small RNA): study design, sample size, platform selection, analytical methods, tertiary analysis, pathways and network analysis
d. Whole genome and targeted sequencing: study design, sample size, platform selection, analytical methods, tertiary analysis, pathways and network analysis
e. Omics based techniques: introduction to – NGS, sequenome mass array, reverse phase protein array, circulating tumour cell isolation, single cell omics
f. Epigenomics: study design, sample size, analytical methods, tertiary analysis

ELECTIVE 10: Molecular epidemiology

a. Markers of exposure (chemical metabolite, biological agents, diet, DNA adduct)
b. Marker of effect (gene mutation, epigenetic alteration, cytogenetic abnormalities)
c. Markers of susceptibility (high penetrance gene, genetic polymorphism, DNA repair)
d. Brief description laboratory methods in molecular epidemiology
e. Outline of analysis for quality of molecular epidemiology data

ELECTIVE –11: Human genetics & Pathological anatomy of cancer

a. Mendelian genetic
b. Chromosome structure and function
c. Chromatin structure and function
d. Pathology-1 (Classification of neoplasm)
e. Pathology-2 (Carcinomas)
f. Pathology-3 (Sarcomas)
g. Pathology- 4 (Lymphoma)
h. Pathology- 5 (Leukemia)
i. Diagnostic tests for cancer

ELECTIVE – 12: Cancer registries & Biological sample collection and storage

a. Types of registries and their operation
b. Analysis of registry data
c. Methods of follow- up
d. Visit to PBCR, Mumbai
e. Storage and collection of biological samples in large scale studies
f. Pre- analytical methods to assess the quality
g. Quality assurance for collected samples
h. Use of advanced instruments – 1
i. Use of advanced instruments – 2

Elective 13: Pediatric Onco Nutrition

Content	Contact Hours	Credit Points
Onco Nutrition- Introduction, Concepts and Principles i. Assessment of various types of cancers through case study. (2) ii. Types of treatment – chemo, radiation and surgery along with drugs (2) iii. Nutritional assessment methods- Use of algorithms and TMH approach (2) iv. Energy and protein requirements for various types of cancer (2) v. Nutritional complications in cancer (4) vi. Review diets for Survivors of childhood cancer (1)	**50 + 5**	**3**
Medical Nutrition Therapy – Assessment and Dietary Principles i. Nutrigenomics & Nutrigenetics / immunomodulators (2) ii. Dietary guidelines in cancer patients including neutropenic diet (2) iii. Management of severe acute malnutrition (2) iv. Dietary assessment & estimation of protein & energy needs in children (2) v. Nutritional Risk assessment (2) vi. Enteral nutrition in children (2) vii. Parenteral nutrition in children (1)	**50 + 5**	**3**

Pediatric Onco Nutrition – Concepts and Principles i. Assessment of various types of cases through case study (2) ii. Types of treatment – chemo, radiation and surgery along with drugs (2) iii. Nutritional assessment methods – Use of algorithms and TMH approach (2) iv. Plan diets according to energy and protein requirements for various types of cancer (10) v. Plan diets for various nutritional complications in cancer (10) vi. Review and plan diets for Survivors of childhood cancer (4)	**50 + 5**	**3**
Medical Nutrition Therapy – Allied Services i. Diet Counselling (5) ii. Enteral nutrition in children- Practical aspects (Indications, algorithms for choice/access sites monitoring), RT feedingetc, Micronutrientsupplementation (5) iii. Parenteral nutrition in Children-Practical aspects (Indications, algorithms for choice. Access sites monitoring, nutrients- drug interaction) (5) iv. Psychosocial aspects of Nutrition in children with cancer families (4) v. Speech Therapy, occupational psychologists counselling (4) vi. Management of side reactions (4) vii. Keeping track of prognosis (3)	**50 + 5**	**3**

Mandatory Electives without Marks: Safety in Health Science Research

1. **Cyber Safety and Security (2 Lectures)**
2. **Fire Safety (2 Lectures twice in a year)**
3. **Radiation Safety (12 Lectures)**

ELECTIVE: RESEARCH METHODOLOGY – I

I. Basic tools of research

a. The flow and structure of a paragraph case study. Grammar common unscientific terms used in writing, the common pitfalls seen, direct translation of words from mother tongue to English
b. Literature review – where to get material, the quality and quantity of content. Establishing a background for a research project
c. Laboratory notebook maintenance – Do' s and Don'ts, Good research practice, ethics, plagiarism
d. The art and science behind manuscript writing and successful research proposal
e. The fine art of power point presentation

ELECTIVE: RESEARCH METHODOLOGY – II

Basic Epidemiology

a. Basic concept in epidemiology, study designs, Sample size determination, Descriptive studies, Interventional trials
b. Cohort studies, case- control studies
c. Bias and confounding, Interaction, Exposure assessment
d. Epidemiological field work in population based studies
e. Interpretation of epidemiological studies, Sample size determination
f. Principles of data analysis

ELECTIVE: RESEARCH METHODOLOGY – III

Clinical trial methodology introduction to evidence based medicine

a. Study designs in clinical trials, Study objectives and endpoints
b. Sample size determination, likelihood ratio
c. Study population, Baseline assessment, Randomization, Blinding
d. Follow –up, Counting events
e. Non- inferiority trials, Cross- over trials, Meta- analysis, Systematic reviews
f. Data Monitoring, Stopping rules
g. Ethical issues in clinical trials

ELECTIVE: RESEARCH METHODOLOGY – IV

Tumor Immunology & Stem Cell Biology

a. Differentiation, Development and Cancer
b. Stem cells & Cancer stem cells, Embryonic Stem cells, reprogramming &pluripotency, Adult stem cells
c. Tumour Immunology – I: Basic Concepts in immunology, immune evasion strategies, cell types participating in tumour immunity, immunotherapy
d. Tumour Immunology – II: Monoclonal Antibodies: Applications in cancer diagnosis / therapy, Vaccines, cell-based therapies
e. Tumour Immunology – II: Tumour microenvironment, Role of cytokines/ chemokines, role of tumour associated macrophages, role of myeloid derived suppressor cells, role of T-reg cells
f. Nude/ SCID mice: origin of nude /SCID mice, immune scenario/ immune defects; Models for tumour development, newer Strains, Applications in cancer research

Cancer Biology: Elective Courses

Sr. No.	Subject	Marks	Hours (Hrs)
1	Biostatistics	100	200 Hrs
2	Cancer Therapeutics	100	
3	Carcinogenesis, Chemoprevention and DNA repair	100	
4	Metastasis	100	

1	Biostatistics	100	200 Hrs
2	Animal models in cancer research	100	
3	Cancer Therapeutics	100	
4	Carcinogenesis, Chemoprevention and DNA repair	100	

1	Biostatistics	100	200 Hrs
2	Animal models in cancer research	100	
3	Cancer Therapeutics	100	
4	Deregulation of Cell Growth in Cancer	100	
5	Molecular biology of gene		

ANY 3 - TOTAL 300 MARKS

1	Bioinformatics	100	
2	Basic tools of research	100	
3	Tumour Immunology & Stem Cell biology	100	
4	Basic Epidemiology	100	
5	Molecular Epidemiology	100	
6	Clinical trial methodology	100	
7	Human genetics & Pathological anatomy of cancer	100	
8	Cancer registries & Biological sample collection and storage	100	

Pediatric Onco nutrition: Elective courses

Sr. No.	Subject	Marks	Hours (Hrs)
1	Biostatistics (Written Test)	100	200 Hrs
2	Cancer Therapeutics	100	
3	Carcinogenesis, Chemoprevention and DNA repair (Presentation)	100	
4	Deregulation of Cell Growth in Cancer (Assignment & Presentation)	100	

Mandatory (Research Methodology)

Research Methodology	No. of Lectures	Marks
Lectures	6 Lectures	No marks
Laboratory work	All through the year	200 marks = 100 hrs = 6 credits
Scientific writing	Assessed at final seminar	100 marks = 50 hrs = 3 credits

- **Course work duration : 3 trimesters**
- **No. of core courses to be taken: 4 Nos.**
- **Minimum No. of elective courses to be taken: 4 Nos. from a total of 7 available elective courses**
- **Research project assignment to be taken: 2 nos.**

Clinical Research: Elective Courses

Sr. No.	Subject	Marks	Hours (Hrs)
1	Oncology health care systems and optimal resource utilization	100	200 Hrs
2	Oncogenetic counseling & risk management	100	
3	Genetic testing & its interpretation	100	
4	Applied Biostatistics	100	

Medical Physics: Elective Courses

Any 2 _ 20 Lectures / 40 academics hrs/200 marks **20 Lectures / 100 academics hrs/200 marks**			
Sr. No.	**Subject**	**Marks**	**Hours (Hrs)**
1	3DCRT Planning & Image Fusion	100	100 Hrs
2	IMRT Commissioning / Planning	100	
3	IGRT Commissioning / Planning	100	
4	3D Brachy Planning	100	
5	QA Lin. Accelerator & Brachytherapy	100	

TATA MEMORIAL CENTRE

(A Constituent Institution of the HomiBhabha National Institute*, Mumbai, India)

Ph.D Course in Health Sciences

MARKSHEET

Academic Year: 2018 - 2019

Program Name: Ph.D. Discipline: Health Sciences

Student Name: Enrolment No.: HLTH

Core Course (Total 1000 marks)	Maximum Marks	Marks Obtained
I . Cell Biology and Cancer Cell Biology	250	
II. Molecular Biology and Epigenetics	250	
III.Tumour Immunology, Stem Cell Biology and Macromolecular Biophysics	200	
Presentation - I	100	
Presentation - II	100	
Advanced Technology	100	
Sub Total	**1000**	
Electives (totaling 400 marks) (Any 4)	**Maximum Marks**	**Marks Obtained**
Biostatistics	100	
Animal Models in Cancer Research	100	
Cancer Therapeutics	100	
Carcinogenesis, Chemoprevention and DNA Repair	100	
Deregulation of Cell Growth in Cancer	200	
Structural Bioinformatics, Biophysics and Structural Biology	100	
Tumour Immunology	100	
Sub Total	**400**	
Seminar	**200**	
Research Methodology	**300**	
General Comprehensive Exam	**100**	
Total Marks: / 2000 (%)	**Pass / Fail**	

Date:

Dr. Rajiv Sarin
Chairperson, Academic Committee
TMC

Dr. ShripadBanavali
Director - Academics, TMC

Checked by:
Prepared by:

*University established under section 3 of the UGC Act, 1956 vide Notification no.F.9-5/2004-U3 dated June 3, 2005 of Govt. of India

Homi Bhabha National Institute

Ph.D. PROGRAMME (Health Sciences)

PROGRESS REVIEW[1] REPORT

1. **Name of the Student:**
2. **Name of the Constituent Institution: Tata Memorial Centre-ACTREC**
3. **Enrolment No. and Date of Enrolment:**
4. **Title of the Thesis:**
5. **OGCE:** Held on / yet to be held
6. **Review Period and Date of Meeting:**

1. Report of Doctoral Committee

2. Recommendations

Grade : Excellent/Very Good/Good/Satisfactory/Poor

Recommendation for continuation: Yes/No

Likely year of finishing the programme(in case recommended to Continue):

3. Future Guidelines

[1] To be conducted only after a student has submitted a brief progress report to doctoral committee explaining progress made during the period in research, papers published, completed courses with marks obtained (taught courses, self-study courses, credit seminars) with appropriate certification thereof, pending courses and work planned in next year. Report from the student should be attached to the progress review report.

4. **Next[2] Progress Report due on:**

5. **Doctoral Committee:**

Sr. No.	Name	Designation	Signature	Date
1.		Chairman		
2.		Guide &Convener		
3.		Co-guide (if any) Member		
4.		Member		
5.		Member		
6.		Member		
7.		Technology Adviser		

Forwarded through :

Dr. Rajiv Sarin

Chairperson, Academic Committee, (PhD. Health Sciences),

TMC

Dr. Shripad D. Banavali

Dean-Academic

T. M. C.

To

Dean, HBNI

[2] One progress report per year is mandatory. Doctoral committee can ask more frequent progress reports.

C.C. All monitoring committee members and Reporting Student

TATA MEMORIAL CENTRE

REPORT OF THE FIRST DOCTORAL COMMITTEE MEETING OF

____

Mr./Ms................................

FOR REGISTRATION TO HBNI FOR THE Ph.D. DEGREE (Health Sciences)

Doctoral Committee of Mr./ Ms. ________________________________, Ph.D. student with Research Guide, Dr. ________________________________ was held on _______________ at ______ ____________________________, The committee comprised of the following members:

1. Dr. _______________________ (Chairperson)
2. Dr. _______________________ (Guide)
3. Dr. _______________________ (Member)
4. Dr. _______________________ (Member)
5. Dr. _______________________ (Member)
6. Dr. _______________________ (Invitee)
7. Dr. _______________________ (Advisor)

The committee questioned the candidate on his / her project entitled '____________________ ____'. They are of the opinion that:

1. The candidate is suitable for conducting research
2. He / She has the adequate knowledge base to pursue research

Based on his / her performance the committee recommends _____ **/100** marks as an evaluation parameter. He / She may **thus proceed with the project work for Ph.D. degree of the HBNI**. His / Her fellowship may be continued for the second year.

____________ ____________ ____________ ____________

Dr. XYZ, Chairperson Dr. ABC, Guide Dr. EFG, Member Dr. EFG, Member

____________ ____________ ____________ ____________

Dr. EFG, Member Dr. EFG, Invitee / Tech. Advisor Dr. EFG, Invitee / Tech. Advisor

Dr. Rajiv Sarin

Chairperson, Academic Committee (Ph. D. Health Sciences), TMC

Homi Bhabha National Institute

Ph.D. PROGRAMME (Health Sciences)

ORAL GENERAL COMPREHENSIVE EXAMINATION REPORT (OGCE)

3. **Name of the Student:**

4. **Name of the Constituent Institution: TMC-ACTREC**

3. **Enrolment No.:**

4. **Board of Studies: Life Sciences**

The Oral General Comprehensive Examination of Shri/Ms.______________________ was conducted on __________. The monitoring/doctoral committee is fully satisfied with his/ her performance and permits him/ her to continue with his/ her Ph.D. Programme.

The student has studied research methodology theory and on examination was found to be proficient in research methodology as applicable to his/her field of study. He / She fulfills the criterion 4 and criterion 6 of UGC 11 point criteria.

Doctoral Committee:

Sr. No.	Doctoral Committee	Name	Signature	Date
1.	Chairman			
2.	Guide/Convener			
3.	Co-Guide (if any)			
4.	Member-1			
5.	Member-2			
6.	Member-3			
7.	Technology Advisor (if any)			

Forwarded through :

Dr. Rajiv Sarin

Chairperson, Academic Committee, (PhD. Health Sciences),

TMC

Dr. Shripad D. Banavali

Dean-Academic

T. M. C.

To

Dean, HBNI

CC. Dean-Academic& Student

TATA MEMORIAL CENTRE

(A Constituent Institution of the HomiBhabha National Institute*, Mumbai, India)

Assessment Report of Doctoral Committee (Ph.D. Health Sciences)

For Upgradation To SRF

Name of Ph.D. student : Shri. / Ms………………………..

Enrollment Number : …………………………………..

Date of Open DC Meeting : …………………………………..

Venue : ………………………………….

The committee members were satisfied with the work done and presented by Shri/Ms………….. and Doctoral Committee recommends her/him to be upgraded from JRF to SRF and that he/she can continue the fellowship for the next year.

RCOMMENDATION :(strike out whichever is not admissible)

1. Shri/Ms ___________________________ may be upgraded as SRF and his/her Stipend per month may be raised as per rules.
2. Shri/ Ms __________________________ may be allowed to continue for third year on the existing rate of stipend.

DOCTORAL COMMITTEE:

Sr. No.	Name	Designation	Signature	Date
1.		Chairman		
2.		Guide & Convener		
3.		Co-guide(if any) Member		
4.		Member		
5.		Member		
6.		Technology Adviser		

Forwarded through :

Prof. Rajiv Sarin
Chairperson, Academics Committee,
Ph.D. (Health Sciences),
TMC

To
Dr. S. D. Banavali
Dean-Academic
T. M. C.

CC. Dean, HBNI
Reporting Student

BACK TO MAIN

GOVERNMENT OF INDIA

BHABHA ATOMIC RESEARCH CENTRE

SYLLABUS

Orientaion Course for Engineering Graduates and Science Post Graduates (OCES)

INTEGRATED Ph.D.(DOUBLE DEGREE) ENGINEERING SCIENCES (PROGRAM CODE: ENGG05)

BARC Training School, Mumbai

HUMAN RESOURCE DEVELOPMENT DIVISION

MUMBAI 400085

PREFACE

The Department of Atomic Energy (DAE) has the multi pronged mandate of the utilisation of the power of the atom towards generation of power, development of advanced technologies, directed research in various scientific and engineering disciplines, production of radioisotopes for societal applications in medicine and agriculture and towards national security. In order to become self reliant and self sustaining in this high technology area, the need for generating highly skilled manpower and ensuring its continuous availability was indispensable. Thus in 1957, the BARC Training School (BARCTS) was established as a centre for in house training of professionals. These professionals today form the backbone of the Nuclear Power Programme. More than 9000 trainees have graduated from BARC TS over the last 61 years and provide the technological leadership in DAE for all its important programmes. Over the last five and a half decades, the BARCTS has grown into a model institute, recognised internationally as a school of excellence.

The academic activities of BARCTS are carried out by the Human Resource Development Division (HRDD) from its campus situated at Anushakti Nagar, well away from the hustle and bustle of Mumbai, nestling between wooded hills and sylvan surroundings, close to the BARC premises. This crucible of learning has been a focus of attraction to many a bright young talent, eager and willing to learn, guided and mentored by an academia drawn from the pool of experts available within DAE. Hailing from some of the best universities in India, they are nurtured with care and concern, by means of a holistic approach to training and personality development. A judicious mix of academics, practical training and soft skills training is imparted at the Training School and at the state of the art laboratories of BARC. A well equipped hostel with sports, recreation, and internet facilities provides the right environment needed for wholesome development. The lure of a professionally challenging career with opportunities for upgradation of skills, an objective merit recognition based career growth pattern and attractive compensation packages have attracted the best talents to BARCTS.

The BARCTS has two principle programmes, the One-Year **Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)** and the **DAE Graduate Fellowship Scheme (DGFS)**

Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)

OCES is the flagship programme of the BARC Training School and its affiliates. Under this scheme, engineering graduates from eight engineering disciplines- Mechanical, Chemical, Metallurgy, Civil, Electrical, Electronics, Instrumentation & Computer Science and Science Post-Graduates from Physics, Chemistry & Biological Sciences are selected and imparted a

rigorous one year training in the field of Nuclear Science and Technology. In addition to the above 11 disciplines, selected post graduate candidates from the Physics and Chemistry disciplines are also inducted into a course specifically designed for the purpose of providing a holistic training in all aspects of radiological safety. This course has been named as "Radiological Safety Engineering' course.

The curriculum provides multidisciplinary training in topics relevant to the nuclear industry, frontier areas of science and technology and some super specialized areas. Training is imparted by adjunct faculty comprising the scientists and engineers working in various projects of DAE. In this manner, not only the objective of training but also the greater task of seamless and effective knowledge transfer from the expert to the acolyte is carried out successfully. The scheme also ensures the retention of the trained manpower within the Department thereby maximising the benefits of the training programme to the Department.

A total of about 150 courses in the above disciplines comprising more than 4000 lectures are delivered by more than 500 adjunct faculty members from BARC and other educational institutes during this period.

OCES Training Objectives: It involves one year of academic and training programme at the BARC Training School. The training programme aims to ensure that the selected candidates are provided with the necessary facilities and opportunities to acquire knowledge and develop skills for meeting the challenging technological goals of the country in the field of nuclear S&T. The training courses are organized in a structured manner as detailed below

- Foundation courses impart multidisciplinary training in the topics relevant to the nuclear industry.
- Core courses bring all selected candidates from different universities to the same or common level of understanding in the core subjects of the respective disciplines.
- Elective courses impart training in few specialized areas in respective disciplines.

OCES graduates are also eligible for the award of Post Graduate Diploma in Nuclear Science/Engineering & Technology of HBNI. After joining the DAE, the eligible OCES graduates can undertake one year project work leading to the award of M.Tech./M.Phil. Degree of the HBNI.

DAE Graduate Fellowship Scheme (DGFS)

In order to meet the requirement of highly specialised professionals in specific areas, DAE initiated the DGFS Programme for inducting engineers at MTech level in collaboration with the six IITs viz. Bombay, Delhi, Kanpur, Kharagpur, Madras, Roorkee and BHU in addition to some other elite institutes such as NIT Rourkela and ICT, Mumbai. The scheme strengthens the research-education linkage with premier institutes of the country in the areas of interest to DAE and provides useful synergy between the nuclear sector and the academia

Under this scheme, trainees selected for the OCES programme as well as one of the above institutes pursue the M.Tech degree under the sponsorship of DAE. On completion of the MTech degree, the candidates are absorbed into DAE as a Scientific Officer with advance increments. These Fellows then undergo a 4-month Orientation Course for DGFS Fellows (OCDF) after successful completion of M.Tech.

Orientation Course for DGFS Fellows (OCDF)

Several topics of interest to the Department do not form part of the MTech curriculum. To provide an exposure to such topics, the DGFS Fellows undertake a four months orientation course in the BARC Training School **(Orientation Course for DGFS Fellows- OCDF)** after successful completion of their MTech. Programme.

This document furnishes the course structures of all disciplines and syllabi of the courses conducted by the BARC Training School under each discipline.

CONTENTS

SYLLABUS

ENGINEERING SCIENCES

Annexure-I

REVISED CREDITS
FOR
COURSES IN ENGINEERING SCIENCES

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (MECHANICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for PVP	EN610	60	6	250
2	Computational fluid Dynamics and Heat Transfer	EN611	50	6	200
3	Finite Element Method	EN621	30	4	125
4	Fracture Mechanics	EN622	40	4	150
5	Mechanics of Solids	EN624	40	4	150
		Core Total	**220**	**24**	**875**

ELECTIVES (MECHANICAL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Machine Design	EN711	25	2	100
4	Material Science in Nuclear Engineering	EN712	25	2	100
5	Multi-scale material modelling	EN715	30	4	125
6	Preparedness & Response to Nuclear Emergencies	EN716	35	4	150
7	Reliability Engineering	EN718	25	2	100
8	Vibration	EN721	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CHEMICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25	2	100
2	Advanced Mass Transfer	EN604	25	2	100
3	Code design for PVP	EN610	30	4	125
4	Computational Fluid Dynamics and Heat Transfer	EN611	50	6	200
5	Nuclear Chemical Engineering	EN628	35	4	150
6	Process Dynamics and Control	EN634	45	6	200
7	Process Modeling, Simulation and Optimization	EN635	45	6	200
	CORE TOTAL		**225**	**30**	**950**

ELECTIVES (CHEMICAL) – Any 3 Courses - 9 CREDITS

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Material Science in Nuclear Engineering	EN712	20	2	75
4	Membrane Technology	EN714	35	4	150
	ELECTIVES TOTAL (APPROX)		**90**	**8-10**	**350**

	THEORY TOTAL	**535**	**62-64**	**2175**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 535; Total Credits: 106-108; Total Marks: 2775

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - METALLURGY

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (METALLURGY)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	2	75
2	Extractive Metallurgy	EN620	40	4	150
3	Mechanical Metallurgy	EN623	30	4	125
4	Nuclear Materials	EN629	50	6	200
5	Nuclear Metallurgy	EN630	30	4	125
6	Physical Metallurgy	EN631	40	4	150
7	Process Control & Instrumentation	EN632	25	2	100
		CORE TOTAL	**230**	**26**	**925**

ELECTIVES (METALLURGY) Any 3 Courses- 9 Credits

S.No.	Subject Title		Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Image processing and Machine Vision	EN710	30	4	125
4	Materials Characterization	EN713	20	2	75
5	Multi scale Material Modeling	EN715	30	4	125
6	Nuclear Chemical Engineering	EN628	35	4	150
7	Nuclear Emergencies	EN716	35	4	150
8	Welding Science & Technology	EN723	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**8-12**	**350**

	THEORY TOTAL	**540**	**58-62**	**2150**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 540; Total Credits: 102-106; Total Marks: 2750

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (CIVIL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1	30	4	125
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2	30	4	125
3	Design Basis Hazards & Geotechnical Engg	EN621	40	4	150
4	Earthquake Engineeing & Structural Dyanmics	EN609	45	6	200
5	Finite Element Method	EN626	30	4	125
6	Mechanics of Solids	EN624	40	4	150
		Core Total	**215**	**26**	**875**

ELECTIVES (CIVIL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Struct Dynamics & Earthquake Engg	EN724	30	4	100
2	Construction Materials, Management & Quality	EN714	30	4	100
3	Safety & Reliability of Civil Engineering	EN722	25	2	100
4	Project Management	EN717	25	2	100
	ELECTIVES TOTAL (APPROX)		**80**	**8-10**	**300**

	THEORY TOTAL	**515**	**58-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 520; Total Credits: 102-104; Total Marks: 2600

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECRICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	20	2	75
2	Computer Based System Design I	EN612	25	2	100
3	Electrical Systems for Nuclear Power Plants	EN618	30	4	125
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**195**	**22**	**800**

ELECTIVES (ELECTRICAL) Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design II	EN702	25	2	100
2	Artificial Intelligence and its Applications	EN703	30	4	125
3	Computer Based System Design II	EN704	25	2	100
4	Digital Signal Processing & Image Processing	EN706	30	4	125
5	Image Processing & Machine Vision	EN710	30	4	125
6	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
7	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**525**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECTRONICS)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	4	125
2	Advanced Nuclear Instrumentation	EN605	40	4	150
3	Embedded & Computer Based Sys. Design	EN619	45	6	200
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**200**	**28**	**825**

ELECTIVES (ELECTRONICS) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Embedded Electronics Software	EN707	25	2	100
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**60-66**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 104-110; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (INSTRUMENTATION)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40	4	150
2	Computer Based System Design I	EN612	25	2	100
3	Modern Control Systems Design and Simulation	EN625	35	4	150
4	Reactor C&I and Human Machine Interface	EN636	40	4	150
5	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
6	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		EN639	**20**	**775**

ELECTIVES (INSTRUMENTATION) Any 3 Courses-- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	125
2	Computer Based System Design II	EN706	25	2	100
3	Digital Signal Processing & Image Processing	EN707	30	4	125
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**8-12**	**350**

	THEORY TOTAL	**525**	**54-58**	**2075**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-102; Total Marks: 2675

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25	2	100
2	Computer Graphics & Visualisation	EN613	35	4	150
3	Distributed Computing	EN616	45	6	200
4	Networking & Information Security	EN6627	40	4	150
5	Reactor Control Engineering	EN637	15	2	75
6	Software Engineering and Formal Methods	EN640	40	4	150
	CORE TOTAL		**200**	**22**	**825**

ELECTIVES (COMP. SCIENCE AND ENGINEERING) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Data Base Management System & Web Technology	EN705	30	4	100
3	Digital Signal Processing & Image Processing	EN706	30	4	125
4	Embedded Electronics Software	EN707	25	2	100
5	Feedback Control System	EN708	25	2	100
6	Image Processing & Machine Vision	EN710	30	4	125
	3 ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)

Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

FOUNDATION COURSES

EN501: Accelerator Physics and Technology

Basic Accelerator Physics (5)

- Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons;
- Ion sources.
- General equations of motion in a combined electric and magnetic field, beam rigidity; relativistic expressions, weak and strong focusing principle; condition for strong focusing.
- Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.
- General design of a cyclic accelerator.
- Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;
- Matrix techniques in beam optics; first order transfer matrix of dipole, quadrupole, transfer matrix of a drift space; quadrupole doublet;
- Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters
- Introduction of normal (room temperature) DC and pulsed magnets, construction features. Superconducting coils, magnets and their construction features.
- Momentum compaction; Phase stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.
- Synchrotron radiation sources; spectrum of emitted radiation; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators.

RF Linacs (12)

Introduction to Linacs

- Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.
- Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac
- Transit time factor and the energy gained in a linac.
- Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.
- General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature RF structures.

Proton Linac

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.
- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
- Introduction to Space charge effects.
- Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Accelerator Driven Systems & RF electron accelerators

Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.

Accelerator Technology (13)

General

- Material selection for Accelerator components
- Mechanical Design and fabrication issues; tolerances, surface finish, etc
- Thermal management in accelerator systems
- Alignment requirements of accelerator magnets and RF structures, methods and instruments for alignment and surveying in accelerators.

Ultra High Vacuum Systems

Basic concepts in Vacuum

- The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
- Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
- Basics of low pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, Sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.

Cryogenics Systems

Introduction to Cryogenic Engineering

- General and basics, Cryogenic properties, Basic cycles
- Large Cryogenic Systems for Accelerators

Cryogenic Equipments

- Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

References

1. Principles of RF Linear Accelerators, T. P. Wangler, (John Wiley & Sons Inc., 1998)
2. Introduction to Accelerator physics – Arvind Jain
3. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer, (John Wiley & Sons Inc., 1982)
4. An Introduction to the Physics of Particle Accelerators - M. Conte, W.W. Mac Kay.
5. Handbook of Accelerator Physics and Engineering - A. Chao, M. Tigner.
6. Particle Accelerator Physics (Vol 1 and Vol 2) - Helmut Widemann.
7. Principles of Charged Particle Acceleration – Stanley Humphries.
8. Fundamentals of Beam Physics - James Rosenzweig.
9. An Introduction to Particle Accelerators - E. J. N. Wilson.
10. Accelerator Physics - S. Y. Lee.
11. The Physics of Particle Accelerators, An Introduction - Klaus Wille.
12. The Principles of Circular Accelerators and Storage Rings - Philip Byrant.
13. Introduction to Vacuum Technology-Compiled by K.G. Bhushan, BARC

EN 502:Engineering Maths-I (15) (All Engg)

- Overview of arithmetic errors in computations
- Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
- Linear systems solutions by direct methods, iterative methods and acceleration techniques.
- Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
- Linear systems: Eigen values.
- Non -Linear systems: Newton-Rapson & Successive Approximation methods
- Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
- Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
- Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and
 Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 503: Engineering Maths-II (20) (ME Group)

- Introduction to discretization methods and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations, wave equation
- Formulation of the matrix methods by equilibrium concepts (1D-heat conduction, 2D-truss and 1D-hydraulic flow examples).
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's methods, Piecewise approximations. Basis of Finite Element Method, energy principles in structural mechanics and principles of minimum potential energy, assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit methods.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.
- Finite element formulation for laminar and turbulent flows.
- Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
- Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
- Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
- Response Surface Method 2K+1, factorial design, 3k factorial design
- Monte Carlo Method
- Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Artificial Intelligence and Genetic Algorithm
- Artificial Neural Network
- Gram-Schmidtt Orthogonalization
- Transformation of matrix

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
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10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 504:Engineering Maths-II (20) (MT)

Applications in Materials Science:

- Use of matrix in crystallography. Stereographic analysis, lattice correspondence, orientational relationship, applications to twinning and martensitic. transformations,
- Tensor analysis in phase transformation and deformation studies
- Analysis of diffusion data, Solutions of diffusion equations - error function and Eigen value analysis, Polynomial fitting of diffusion profiles.

Application in thermodynamics of metallurgical systems:

- Temperature dependence of thermodynamic quantities, graphical and analytical integration of Gibbs-Duhem equation. Introduction to database for thermodynamic tables
- Analysis and synthesis of phase diagrams, introduction to first principles calculations of phase diagrams with computer demonstration, cluster variation and Monte Carlo methods

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wilev, 1966.
2. Todd R.J. "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods.
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McCraw-Hill Book Co. 1983.
6. Rajaraman V,, "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C. "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis

1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B,, "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers. 1968.
11. Conte S.D,, "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo,McGraw Hill. 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G,, "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis". Addison Wesley, 1984.
15. Rajsekaran S,, "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987; •
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation' Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.-• •
19. Acton, "Numerical Methods That Work"
20. Forsythe et. al,, "Computer Methods for Mathematical Computations"
21. Forsythe et. al,, "Computer Solution for Linear Algebraic Systems"
22. Golub Gene H., "Matrix Computations"
23. Griffiths D. V., "Numerical Methods Engineers: A Programming Approach"
24. Williams P. W,, "Numerical Computation.
25. Strang G,, "Applied Mathematics"
26. Crank J,, "Mathematics of Diffusion"
27. Worked Examples in the Geometry of Crystals: MKDH Bhadesh
28. Materials Science & Technology, Vol.4; Rudman.

EN 505: Engineering Maths-II (20)(EE Group)

- Transforms: Laplace & solution to ODE, Bilinear & Z transforms, Discrete cosine transforms & compression, Entropy & Haufman coding for compression
- Solution of Matrix Differential Equation: Existence & uniqueness of solutions, Solution of Non-Linear continuous time state equation, Solution of Linear time varying continuous time state equation, Solution of linear time invariant continuous time state equations
- Basic Procedure for Designing Conservational Logic: Quine McCluskey method, Iterative consensus method, Design example
- Design of Sequential Circuit Using Sequential Machine Flow Chart: Sequential machine flow chart, Reading reduced dimension maps, Output function synthesis, Next state function synthesis, State assignment & design examples
- Counting Statistics and Error Prediction: Statistical models -Binomial, Poisson and Gaussian distributions, Application of statistical models: Error propagation, Optimization of counting experiments, Limits of detectability, Distribution of time intervals

References:

1. F R Grantmacher, "The Theory of Matrices", New York: Chelsea Publishing Co., 1960.
2. R Bellman, "Introduction to Matrix Analysis", II ed., New York, McGraw Hill, 1970.
3. E Kreyszig, "Advanced Engineering Mathematics, 5th ed., Wiley Eastern Ltd., 1985.
4. Paul R Halmos, "Finite Dimensional Vector Spaces", and New York: D Van Nostrand Co. Inc., 1965
5. Bajpei et.al, "Numerical Methods for Engineers and Scientists"
6. Dahlquist et.al, "Numerical Methods"
7. G Strang, "Applied Mathematics"
8. Golub Gene H, "Matrix Computations"
9. Numerical Methods for Scientists and Engineers, By H.M.Antia, Hindustan Book Agency,New Delhi.
10. Numerical Methods for Mathematics, Science and Engineering, Mathews(IInd Ed), Prentice Hall of India.

EN 506:Health Physics and Radiological & Industrial Safety (20)

Health Physics

Introduction

- Radiation sources, its interaction with matter and units**:** Natural and Induced radioactive sources,
- Units of radioactivity, half-life and decay constant, specific activity.
- Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter.
- Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given).
- Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given),
- Exposure-dose relationship, Bragg-Gray principle.

Biological effects, Radiation Protection and Regulation:

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Importance of radiation protection programme in DAE.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.

- Radiation protection philosophy,
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Principles of radiation detection and monitoring

- Basic operating principles ofa) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type ofRadiation monitors/Radioactivity measurement methods adopted for radiation protection should be taught.

Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management.
- Personal monitoring, area-monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures:

- Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper),
- Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation, Protective equipments

Nuclear Accidents, Emergency Preparedness and Management:

- Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

INDUSTRIAL SAFETY ASPECTS

Introduction:

- Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques

Hazards due to physical agents:

- UV and IR radiation, Lasers, Microwave radiation; noise, heat

Chemicals hazards:

- Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals

Evaluation:

- Instrumental methods, air sampling methods**,** liquid effluent monitoring

Occupational exposure limits:

- Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50

Handling, storage and control:

- Engineering control measures and safety features,
- Safety management techniques such as safety audit, Personal/ administrative control, and Medical control

Fire and explosion hazards:

- Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits,
- USNFPA Classification of Flammable/combustible liquids: flammable gases;
- Engineering safety for prevention of fire and explosion,
- Hazard area classification, selection of equipment, detection and extinguishing systems.

Hazard identification, assessment and control:

- Hazard identification: Concept of risk and Risk management
- Formal methods of hazard identification and assessment:
- Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies
- Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation.

Management of major hazard Installations:

- Plant Layout and Engineering Design Consideration
- Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic Releases,
- Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment,
- Emergency Planning Guidelines, Development of Emergency Plan

Health and safety regulatory aspects:

- Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate.
- EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

References:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute Of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment And Control; Vol-1, 1996 2 Edition, Frank P Lees.

EN 507:Material Science in Nuclear Engineering (EE) (20)

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction methods --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices.
- Material characterization techniques --- XRD, RBS, SEM, TEM, EDAX, XPS, IR and Raman Spectroscopy.
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials, mechanical properties and measurement techniques, strength and ductility, creep, fatigue and wear testing
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Reactor core materials, Zircalloys, Zr-Nb alloys --- fabrication, properties and applications in reactors
- Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels) --- fabrication, properties and applications.
- Chemistry of fuel materials: Production of Uranium, Plutonium and Thorium.
- Heavy water: Production process, purification, properties and applications.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)
2. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)
3. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)
4. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)

EN 508: Nuclear Fuel Cycle Technology(35)

An overview (1)

FRONT END

Mining, Milling and Associated Processing of Indian Uranium Resources(1)

- General Introduction
- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.

Case Studies (1)

- Jaduguda and Turamdih Uranium Ore Processing
- Tummalapalle Uranium

Metal Purification using Hydro-Metallurgical Processes (1)

- Process, Equipment, Quality control

Metal Production by Metallothermic Reduction Processes (1)

- Process, Equipment, Quality control

WasteManagement and Safety (1)

- Associated wastes, characterisation and management

BACK END

Reprocessing (4)

- Nuclear fuels and generation of Pu239 & U233
- Spent fuel management options.
- Characteristics of spent fuel (RR, PHWR, AHWR ,FBR&LWR).
- Reprocessing by PUREX -Head end operations, solvent extraction cycles including the conversion of nitrates to oxides.
- Reprocessing of AHWR and FBR spent fuels.
- Prevention of criticality in reprocessing plants.

Waste Management (3)

- Waste sources.
- Radioactive waste classification.
- Management of low and intermediate level wastes.
- Vitrification of high level liquid waste.
- Schemes for partitioning of high level waste including recovery of valuable fission products.
- Storage and disposal of radioactive wastes.
- Various decontamination techniques to address alpha bearing materials.

Instrumentation & Control (3)

- Measurement techniques for level, pressure, temperature, interface density and flow Instrumentation and control associated with transfer devices—steam jets, pumps and air lift pots
- Interlocks related to major equipments like pulse column, dissolver, evaporator, joule melter and ion exchange column
- Computerised data acquisition and control system

Radiation Monitoring System (2)

- Area monitoring instruments, stack monitors, criticality alarm systems, effluent monitors,PCW & steam condensate monitors
- Single line diagram for Class-4, Class-3 and UPS
- Earthing, cabling, lightening protection system, VF drives

Civil (1)

Design aspects of back end technology facilities- Design classification and seismic categorization, considerations for external events, Standards/codes for design

Metallurgy (2)

- Corrosion aspects and material of construction for reprocessing and waste management plants.
- Degradation modes of SS 304L in nitric acid.
- Welding techniques, quality assurance and special requirement for in cell equipment.

Mechanical (7)

- Spent fuel transportation- shipping cask design and regulatory requirement.
- Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
- Remote handling system in reprocessing.
- Automation in plutonium powder handling.
- Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
- Sampling system. Transfer devices and valves for radiochemical plants.

Features of Radiochemical Plant (7)

- Layout considerations and design philosophy for back end operation.
- Control of radiation exposure including shielding and barriers.
- Ventilation aspects and Off gas handling and treatment.
- Utilities requirement for back end.
- Mechanical design aspects of metallic and joule melter.
- Radiation shielding windows.
- Remotisation and remote handling in vitrification plants

EN 509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40)

Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulas gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

1. Wakil M.EI, "Nuclear Power Engineering", McGraw- Hill.
2. Strosal and Vapet, "Power Plant Engineering & Economics".
3. Lewis E.E., "Nuclear Power Reactor Safety", Wiley Inter Science.
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von-Nostrand, 1981.

Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time.Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
  - Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio, blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly
  - Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
  - Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination

References:

1. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors", Pergamon Press
2. Yevick J.G., "Fast Reactor Technology", Plant Design, M.I.T, Press.

Module 3:Advanced Reactor Concepts (6)

Introduction(1)

- Need for Advanced Reactors and in what way these are different from conventional reactor
- International initiatives – INPRO, GIF etc.
- Definition of sustainability and INPRO areas of sustainability
- Brief Description of the INPRO Guidelines and Methodology to Evaluate INES
- Basic principles, User requirements, Key Indicators, Allowable parameters etc.

Directions of Development in the World(1)

- GIF and other advanced reactor concepts

Indian Programme on Advanced Reactors and Associated Challenges (2)

- AHWR
- AHWR-LEU
- CHTR, IHTR, MSBR etc.

Reactor Physics Design Challenges(1) ADS and applications(1)

EN 510:Reactor Physics & Engineering (55)

Module 1 :Nuclear Reactor Physics (33)

Properties of Nuclei

Binding energy-formula and interpretation, nuclear forces, nuclear structure.

Fission Process

- Fission rate and reactor power
- Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
- Fissile, fertile and fissionable materials
- Fission product activity after shut down –decay heat.

Interaction of Neutrons with Matter

- Production of neutrons

Concept of microscopic cross section:

- Inelastic and elastic scattering

Variation of cross-section with energy

- Fast, resonance and thermal ranges
- 1/v law of neuron cross-section
- Resonance absorption, Doppler effect.
- Eta vs E curve conversion & breeding concept
- Thorium utilization

Diffusion of Neutrons

- Fick's law and its validity
- Steady state neutron diffusion equation
- Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.

Chain Reaction

- Four Factor formula
- Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
- Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,

Slowing Down Process

- Neutron slowing down
- Slowing down power/ moderating ratio of moderators
- Slowing down with spatial migration
- Fermi age concepts, migration length
- Multi zone reactors
- Ideas of reflectors/blankets, reflector savings, form factor.

Heterogeneous Reactors

- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

Reactor Kinetics

- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

Core Burn Up

- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

Neutron Poisons

- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

Reactivity Coefficients

- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Module 2: Reactor Engineering & Radiation Shielding (22)

Reactor Engineering (14)

- Introduction to reactor system & Indian Nuclear power programme
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems
- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR),
- Fast reactors;
- Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
- Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.

Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.

- Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
- Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.

Nuclear Fuel Cycle (2)

- Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
- Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
- Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
- Advanced fuel cycles

Radiation Shielding (6)

- Source of various neutron & Gamma radiation within the reactor system
- Attenuation of neutrons & gamma rays

- Dose rates for gamma rays for various source geometries
- Buildup factors for homogeneous & multiple layer shields
- Removal diffusion theory for neutron attenuation
- Coolant activation, heat generation
- Streaming of radiation through gaps & void in the shield

CORE COURSES

E601: Advanced Chemical Reaction Engineering (25)

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
- Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
- Reactor design: counter-current moving bed reactors, fluidized bed reactors.
- Advanced topics in reaction engineering- three phase reactors, photochemical reactors, integral reactor-separators, complex systems.
- Examples from nuclear chemical engineering.

References:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

EN602: Advanced Electrical Engineering Design-I (20)

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Methods, Finite Element Methods, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Methods: MFL Technique, Eddy current Technique, Remote Field eddy current Methods. (5)

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronics Circuit Design Techniques (30)

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Programmable Logic Devices: PLD, CPLD and FPGA, Technology architecture (4)
- Hardware Description Languages: VHDL – language details (6)
- Digital Circuit Design using VHDL: Design methodology and optimization, Design of a multiplexer, counter, finite state machine etc., test bench (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. Actel HDL Coding Style Guide, 2009 edition, Published by Actel Corporation, Mountain View, CA 94043. Free softcopy available on Actel website (www.actel.com).
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles

10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25)

- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Rate based approaches for design.
- Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors.
- Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors.
- Adsorption and ion exchange equipment.
- Membrane separation and other advanced mass transfer processes.
- Process intensification approaches.

References:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)

EN605: Advanced Nuclear Instrumentation (40)

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and methods of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems ,Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.

Reactor Instrumentation:

- Fundamental Considerations / Philosophies, requirements, and scope.
- Measurement ranges of reactor neutron flux and considerations
- Types of neutron detectors FC,10B, BF3, CIC and SPND for in-core and out-of-core use.
- Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR,LR, Lin, LinR and ρ)
- Noise reduction techniques, considerations and practice: EMI Interference, Grounding and shielding.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma Monitors, Neutron Monitors, Contamination Monitors, including networking and RADAS.

References

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

EN606: Advanced Operating Systems (25)

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Processs Subsystem : Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem : Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Interprocess Communication : Message Queues, Shared Memory, Semaphores, Mailboxes, Sockets, Fundamentals of Socket Programming, Remote Procedure Calls [1][6]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing, Features of distributed Unix, Logical time, Concurrency Control [1][5]
- Unix Shells: Unix Shell Commands & Fundamentals of Shell Programming [1][2]

- Linux: Packaging and Distribution, Loaders, Virtual Terminals, Internal and External Drivers, Threads, Interfaces, X Window System, Hard Disk Partitions, File System Enhancements, Extended File Systems, Virtual File System, System Tuning. [3, 9, 10]

References:

1. The Design of Unix Operating Systems : Maurice J. Bach, Prentice Hall
2. Unix Programming Environment : Kerninghan & Pike, Prentice Hall
3. Linux Internals : Rubini, O'Reilly & Associates
4. Operating Systems Concepts: Silberschatz, Galvin, John Wiley
5. Distributed Operating Systems : Tanenbaum, Prentice Hall
6. Unix Network Programming : W. Richard Stevens, Prentice Hall
7. Xlib Programming : Adrian Nye, O'Reilly & Associates
8. Inside Windows NT , David A. Solomon, Microsoft Press
9. Demblon & Spitzner, http://learnlinux.tsf.org.za/courses/build/internals/internals-all.html
10. Tigran Aivazian, http://www.faqs.org/docs/kernel_2_4/lki.html or http://students.mimuw.edu.pl/SO/Linux-doc/LinuxKernel-2.4.pdf

EN607: Applied Process Instrumentation (40)

- Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables:
- **Flow**: Differential pressure flow elements: Orifices , venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters. Applications and limitations of various flowmeters. Two phase flow measurements.
- **Pressure**: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.
- **Level**: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
- **Temperature**: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
- **Temperature transmitters**- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
- **Analytical Instrumentation**: Conductivity, pH, ORP and Turbidity measurement.
- **Other Measurements**: Relative humidity; viscosity and density measurement
- **Control valves:** Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
- **Instrument Impulse lines and instrument fittings**: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
- **P & I Diagrams, loop and hook up diagrams:** P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

EN 608 Civil Engineering Design of Concrete and Steel Structures

EN 608.1Civil Engineering Design of Concrete and Steel Structures-I (30)

Introduction to various structures of nuclear facilities Classification of structure and design basis

Radiation protection objectives, defense in depth, safety functions, safety classification, seismicclassification, quality classification, design classification, design for natural and man induced events.

Design Loads:

- Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
- Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
- Severe Environmental Loads: operating basis earthquake,severe windincluding gust effect and aerodynamic instability, design basis flood load,tsunami.
- Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind- induced missile

Design of RC structures:

- DesignofRC structures as per IS456,AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 ,designloadcombinations,design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies

Design for shrinkage, creep & heat of hydration:

Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies..

Foundation design

- Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
- Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
- Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

EN 608.2 Civil Engineering Design of Concrete and Steel Structures-II (30)

Introduction to Prestressed Concrete structures

Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.

Design of lined and unlined containment structures

Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.

Design of steel structures of nuclear facility

Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections,design of embedded parts and anchor boltsas per AERB and ACI standards, case studies.

Design of water-retaining structures

Design of overhead and underground tanksusingun-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.

Design of cooling towers

Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

References

1. **I**S 456 (2000) "Plain and Reinforced Concrete – Code of Practice ".
2. ACI 318 (2014) "Building code requirements for structural concrete".
3. ACI 349 (2013) "Code requirements for Nuclear Safety related concrete structures".
4. RCC-G "Code of Practice for Design of Prestressed Nuclear Containment Structures". 5. ISO 14000
6. Raju, N. K. (2006), "Prestressed concrete", Tata McGraw-Hill Education.
7. ACI 207 (1995) "Effect of restraint, volume change and reinforcement on cracking of massive structures".
8. Bowles, J. E. (2001) "Foundation analysis and design", Tata McGraw-Hill Education.
9. Rao, N.S.V.K. (1988),"Vibration analysis & foundations dynamics", Wheeler publishing.
10. IS 2974-1, 1984,"Code of practice for design and construction of machine foundations".
11. Arya, S.C., Oneill, M.W. and Pincus, G. (1979), "Design of structures and foundations for vibrating machines", Gulf Publishing Co.
12. Manohar, S. N. (1984) "Tall Chimneys design and construction", Mcgraw-Hill Book Comp.
13. ANSI/AISC N690 (1984), American and National Standard – Nuclear facilities, "Steel safety related structures for design fabrication and erection".

EN 609 Earthquake Engineering and Structural Dynamics(45)

Introduction to Seismology

- Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA),Design Basis Earthquake,Concept of

Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra

- Seismic instrumentation for micro-earthquake and strong motions.

Structural Dynamics

- Introduction to dynamic loading, different types of dynamic loadings, concept of damping,derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
- Single degree of freedom of system (SDOF)–undamped& damped system, free & forced vibration; Response to harmonic and impulse loading,concept of transmissibility and vibration isolation,estimation of damping of structural system using free & forced vibration approach;response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
- Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
- Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies)& eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
- Introduction to dynamics of continuous system

Seismic Response Analysis of Structures

- Seismic response analysis using response spectrum and time history approach
- Modal superposition method, Modal combinations and spatial combinations, missing mass correction
- Time history analysis using direct time integration,
- Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction

Random vibrations

- Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.

Special Seismic Design Considerations

Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain, curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures;Seismic Design Optimization, Principles of performance based design, dynamic response control techniques such as base isolation, dampers etc.

Seismic Requalification of Existing Installations

Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection, review basis ground motion, evaluation of seismic margin capacity, retrofitting.

Case Studies

Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear installments.

References

1. Chopra, A.K. (2007), "Dynamics of structures: Theory and application to earthquake engineering", Prentice Hall.
2. Clough, R. W. and Penzien, J. (1993). "Dynamics of structures", McGraw Hill, Inc.
3. Mario Paz and William Leigh (2006), "Structural Dynamics-Theory and Computation", Springer.
4. Thompson, W. T. (1972),"Theory of Vibrations with Applications" Prentice-Hall, Englewood Cliffs.
5. ASCE 4-98 (1998), "Seismic Analysis of Safety related Nuclear Structures and Commentary on standard for seismic analysis of safety related nuclear structures".
6. AERB/SG/S-11, "Seismic Studies and Design Basis Ground Motion for NPP Sites".
7. IAEA SAFETY STANDARDS SERIES No. NS-G-3.3 (2002), "Evaluation of Seismic Hazards For Nuclear Power Plants".
8. IS 1893-1 (2002), "Criteria for Earthquake Resistant Design of Structures".
9. IS 13920 (1993),"Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces".
10. Dowrick D.J., "Earthquake Resistant Design"
11. Park and Pauley, "Reinforced Concrete Structures"
12. Pankaj Agrawal, Manish Shrikhande, (2006), Earthquake Resistant Design Of Structures
13. AERB monograph, (2008), SEISMIC SAFETY OF NUCLEAR POWER PLANTS

EN 610: Code Design for PVP (60)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin- walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
- Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material

and allowable stresses. Design of saddle supports.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 and Div.2.
- Difference between metallic pressure vessel and FRP pressure vessels

Nuclear Pressure Vessels and Piping (30)
- Monotonic and Cyclic Stress-Strain Curve, Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Failure modes of pressure vessels, Ratchetting and shakedown.
- Organization of Boiler and Pressure vessel Sec. Ill code. Safety classification and Criterion for selection of ASME sec. Ill classes. Design loadings and service loadings as per NCA 2140.
- Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Definition of B, C and K stress indices.
- Design of Nuclear piping as per Sec. Ill div.1. Design rules for standard support as per NF 3400, Design rule for piping support - NF 3600.
- ASME code rule for component support
- Design rule for Plate and shell- Type support as per NF 3200, Design rule for Linear-type support - NF 3300.
- Design rule for component support - NF 3500, Core support structure Design - NG 3300.
- Fracture Toughness requirements for materials for pressure vessels, pipings and boltings.
- Failure Analysis Diagram.
- Protection against Nonductile Failure - Appendix G, Basis of Low Cycle fatigue Design. Fatigue evaluation of vessels.
- Strain concentration factor ' Ke', Local strain approach: Neubar and Zarka rule, Elastic and elastic-plastic fatigue analysis of nuclear pipings, Leak-Before-Break Design Concept.
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec. Ill.
- NDE requirements, Examination of welds, Acceptance standard.

References:

1. Harvey J.F., “Pressure Vessel Design”, CBS Publication
2. Brownell L.E., and Young E.D., “Process Equipment Design” Wiley Eastern Ltd., India
3. ASME” Pressure Vessel and BoilerCode”, Sec. VIII, Div. I and Div. II, 1985
4. American StandardCode for Pressure Piping”, - B31.1, 1972
5. American Standard Code for Pressure Piping”, - Petroleum, Refinery Piping, B31.3, 1972
6. “Standard of Tubular Exchanger Manufactures Association”, 7th Edition, 1988.

EN 611: Computational Fluid Dynamics & Heat Transfer (50)

Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):
- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme
- Laminar Boundary Layer and Forced Convective Heat (5):
- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
- Convective heat transfer for internal and external flows
- Low and high Prandtl number limits and different thermal boundary conditions
- Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer (5):
- Reynolds decomposition for turbulence
- Prandtl's mixing length theory, Mixing length models
- Structure of turbulent boundary layer over flat plate and through circular cylinder
- Calculation of friction factor and drag coefficient
- Analytical and semi-analytical correlations for calculating heat transfer coefficients
- Analogy between heat and momentum transfer

- Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
- Turbulence Modeling:
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
- Reynolds stress models: algebraic and differential models
- Low Reynolds number models
- Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
- **Natural Convection (3):**
- Basic Equations of natural convection
- Boussinesq approximation
- Derivation of Dimensionless groups from basic equations
- Analytical approximations
- Numerical solution of approximate equations

Numerical Solution of Complete Fluid Flow and Energy Equation (10):

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation
- Streamfunction-vorticity-temperature formulation
- Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
- Primitive-Variable (P-V-T) formulation
- Pressure velocity coupling for incompressible flow:
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
- Simple grid generation techniques for structured grid:
- Elliptic, parabolic and hyperbolic equation method
- Grid adaptation
- Domain decompositions in CFD and heat transfer
- SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer (12):

- Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
- Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.
- Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
- low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
- Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
- Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff’s law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.
- **Heat Transfer With Phase Change (10):**
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
- Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi’s model)
- Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow’s correlation) and flow boiling (Chen’s correlation)
- Condensation heat transfer: Nusselt’s theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
- Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
- Critical Flow: Models for single – phase and two-phase critical flow.

References for CFD:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.

14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor &Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

EN 612: Computer Based System Design- I (25)

Hardware Design

- Overview of microprocessors and peripherals: 8086, 68000, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications
- Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL)
- Case Study: Design of a single board computer with shared memory interface, I/O board design using ADC, DAC etc with emphasis on signal conditioning and isolation
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues

EN 613: Computer Graphics and Visualization (35)

- Introduction overview, Graphics software/hardware and types of graphics applications (1)
- 2D/3D Geometric Transformations, Affined transformations-Translation, Rotation, Scaling, Shear and reflection. (3)
- Homogeneous coordinates, composite transformations, rotation with qutenion, current transformations and matrix stacks. (3)
- Two dimensional viewing 2D viewing – window, viewport, viewport transformations, clipping operations, line clipping algorithms – Cohen-Sutherland, Liang-Barsky, polygon clippimg algorithm – Sutherland-Hodgman. (4)
- Three dimensional graphics – Planer geometric projections – parallel and perspective, Mathematics for projections, classical three-dimensional viewing, specifying views, viewing transformations, 3D clipping operations. (4)
- Hidden surface removal, object space and image space approach, back face culling, z-buffer algorithm, LOD.(2)
- Illumination and shading – Basic illumination models, light sources, material properties, polygon shading methods – flat, gouraud and phong shading, ray tracing methods. (2)
- Color - Color perception, color models – RGB,CMY,HSV (1)
- Visual Realism – Depth cuing, texture mapping, transparency, shadow, steropsis. (2)
- Curves and surfaces – Representation of curves and surfaces, Algebric and geometric form, Blending functions, interpolation, Hermite, Bezier, B-spline curves and surfaces, Rational polynomials, NURBS (5)
- Modern Graphics Architecture – Graphics Pipeline, GPU, PCI Express (2)
- Case Study – Using OpenGL (3)
- Scientific Visualization – Introduction, Geometry (Structured & Unstructured Grids), Data Representation (Scalar, Vectors), Volume Rendering (Marching Cubes, Ray Casting) (3)

EN 614 Construction Materials, Management and Quality Assurance (30)

Construction Materials

- Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
- Reinforcement: Passive and active (Prestressing)
- Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
- Paints
- Water-proofing materials & membranes

Shuttering/Formwork

Design philosophy, different design requirements, climbing shutter design, slip form work.

Prestressing system

Cable ducts, anchorage and grouting, qualification of Prestressing system

Quality Assurance (QA)

- QA in Civil Engineering design
- QA in materials
- QA in construction
- QA in operation & maintenance
- Inspection during construction, Regulatory inspection

Construction Procedure & Construction Safety

- Dewatering, rock excavation, consolidation grouting

- Construction safety, Job Hazard Analysis.

Contract Management

Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication

References:

1. Singh, K. A. N."ISO 9000-Quality Systems", Dolphin books, New Delhi.
2. Quality systems requirements (QS 9000) – Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 3rd edition
3. Quality system assessment (QSA) Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 2nd edition
4. CPWD Works Manual (2012), Central Public Works Department, Government of India, Published by DIRECTOR GENERAL, CPWD, NIRMAN BHAWAN, NEW DELHI-110 011.
5. Manual of Internal Inspection/DAE Works Procedure (2010), Department of Atomic Energy, Government of India.
6. ATOMIC ENERGY (FACTORIES) RULES (1996), Atomic Energy Regulatory Board, Government of India.

EN 615: Corrosion (15)

- Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables, composition and heat treatment. (3 Lectures)
- Forms of corrosion: uniform attack; corrosion rate measurements, Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion, low temperature sensitization, corrosion of weldments; stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen embrittlement, hydrogen attack, corrosion fatigue; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, failure analysis, specification tests, advanced methods for on-line corrosion monitoring. (7 Lectures)
- General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification. (1 Lecture)
- Corrosion in the nuclear industry – Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. corrosion in fluoride and ammonia containing environments; liquid metal corrosion. low alloy steels, stainless steels and Ni and Cu base alloys, protective magnetite formation on carbon steel, stress corrosion cracking of stainless steels and nickel base alloys. high temperature oxidation and hydriding of zirconium alloys, materials for fast breeder reactor system. Effects of radiation on corrosion (4 Lectures).

References:

1. Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. Corrosion – L.L. Shrier (Ed.) Vol.I & II, 1963.
5. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
6. Modern Electrochemistry, Vol. 1 & 2 – J. O.M. Bockris and A.K. Reddy
7. Corrosion of Stainless Steels – A.J. Sedricks.
8. Stress Corrosion Cracking – Materials Performance and Evaluation – Ed. Russel H. Jones, ASM Int., 1993
9. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN 616: Distributed Computing (45)

Advanced Computer Architecture

- Advances in CPU Architecture
  a. Advancements in CPU architecture – Dynamic Instruction level parallelism, Branch prediction, register renaming
  b. Static instruction level parallelism - EPIC, VLIW
  c. Hyperthreading
- Multi core architectureAdvances in Memory
  a. SDRAM, DDR, DDR-2
  b. Registered ECC, FB-DIMM
  c. CPU – Memory Interfacing techniques - FSB, Hypertransport, Quickpath
- Advances in I/O interfaces
  a. Shared I/O bus
  b. Switched I/O fabric
  c. Serial and parallel I/O bus
  d. Case studies - PCI, PCI-X, PCI-Express, PCI-Express Gen2
- Advances in Interconnect techniques
  a. Shared and switched networks
  b. Interconnect fabrics

  c. Approaches for improving interconnect performance
  d. Case studies – Ethernet, Infiniband, SCI

- Cache
  a. Associative, Direct mapped
  b. Write through, Write back
  c. MESI
  d. Shared caches
- Advances in storage systems
  a. Direct attached storage, Network attached storage, Storage Area Networks
  b. File level and block level accesses
  c. Storage protocols
  d. Case studies - ATA, SATA, SCSI, SAS, Fiber channel
  e. Case studies - FC, iSCSI, iSER, SRP

Parallel Computing

- Introduction to High Performance Computing
  a. Need for HPC
  b. Applications of HPC
  c. HPC Overview – Conventional Supercomputers, Parallel Computers, Classification (SISD, SIMD, MIMD)
- Pipelining, Vector processing, SIMD
  a. Pipeline, Speedup and Efficiency of pipeline
  b. Pipeline stalls, out of order execution
  c. Techniques to improve pipeline efficiency
  d. Superscalar, Superpipelined, VLIW, EPIC architecture
  e. Vector processors, vector instruction sets, registers
- MIMD Architecture
  a. Classification of MIMD machines
  b. UMA, NUMA, CC-NUMA, COMA, NORMA
- Interconnection networks and topologies
  a. Interconnection Concepts – Bandwidth, Latency, Network Diameter, Bisection Width, Node degree, Static and Dynamic Networks
  b. Various topologies – Ring, Hypercube, Torus, Mesh, CLOS, Fat tree etc.
- Current Parallel Architectures
  a. Parallel Vector processor
  b. Symmetric Multiprocessors
  c. CC-NUMA
  d. Massively Parallel Computers
  e. Clusters of workstations
- Clusters
  a. Classification of clusters
  b. Cluster software
  c. File systems for clusters
- Software concepts of High Performance Computing
  a. Parallelism – Algorithmic, Geometric, Event, Data
  b. Granularity – Coarse and Fine grains
  c. Speedup, Efficiency, Amdahl's and Gustaffson's Laws
- Parallel Programming Models
  a. Shared Variable Model
  b. Message Passing Model
  c. Threads Model
  d. Data parallel Model
- Design of parallel algorithms
  a. Data dependencies
  b. Data partitioning
  c. Communication patterns
  d. Synchronization
  e. Load balancing
- Parallel Programming Environments
  a. Parallel Languages
  b. Parallel Extensions to Sequential Languages
  c. Parallel APIs – MPI, OpenMP
- Parallelization of example programs – Dot product, Matrix Multiply, etc. at the pseudo code level
- Message Passing Interface (MPI)
  a. Introduction to MPI
  b. MPI constructs
  c. Example programs in MPI
- Benchmarking
- Case studies – ANUPAM series of parallel computers

Grid Computing

- Introduction to Grid Computing
  a. Evolution of Grid Technology comparison with contemporary technologies,
  b. Issues of virtualization, events that have lead to grid computing, client-server, peer-peer, operating system perspective,
  c. Overview of Grids: Formal definition of Grids - how do they work?
  d. How are they different from clusters? Computational Grids, Data Grids, Production Grids worldwide - Applications of Grid.
- Components of Grid
  a. Grid Security- concepts of single sign on, How the security requirements are met?
  b. Concept of Digital certificate- How RSA works? - Working of Kerberos
  c. Concepts of Myproxy services
- Grid Resource management
  a. Issues in Grid Resource management
  b. Abstract model for Grid Resource Management
- Grid Scheduling
  a. Issues in Grid Scheduling
  b. Taxonomy Of Grid Schedulers
  c. Resource Discovery issues
- Visualization and interactivity in Grids, High Performance Computing in Grids- Grid enabled MPI – MPI-G2
- Grids Services
  a. How are they different from Web services?
  b. Concepts and their implementation
- Data Management in Grids
- Information services- Building information services in Grids
- Grid Portals, Their Purpose, Issues in Portal design, discussion on portlets
- Grid Workflow
  a. Concepts
  b. Taxonomy of Grid Workflow
- Semantic Grids
- Virtualization
  a. Concept
  b. Its utility in Grid Computing
- Grid Enabling Applications
  a. Issues
  b. Implementations
- Discussion about GRID standards
  a. OGSA
  b. OGSA-DAI
- Comparative study of different Grid Middlewares
  a. Lacuna in current Grid Architectures
  b. Grid as operating system of operating systems
- Case study of Middlewares:
  a. GT4,
  b. Glite
  c. DAE Grid
- Future of Grids - Concepts of Cloud Computing

References

1. Advanced Computer Architecture, Kai Hwang
2. Scalable Parallel Computing, Kai Hwang, Zhiwei Xu
3. Introduction to Parallel Computing, Ananth Grama, George Karypis, Vipin Kumar and Anshul Gupta
4. High Performance Computing – Paradigm and Infrastructure, Laurence T.Yang, Minyi Guo
5. Storage Networks Explained, Ulf Troppens, Rainer Erkens, Wolfgang Muller
6. Computer Organization and Architecture: Designing for Performance, William Stallings
7. Grid Computing – Making the Global Infrastructure a Reality, Fran Berman, Geoffery Fox, Anthony J. Hey
8. The Grid2 Blueprint for a new Computing Infrastructure, Ian Foster, Carl Kesselman
9. Grid Computing for developers, Silva
10. Current Journal Articles in the area of Parallel Computing, Computer Architecture and Grid Computing

~~EN 617~~

EN 618: Electrical Systems for Nuclear Power Plants (30)

- Interaction of Nuclear Power Station With The Grid Number of evacuation lines; Optimum size of NPP in grid; Brief introduction to Power System Analysis - Short circuit, load-flow and stability studies, Tariff and Capacity factor.
- Ehv Switchyard Design Switching schemes; Clearances; Com parison between types of svvitchyards; Brief introduction to equipments in switchyard and their functions; Lightning arresters and insulation co-ordination; Lightning protection.

- Protection Line protection; Generator protection; Transformer protection; Motor protection.
- Selection of Transformers Accessories; Types; Specifications and testing; Voltage regulation calculations.
- Selection of MV & LV Switchgear Types; specifications and testing, MCCS; Distribution boards; Generator circuit breaker; ELCB.
- Motors In NPP Types of motors; Radiation withstand requirements; Performance requirements.
- Station Auxiliary Systems of NPP Class 1, 11, Ill and IV systems classifications; Nature of electrical loads and supply voltages; Effect of voltage variation on Electrical equipments and remedial measures; Emergency transfer system; Load shedding scheme; Auto transfer schemes; synchronizing schemes.
- Class 1 e requirements Cabling, lighting & grounding Specific requirements for safety related electrical equipments & systems in NPR Cabling, Lighting, Grounding systems in NPP; Bus ducts. Introduction to seismic qualification of electrical equipments., Electrical system control from Control Room. Introduction to [)G sets, UPS & Batteries.
- Billing and metering scheme for a typical NPP. Introduction to brushiess and static excitation systems for Generators. Introduction to SCADA systems.

References:

1. Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity :.CBProblems and Remedial Measures. IAEA Report - Technical Reports Series No. 271.
2. Elements of Power System Analysis - W.D. Stevenson
3. Electrical Transmission & Distribution Hand Book - Westinghouse Electrical Co., USA
4. Protective Relays - Application Guide, GEC Measurements.
5. Manual on Layout of Substations - CBIP, New Delhi
6. The J & P - Transformer Book
7. The J & P - Switchgear Book
8. Utilization of Electrical Energy - E. Openshaw Taylor
9. Cabling - Siemens Hand Book
10. Illumination Engineering Society - IES Lighting Hand Book
11. Modern Power Station Practice - Volume D - Electrical System & Equipment, British Electrical International.
12. Standard Hand Book for Electrical Engineers - Donald G. Fink and H. Wayne Beaty
13. IEEE-80 - IEEE Guide for Safety in AC Substation Grounding
14. IEEE-308 - Criteria for class 1E Equipments for Nuclear Power Generating Stations
15. IEEE-323 - Qualifying class 1E Equipments for Nuclear Power Generating Stations
16. Indian Nuclear Power Programme with PHWR - Published by Directorate of E & P A, NPCIL, Bombay
17. IS-3716 - Application Guide for Insulation Coordination
18. IS-2309 - Code of Practice for the Protection of Buildings and Allied Structures Against Lightning
19. Handbook of Batteries and Fuel Cells - McGraw Hill Book Company

EN 619: Embedded & Computer Based System Design (45)

Module I [22]

Part A - Microprocessor based Design [10]

- 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
- Introduction to Microcontrollers and comparison with Microprocessors
- Introduction to DSP Processors

Part B [12]

- ARM processor: architecture details and introduction to programming
- Board level buses: I2C and SPI
- Introduction to USB

Module II [23]

Part A – Computer based hardware design [8]

- Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
- Industry standard bus systems: ISA, PCI, VME: Mechanical, electrical, functional and procedural specifications
- Multi processing, bus arbitration and Plug and Play
- System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
- Design Case Study:
- I/O Board design, bus interface (ISA, PCI) FIFO and shared memory interfaces.

Part B - Computer Communication and Networks [7]

- Overview of asynchronous and synchronous communication standards
- Encoding (NRZ, Manchester),
- Ethernet, Industrial networks, Field Bus, CAN bus
- Networking hardware: Cables, Hubs, switch and routers.

Part C - Software development for embedded and PC based systems (8)

- Basic RTOS concepts
- C programming for ARM based applications
- Programming for PC based systems:
  - Interface between applications & device drivers
  - Windows: Programming of I/O, ISR, DMA

References:

1. Computer Networks. By: A.Tanenbaum

2. Principles of Communication. By: Taub and Schilling.
3. Microprocessors and Interfacing. By: D.V.Hall
4. CAN Application Note: Robert Bosch GmBH
5. Microcomputer System 8086/8088 family- Architecture, Programming and Design.
Yi -Cheng Liu & Glenn.A.Gibson.
6. The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486 and Pentium series: Architecture, Programming and Interfacing. By: Barry.B.Brey.
7. The Scientist and Engineer's guide to DSP. By: Steven.W.Smith
8. High speed digital design: A handbook of black magic. By: Howard Johnson & Martin Graham
9. Interference control in computer and microprocessor based equipment. By: Michel Mardiguian
10. Interfacing to the IBM Personal Computer. By: Lewis C. Eggebrecht
11. PCI bus system architecture – Mindshare publication
12. VME bus standard document
13. USB complete. By: Jan Axelson
14. ARM System Developer's Guide. By: Andrew Sloss, Dominic Symes, Chris Wright
15. Designing Embedded Hardware. By: John Catsoulis

EN 620: Extractive Metallurgy (40)

Principles of Metallurgical Thermodynamics (15)

- Thermodynamic Functions: Enthalpy, Entropy, Free Energy, Chemical Equilibria
- Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Phase Diagrams
- Solution Thermodynamics, Integral and Partial Molar Thermodynamic Properties
- Experimental Methods- Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.
- Computation of predominance area diagram and Phase diagrams

Kinetics(5)

- Principles of Chemical Kinetics, Homogeneous Reactions, Effect of Concentration, Effect of Temperature
- Theory of Reaction Rates, Heterogeneous Reactions, Reaction Models, Mass Transport Phenomena, Heat Transport Phenomena.

Process Metallurgy (25)

- Methods of attaining High Temperatures,Measurement of Temperature,
- Vacuum Metallurgy Principles and Equipments,
- Process Metallurgy of Rare and Refractory Metals,
- Resources of Special Metals, Beneficiation Methods, Physical, Chemical, Separation Methods, Halide Metallurgy, Vacuum Metallurgy, Electro Metallurgy, Reduction Processes, Refining Processes, Ultrapurification Processes,
- Preparative aspects of Special Materials and Alloys,
- Advanced Materials Processing Techniques,
- Reprocessing of irradiated nuclear fuels, Process Metallurgy of - Uranium, Thorium, Plutonium, Beryllium, Zirconium, Hafnium, Niobium, Tantalum, Rare Earths.

EN 621: Finite Element Techniques (35)

- **Introduction to FEM:** Weighted residual method, Galerkin's methods, Weak form formulation, Piecewise approximations. Basis of Finite Element Method, Variational principles, energy principles in structural mechanics, Element libraries 5
- **Element shape functions**: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements. 15
- **Bar element:** Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss
- **Beam element:** Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- **2D plane elements** – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- **2D isoparametric formulation** – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature.
- **Incompatible displacement model**: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements.
- **Introduction and Application to 3D elements:** Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Plate bending elements: Thin and Thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration

- **Shell element**: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking.
- **Introduction to Nonlinear problems:** Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method
- **Finite element applications for design**:Finite element modelling and discretization criterion, h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

References:

1. **Bathe K.J., Finite elemen**t procedures in engineering Analysis, Prentice Hall of India, 1990
2. Cook R.D., D.S. Malkus and M.E. Plesha, Concepts and Applications of finite element analysis, John Wiley, 2000.
3. Reddy J.N., An Introductions to Finite Element Method, 4th Edition, McGraw Hill, 1993.
4. Seshu P., Finite Element Method, Prentice Hall of India, New Delhi, Fourth printing, 2006.
5. Zeinkiewicz, O.C., and K. Morgan, Finite elements and approximation, John Wiley, 1983.
6. Zeinkiewicz, O.C., and R.L. Taylor, The Finite Element Method, Vol. 1 & 2, Tata McGraw Hill.
7. M. Asghar Bhatti, Advanced Topics in Finite Element analysis of Structures, John Wiley, 2006.

EN 622: Fracture Mechanics (40)

Linear Elastic Fracture Mechanics (5)

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks and concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture
- Superposition of K
- Plastic zone correction - Irwin's approach
- Basic design principles in LEFM
- **Plane stress vs. plane strain - Variation of toughness (KIc and Kc)**

Elastic-plastic Fracture Mechanics (5)

- J-integral as energy release rate
- J-integral as amplitude of HRR singularity
- J-integral as contour integral
- Laboratory measurement of J-integral - η factor approach
- Fracture resistance of materials – J-R curve and JIc and possible explanation for shape of J-R curve
- Stable and unstable crack growth – Tearing Modulus approach
- J-controlled fracture
- Basic design principles in EPFM
- **J-estimation schemes**

Laboratory measurements of material fracture properties (2)

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- KIc testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of JIc from J-R curve – blunting line equation and SZW

Limit load (2)

- Definitions of limit load
- Global and local limit load
- Basic expressions of limit load of some common geometries

R6 method (2)

- Basic principles of R6 method
- Sensitivity analysis

Fatigue (7)

- Conventional high and low cycle fatigue – S-N diagram, Coffin-mansion relation
- Fatigue crack growth under constant and variable amplitude loading
- Rainflow algorithm
- Environmental effects on fatigue crack growth
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- **Experimental determination of Paris law constants as per ASTM procedure Fracture assessments of welds (2)**
- Basic aspects of fracture assessment of welds – residual stress effect
- Special considerations in fracture toughness determination of welds

PTS and ASME reference/Master curve (6)

- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Warm pre-stress effect

- Reference ASME curve in assessment of PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Computational Fracture Mechanics(4)

- Barsoum's crack tip element and showing the singularity from shape function
- Evaluation of SIF by displacement correlation technique from FEM
- Evaluation of 2-D J-integral by contour integral technique
- Evaluation of 3-D J-integral by domain integral technique

Fracture Mechanism (4)

- Basic mechanism of ductile fracture – Void nucleation, void growth and coalescence
- Cleavage fracture- Mechanism of cleavage initiation
- Mathematical model of cleavage fracture toughness, explanation for scatter in cleavage fracture toughness, RKR model

Application of Fracture Mechanics Principles to Leak-Before-Break (1)

- History of LBB
- Basic concepts of LBB – three levels
- Application to Indian reactors

EN 623: Mechanical Metallurgy (30)

Elasticity and Plasticity

- Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
- Equations of equilibrium.
- Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria

Dislocations:

- Elastic stress field of edge and screw dislocation.
- Self energy of dislocations.
- Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP

Deformation Behaviour

- Single crystal deformation, critical resolved shear stress, Schmidt's factor, Thermally activated deformation, Strengthening mechanisms.

Creep of Metals and alloys

- Various stages of creep and creep laws
- Types of creep tests, evaluation of parameters of a creep test and its use
- Factors influencing creep resistance
- Deformation mechanism map and identification of creep mechanisms, Irradiation creep

Fracture Mechanics

- Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
- Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
- Concepts of R-curves, Evaluation of various fracture parameters, fracture control

Fatigue of Metals:

- High cycle and low cycle fatigue
- Factors contributing to fatigue failure and its mitigation
- Various stages of fatigue damage and Fatigue life improvement
- Fracture mechanics approach to characterize crack growth behavior

References:

1. Engineering Fracture Mechanics - S. A. Meguid.
2. Mechanical Metallurgy - G. E. Dieter
3. Mechanical Behaviour of Materials - T. H. Courtney
4. Elementary Dislocation Theory - J. Weertman & J. R. Weertman
5. Introduction to Dislocations - D. Hull
6. Mechanical Metallurgy : Principles and Applications - M. A. Meyers & K. K. Chawla
7. Deformation and Fracture Mechanics of Engineering Materials - R. W. Hertzberg

EN 624: Mechanics of Solids (40)

Introduction to Theory of Elasticity Mathematical Frame Work (2)

- Illustration of concepts of elasticity, Stress-strain curve, Isotropy, Homogeneity
- Illustration of equilibrium equation, Cauchy equation and stress strain relation in 1-D
- Solution of 1-D boundary value problems using theory of elasticity equations: (a) Natural frequency determination. (b) Solution under external excitation force to show resonance condition, stress wave etc.
- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Kronecker Delta, Permutation symbol ; Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of Stress (3)

- Description / Notations of Forces
- Description / Notations of Stress
- Component of stress
- Reciprocity of shear stress in 3D

- Stresses Transformation using direction cosines
- Stress Traction Vectors or Traction Vectors
- Stress component on an arbitrary plane
- Principal stresses
- Stress Invariants
- Mohr's Diagram for 3D state of stress
- Hydrostatic and Deviator components of stress
- Principle planes and their orthogonally
- Octahedral plane, Octahedral stresses
- State of pure shear

Analysis of Strain (2)

- Description / Notation of Strain in 3D
- Components of strain
- Strain Transformation using direction cosines
- Principle Strains, Strain Invariants
- Cubical Dilation
- Strain Deviator Tensor
- Maximum and Octahedral Shear Strains

Principles and Fundamental Equations of Elasticity (8)

- Strain and displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Stress and strain relationship
- Equations of equilibrium (Navier's Equations , Lame's equations)
- Strain Energy
- Uniqueness theorem
- Bounds on elastic constants
- Superposition Principles
- Saint-Venant's Principle
- General Solution Procedures for a elasticity problem

Two and Three Dimensional Formulation (8)

- Elasticity equation for Plane strain
- Elasticity equation for Plane stress
- Biharmonic equations
- Airy's Stress Functions
- Solution for beam bending problems
  a) Special cases by use of polynomials
  b) General solutions using fourier series method
- Solution in polar co-ordinates
  a) Tube subjected to internal and external pressure (Lame's problem) ; shrink fit
  b) Stress Concentration due to a circular hole in stressed plate (Kirsch's problem)
- Stress in spherical shell under internal and external pressure

Thermal Stresses (4)

- Thermal stress definition and their significance
- Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
- 2D thermal stress analysis
  a) The problem of circular disk
  b) The problem of circular cylinder
- 3D thermal stress analysis : The problem of sphere
- Transient thermal stress

Introduction to Plasticity (4)

- Stress-strain curve, Examples of Multiracial stress
- Different Yielding Criteria and their significance
- Yield Surface , Tresca and von-Mises
- Path dependence of Plastic Strains
- Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
- Prandtl-Reuss Equations
- Incremental or flow theory
- Deformation theory of plasticity, Hencky equations
- Plasticity Relations (plastic strain and total strain)

Theory of Plates

- Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
- Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.

- Introduction to analysis of Thick Plates

Theory of Shells

- Introduction to shell theory.
- Classification of shells, Membrane theory of shells of revolution and translation.
- Application to spherical, conical and cylindrical shells.
- Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
- Application to cylindrical shells, spherical and conical shells.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Piblications, Inc.
6. Plasticity Theory and Application, Alexander Mendalson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K .Chandrasekhara, University Press
9. Stresses in shell- W.Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN 625: Modern Control Systems Design and Simulation (35)

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analyti- cal methods of modeling.
- State Space Characterization State 5PaCe representation, solution of state equation, state Transition matrix, properties of STM, computation methods, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kaiman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Control- lability and observability of Discrete data systems.
- Stability liapunov,s stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design Guillemin-Truxal design Procedure, pole placement by state feedback. H,' meth- od, Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kaiman filter as OPtimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency re- sponse methods, Recurise Least square Identification technique.
- Introduction to Adaptive and Robust control.

References:

(Reference materials will be provided during the course)

EN 626 Design Basis Hazards and Geotechnical Engineering (40)

Design Basis Hazards (Natural)

Role of civil engineering in achieving overall nuclear safety: Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.

Introduction to hazard evaluation:

Hazard due to internal and external events, case studies.

Seismic Hazard

Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum

Flood hazard

- Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
- Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
- Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding

Wind hazard

Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India,Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.),

Solar radiation

Temperature map(Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)

Snow hazard

Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides

Design Basis Hazards (Human-Induced)

Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)

Geotechnical Engineering

Soil Mechanics

- Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
- Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
- Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability; Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.
- Bearing capacity – Determination of bearing capacity for soils and Rock.

Geotechnical and Geophysical investigations:

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

Soil Dynamics and Liquefaction

Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

References:

1. Kramer . S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. **I**S 875(Part 3) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. **I**S 875(Part 4) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance”
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – “Basic and applied soil mechanics”.
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities’
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN 627: Networking and Information Security (40)

Networking

General Issues in the transport of data traffic over networks of digital transmission media.

- V.24, V.35, Modems, xDSL, Multiplexing

Circuit switching & Packet switching

- ISDN (BRI), PRI.

Datalink Layer

- Data link layer protocols, Medium access method, Flow control, Error Control
- Ethernet technologies, Bridge, Switching, Analysis of collision domain, Layer 2-based network attacks

Introduction to Satellite communication

- Satellite orbits, VSATs, VSAT network Topologies

Network Layer

- IP, IP Fragmentation, ARP, DHCP, Classes of IP address, CIDR, Layer 3 based network attacks, ICMP
- IP Routing algorithms, RIP, OSPF, BGP.

Transport Layer

- TCP & UDP, TCP Call establishment & Call termination, Sockets, TCP state machine, TCP timers
- RTP, Layer 4 based network attacks

Firewall

- Layer 3 firewall, Layer 4 firewall, Application based firewall

Network Applications

- FTP, DNS, Mail, application based attacks

Network Security

- Data security, type of possible attacks on data etc?
- Ecurity services for secure data communication?
- Like Identification, Authentication, Authorization, Data Integrity, Confidentiality, Non-repudiation, Replay, Availability etc.
- Cryptography and its services Cryptology, cryptanalysis.
- Components of cryptology like algorithms, Keys, Message Digest, Digital signature, Digital Certificates etc. with block diagram.

Types of Algorithms

- Symmetric and Asymmetric.

Symmetric Algorithm

- stream cipher algorithms
- Type of stream ciphers, Unconditional security with stream ciphers, one time pad, LFSRs, Linear complexity in LFSRs, Shanon's concept of perfect secrecy
- Type of possible attacks, Conversion of block ciphers onto stream ciphers etc.

Asymmetric Algorithms

- Diffie-Hellman, RSA with detail mathematics and applications.
- Key management methods for symmetric and asymmetric keys.
- PKI infrastructure, Digital certificates, digital signatures for asymmetric key managements. CRL (certification revocation list)
- Symmetric key certificates. Difference between symmetric and asymmetric key certificates etc.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN 628: Nuclear Chemical Engineering (35)

Intoduction

Role of chemical engineering in the nuclear industry

Recovery & processing of nuclear materials from ores / intermediates (5)

- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources , New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths : Occurrence, importance and separation.

Uranium Conversion / reconversion (6)

- Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF6: choice and problems, Fluorination of UF4, Purification and collection process for UF6, Conversion to UO2.

Isotope Separation (9)

- Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical- exchange: H2S-H20, NH3-H2, monothermal and bithermal process, salient features of equipment like contacting towers, tower internals. Heavy water plants in India. Final enrichment and upgradation plants. Distillation and electrolysis, Tritium removal.
- Laser based separation and new processes (2)
- A brief description of laser based isotopic separation processes.
- Fuel Reprocessing (6)
- Fuel Reprocessing: Introduction to Radiochemistry; Differences between a conventional chemical plant and radio chemical plant- Process and equipment limitations, criticality, safety and other hazards, numerical examples, ventilation, shielding, Typical compositions and burn-up of irradiated nuclear fuels.
- Thermal Reactor Fuel Reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements. Evolution of solvent extraction process fore reprocessing, 'PUREX' and 'THOREX' processes in detail; Head-end process, flow sheet, co-decontamination and partitioning cycles.
- Fast Reactor Fuel Reprocessing and Introduction to reprocessing of Thorium based fuels.

Nuclear Waste Management (7)

- Sources, characteristics and classification of radioactive wastes; general philosophies of management.
- Method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Discussion of the various chemical engineering operations involved. Use of desalination and membrane separation techniques in waste management.
- Conditioning of radioactive waste- cementation, bituminisation, use of polymers and vitrification methods.
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical Engineering in Decommissioning of nuclear facilities.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series,IAEA,Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)

EN 629: Nuclear Materials (50)

Melting & Casting (10)

- Introduction to vacuum measurement units and types of vacuum pumpsincluding diffusion pump & turbo- molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and methods to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits

Mechanical working of Metals (10)

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Methods of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Powder Metallurgy & Advanced Ceramics (30)

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production methods, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.
- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. "Introduction to Ceramics" by Kingery et al.
11. "Ceramics Through Chemistry" by Brinker et al.
12. "Electroceramics" by Buchanan
13. "Ceramics Fabrication Processes" by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman

16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
19. 'Ceramics Fabrication Processes" by Wang.

EN 630: Nuclear Metallurgy (30)

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post- Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradition effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels,definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister fomation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Bengamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brain R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN 631: Physical Metallurgy (40)

- Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor Stereographic projection, X-ray, Electron and Neutron diffraction Common Crystal structures and quasi crystals, Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics
- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation. Ordered omega and Hydride formation.
- Recovery, Recrystalization and Grain Growth

References:

1. Physical Metallurgy Principles - R. E. Reed-Hill
2. Modern Physical Metallurgy - R. E. Smallman
3. Introduction to Metallurgy - A. H. Cottrell
4. Physical Metallurgy - P. Haasen
5. Introduction to Physical Metallurgy - S. H. Avner
6. Structure of Metals - C. S. Barrett & T. B. Massalski
7. Crystallography and Crystal Defects - A. Kelley and G. W. Groves
8. Principles of Phase Diagrams in Materials Systems - P. Gordon
9. Thermodynamics of Alloys - C. Wagner
10. Introduction to Metallurgical Thermodynamics D. R. Gaskel
11. Physical Chemistry of Metals - L. W. Darken and R. W. Gurry
12. Metallurgical Thermochemistry- O.Kubuschewski

13. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering - K. Denbigh
14. Modern Chemical Kinetics - H. Eyring
15. Kinetics of Phase Transformations in Metals - J. Burke
16. Transformation in Metals - P. G. Shewmon
17. Phase Transformations in Metals and Alloys - D. A. Porter and K. E. Easterling
18. Diffusion in Solids - P. G. Shewmon
19. Modern Metallography - R.E. Smallman and K.H.G. Ashbee
20. Electron Optical Applications in Materials Science - L. E. Murr
21. Electron Microscopy and Analysis - P. J. Goodhew and F. J. Humphreys
22. Defect Analysis in Electron Microscopy - M. H. Loretto and R. E. Smallman
23. Thermoanalytical Method of Investigation - P. D. Garn
24. Thermal Analysis - T. Daniels
25. Methods of Surface Analysis - A. W. Czanderna (Ed.)

EN 632: Process Control and Instrumentation (MT)(25)

Principles of Measurement (2)

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.

Sensors, Transducers and Transmission methods for parameters (10)

- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical& Radiation Pyrometers.
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli's Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

Principles of Automatic Control Systems (8)

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doeblin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN 633: Process Control & Instrumentation (EE)(30)

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysterisis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of following process variables
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter, Different types of standard pressure taps for orifices. Variable Area Flowmeters- Glass tube rotameters, armoured rotameters, bypass rotameters,
- Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs- Wire wound and thin film RTDs, self heating error, differential temperature measurement by using RTDs. Thermistors - Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer, two colour pyrometer.
- Pressure and Differential Pressure: Manometers-U tube, well and inclined manometers, mechanical pressure gauges- Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressureTransducers and transmitters, Smart pressure transmitters, Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauges, Mcleod gauge.
- Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass,

Purge system, capacitance probes, displacer type, ultrasonic type, nucleonic type and conductivity type level gauge.
- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- Distributed Control System: Programmable Logic Controllers, Smart Transmitters Control room concepts.
- P & I Diagrams: P &ID symbols, Typical P &ID.
- Class 1E Instruments in nuclear power plant: Definition of Class 1E equipment, various tests for Class 1E equipment qualification.

References:

1. 'Fundamentals of Temperature, Pressure and Flow Measurements" – Bendict
2. "Instrument Technology", Vols. 1 to 5, - E.B. Jones, Butterworth and London
3. "Mechanical and Industrial Measurements" - R.K.Jain, Khanna Publishers, New Delhi
4. "Measurement System, Application and Design", Ernest D. Deophhlin.
5. "Fluid Meters" - ASME Publication
6. "Principles and Practice of Flow meter Engineering" - L.K. Spink, Published by the Foxboro Company
7. "Process Instruments and Control Handbook" - Edited by D.M. Considine, McGraw Hill
8. "Handbook on Applied Instrumentation": Edited by D.M. Considine and S.D. Ross, McGraw Hill
9. "Instrument Engineer's Handbook", Part I & II: Edited by Bela G. Liptak, Chilton Book Company
10. "Instrumentation for Process Measurement and Control", Norman A. Anderson, Hilton Co.
11. "Manual on the use of Thermocouples in Temperature Measurements" (ASME Publication by subcommittee 4).
12. "Process Control Systems: Application Design and Tuning". F.G. Shinskey, Mcgraw Hill.
13. "Fluid Meters - Their theory and Application" Edited by H.S. Bean. ASME Publication

EN 634: Process Dynamics & Control (45)

Instrumentation , Controls & Computers(20)
- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real- time control applications.

Advanced Process Control (25) Background theory
- Introduction to state-space controls, state & measurement equations, general solution **o**f the state equation, state- transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.

Introduction to Advanced Process Controls
- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

EN 635: Process Modelling, Simulation & Optimization (45)

Simulation
- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Methods of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent methods.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution methods for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization:
- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies.Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals,evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.

- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

References:

1. Bisio, A and R.L.Kabel, 'Scale-up of Chemical processes', Wiley-Interscience,NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W.Hoffman, A.I.Johnson, D.R.Woods and P.T.Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Methods and Modelling for Chemical Engineers, Winley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain,A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)
6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs,E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Rekliatis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Methods & applications, John Wiley,N.Y (1983)

EN 636: Reactor Control and Instrumentation and Human Machine Interface (40)

Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
- Practical

EN 637: Reactor Control Engineering & Instrumentation -1(15)

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic methods (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant Tav program, constant pressure program, Boiler level and

pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., " Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN 638: Reactor Control Engineering & Instrumentation-2 (20)

- Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.
- Reactor Instrumentation
  - Measurement ranges of reactor neutron flux and considerations
  - Principles of detection and types of neutron detectors: in-core and out – of –core
  - Modes of signal processing: Pulse, Campbell, DC
  - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- Health Physics Instrumentation
  - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
  - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
  - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Contamination Monitors

References:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerl

EN 639: Reliability Engineering (EE)(20)

Introduction: Reliability Engg Applied to C&I Systems

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

Reliability Maths/Statistics

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

Fault Tolerance and Systems Reliability:

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

QA/QC Concepts in Brief:

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.

Environmental Qualification and Reliability Testing:

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

PSA/PRA Concepts in NPPs:

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

Additional safety concepts:

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
- Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc.

References:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
6. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
7. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
8. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
9. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
10. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
11. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
12. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
13. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN 640: Software Engineering and Formal Methods (40)

Software Engineering (20)

- Importance of Software Engineering (1)
- Life cycle, Phases and Work-Products of different Phases, traditional models, agile models, Extreme programming (1)
- Project Management: Relationship to lifecycle, planning, control, Risk Management, Cost Models.(1)
- Requirements: Gathering, Categorization, Analysis, and Specification.(1)
- Software Architecture and Design: Architectural Styles, Design Notation, Design principles. (5)
- Object oriented Design: OOAD, Design Patterns (7)
- Testing: Principles of program Testing, Test Coverage, Static Analysis, and Tools for testing. (2)
- Support Activities: Configuration Management, Verification and Validation, Software Engineering Standards, Documentation formats, Tools and environments for Software Engineering (2)

Formal Methods (20)

- Introduction to Formal Methods, Role of Formal Methods in Software Life Cycle – development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, Statecharts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing - Assertions and their verification (dynamic and Static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)

- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic,, Case study from hardware and software, model cheking tools (SPIN, NuSMV etc.) (4)

References:

1. Software Engineering: Roger S. Pressman McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Adison-Wesley
3. Unified Modeling Language *User Guide*: G. Booch, J. Rumbugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I & II , Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K. McMilan, Kluwer, 1993

ELECTIVE COURSES

EN 701: Advanced Computational Techniques (30)

Programming Language C++

- C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.
- C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initialisers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogona Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions,parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

EN 702: Advanced Electrical Engineering Design-I I (25)

Special Electrical Machines

- Special Electrical Machines and their applications :Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

Pulse Power Technology

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

EN 703: Artificial Intelligence Methods & Applications (30)

- **AI Basics**Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert

Systems.

- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence **theorem,** Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification methods, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig
2. Genetic Algorithms in Search, Optimization, and Machine Learning, by David E. Goldberg
3. Neural Networks: A Comprehensive Foundation, by Simon Haykin
4. Reinforcement Learning: An Introduction, by Richard S. Sutton and Andrew G. Barto

EN 704: Computer Based System Design- II (25)

Communication, Networking, Realtime systems, RTOS and Software

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- USB
- Encoding schemes
- Local Area Networks
- OSI 7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Networking hardware – cables, hub, switch, router, etc
- Role of fibre optics in communication
- Fieldbus standards
- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking
- Realtime Systems, their characteristics and applications
- Realtime Operating Systems:
- Concepts of
- Process and threads
- Concurrency
- Latency, context switching
- Scheduling policies
- Inter process communication
- Semaphores
- Priority inversion
- Shared memory
- Common systems calls, Communication features in RTOS
- Comparative study of various RTOSs
- Integrated S/W development environment

EN 705: Data Base Management System and Web Technology(30)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

EN 706: Digital Signal Processing and Image Processing (30)

Digital Signal Processing

- **Introduction**

Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**

  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
- Fast Fourier Transform

Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- Digital filters

FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- DSP Applications

  Applications of digital signal processing in nuclear and other fields.

Image Processing

- **Introduction**

  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- **Image Enhancement**

  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- **Image Segmentation andAnalysis**

  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation; Boundary extraction and representation;
- **Morphological operations**

  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy- based methods;

  Image Compression Models, Error free compression, Lossy compression, Standards;

References:

1 Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
1. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles,
2. Algorithms and Applications, Prentice- Hall of India,1995.
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.
4. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine
6. Vision,Vikas Publishing House,2003.
7. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004

EN 707: Embedded Electronics Software(25)

Programmable Digital System Design, Representation & Synthesis [8]

- Introduction to HDLs, Introduction to PLD, FPGA, ASIC. Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Handel-C, VHDL. Introduction to Design Flows and EDA Design Tools.

Real-time Software [11]

- Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion,

Priority Inheritance
- Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development

Introduction to Microprocessors / Microcontroller and Interfaces [6]
- Introduction to Microprocessor and microcontroller, Synchronous and Asynchronous Standards, RS232C, RS485, FieldBus (Profibus, Foundation FieldBus, CAN, Ethernet , MIL-STD-1553B), TTP

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P.Singh & Renu Singh
3. Fieldbus Technology: by N.P.Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN 708: Feedback Control Systems (25)
- Introduction: The control systems, Basic elements of FIB control systems, Types of FIB control systems.
- Transfer Function: Transfer function of linear systems, Impulse response, Block diagrams, Signal flow graphs, Mason's gain formula, Polar plots, Bode plot.
- State Variable Characterization: State concept, State equation, Standard representation, State transition matrix and solution of state equations, relationship between state equations and transfer functions, Characteristic equation, Illus- trative examples of some electrical, mechanical, electromechanical systems.
- Time Domain Analysis: Test input signals, Time domain perform- ance characteristics, Transient response of a typical second order system, PID controllers
- Stability: Definition, Routh-Hurwitz criterion, Nyquist criterion. Relative stability, Gain and Phase margins.

EN 709:Fluid Power Technology (25)
Basic Fluid Power & Components

Basic principles of Hydraulics and pneumatics
- Fluid power introduction and fundamentals of fluid mechanics
- principle of pneumatics, basic definitions
- pressure – gauge, vacuum, absolute; flow
- Pressure loss, Power, torque, energy – mechanical, hydraulic etc. , power, force, speed, viscosity, hydraulic terms in fluid power, resistances, bulk modulus, Pascal’s Law, law of conservation of energy
- Transmission and multiplication of force, Momentum theorem, Angular momentum theorem, continuity equation, Euler's equation of motion, Bernoulli’s theorem, laws of compression, forces developed by jets on plates (curved plate, moving plate, etc.) orifice flow formula, flow measurement, pressure measurement, comparison of Pneumatics with Hydraulic power transmissions.

Hydraulic Fluids and pneumatic air
- Basic properties of hydraulic fluids and pneumatic air, compressibility, pour point, flash point, fire point,
- Desirable properties of fluid, undesirable properties of fluids,
- Types of fluid, composition of fluids, effects of additives to hydraulic fluids,
- Advantages of various types of oil.
- Advantages of oil vs. air as working fluid.

Fluid power pumps and compressors
- Function and purposes of pumps and compressors
- Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump. (ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps (iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
- Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
- Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.

Hydraulic and Pneumatic pressure control

Pressure Control Valves, construction and working principles of relief valves- direct acting and pilot operated relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Hydraulic fuse, pressure switch, Pneumatic Pressure regulating valves.

Flow control valves

Basic two way valves, non-compensated flow control valves, throttle valves, restrictor valve, needle valve, ball tip valve, check valves, control valve circuits, pressure compensated flow control valve, demand-compensated flow control, pressure, temperature-compensated, flow control valve, methods of speed regulation in pneumatics.

Directional control valves

Application of directional control valve (DCVs),, designs, construction and operation of check valves, pilot operated check valves, rotary and spool type valves, two way valves, shuttle valves, three way valves, diversion valves, four way valves, solenoid operated, control valves, operation of directional control valves, mounting interfaces, designation, type of actuation of DCVs, pneumatic direction control valves – two way, three way, four way valves, etc., solenoid operated, push button operated, lever operated pneumatic DCVs.

Actuators

Definitions, linear actuators – Hydraulic cylinders, Plunger type, , piston type, Single acting, double acting cylinders, spring return type, tandem and telescopic cylinder, construction of hydraulic cylinders, cylinder seals – piston seal, rod seal, wipes, wear pads, etc. mounting style of cylinders, Pneumatic reciprocating actuators.

Rotary actuators –motors and limited rotation rotary actuators, their types, construction, advantages, vane type single and double vane rotary actuators, rack and pinion type rotary actuators, gear motors – external and internal, gerotor motors, vane motors, Radial piston motors, non-rotating barrel type axial piston motors, advantages of hydraulic motors. Pneumatic rotary actuator, radial piston, vane, and axial piston type air motors etc.

Seals

Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

Pipes, Tubes and Hoses, fittings

Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.

Accessories

Hydraulic and pneumatic filters, their applications, working principles and designs, beta ratio, absolute filtration, nominal filtration, selection of filters, heat exchangers – types, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, types of pneumatic filters, regulators, lubricators, mufflers, dryers, reservoirs etc.

Hydraulic Circuit Design

- Introduction to fluid Power Symbols, Overview of IS 7513,
- Classification of hydraulic circuits, Criteria for designing open loop hydraulic circuits, Analyzing resistive loads, overrunning loads and inertial loads, Heat generation and control.
- Flow control circuits, Pressure control circuits, Direction control & check valve circuits, Cylinder circuits, Pump circuits, Hydraulic motor circuits, Accumulator circuits, Intensifier circuits, Regeneration circuits.
- Sizing of Hydraulic circuit components :
- Reservoir.
- Heat Exchanger: Oil to air heat exchanger, Oil to water heat exchanger.
- Filters: Sizing of suction filter, return line filter, pressure line filter, Beta ratio, Necessary sizing information for filters.
- Fluid Conductors: Flow v/s Pressure drop, Pressure losses, tube/ hose sizing, Pressure rating, Hose/ Tube designation, Calculation of pressure drop in straight lines, bends, fittings etc.
- Pumps: Fixed displacement, variable displacement pumps, Design of suction side and pressure side of pump
- Hydraulic cylinders and motors.
- Accumulator: Isothermal &Adiabatic charging / discharging of accumulator. Sizing of accumulator for various applications i.e. energy storage, shock absorber etc.
- Valves sizing: Direction, pressure & flow control valves.

- Hydraulic Circuit Dynamics considerations: Bulk modulus, Spring rates, natural frequencies, Transmission line dynamics, Pulses in transmissions, Energy controls, Load energy output interaction, system stability, damping, time constant, system response, hydraulic system parameters i.e. resistance, capacitance, impedance.

Advanced Hydraulic Control Circuits

- Various pilot operated valves, construction features, operation, and advantages.
- Modular valves, Stacked type direction control valves, flow control valves, pressure control valves and

combinations.

- Electrically modulated pressure control valves, flow control valves. Pulse width modulation,
- Proportional controls, Servo controls, construction, Uses, differences, operation, advantages and disadvantages.
- Cartridge Valves: Design and construction features of cartridge valves, Types and Operation of cartridge valves, Advantages of cartridge design.
- Advanced pump controls, load sensing, pressure compensation.
- Integrated Hydraulic Circuit:Construction , Advantages of integrated hydraulic circuit, Case study of PVG32 valve, Various modules of PVG 32 valve block, Features of integrated hydraulic circuit of PVG 32, Electronic control capabilities.
- Pneumatic control circuits, proportional and servo valve, proportional and servo actuators

Water Hydraulics and Component Design

- Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals.
- Case Study-1: Differential Pressure Reducing Valve: Conceptual design and sizing
- Case Study-2: Auto Differential Pressure Control Valve - Conceptual design and sizing.
- Case Study-3: Pressure Compensated Flow Control Valve - Conceptual design and sizing.
- Case Study-4: Pilot Operated Pressure Control Valve - Conceptual design and sizing

Electronics and Instrumentation for Hydraulics:

- Current/ Voltage Sources and its measurements, Electronic components –resistance, capacitor, transistors, Opamps etc. Basic circuits for Addition multiplication, division using Opamps. Digital electronics, Logic gates.
- Analog to Digital converters (ADC) and Digital to analog controllers (DAC), Signal conditioning circuits, filters.
- Sensors-Pressure measurement, pressure switches, Position measurement, limit switches-proximity switches, Velocity measurements, Temperature measurement, temperature switches, Viscosity, density measurement, Force, torque, strain measurements.
- Controllers, Closed loop and open loop controllers, Proportional, Integral, derivative controllers and its uses and characteristics. Analog and digital controllers, comparison between digital and analog controllers. Programmable logic controllers, different I/O modules, wiring sensors to PLC. Introduction to microcontrollers, Applications, programming.
- Data Acquisition, Communication buses RS232,RS485, CAN bus, MODBUS, CANOpen bus uses and applications.

Fluid Logic & Control:

- Need for Fluid Control.
- Building Basic Elements for Control Logic (AND, OR, NOT, NAND, NOR).
- Function Implementations using Control Logic.

Experiments :

1. Tuning of PID controller in rotary actuator test facility.
2. Speed control of hydraulic motor using PLC.
3. Measurement of cleanliness level of hydraulic oil samples using particle counter.
4. Qualitative analysis of oil samples using Ferrograph.
5. Establishing position control using frictionless hydraulic linear actuator.
6. Finding characteristics of Differential Pressure Reducing Valve.
7. Finding characteristics of Auto Differential pressure control valve.
8. Finding characteristics of Pressure Compensated Flow Control Valve.
9. Finding characteristics of Pilot Operated Pressure Control Valve.
10. Study of Rexroth/Bemco oil hydraulic power pack and carrying out pressure setting, flow setting etc. in the same.
11. Experiments on ROHYTAM
12. Testing of oil hydraulic filter using filter test set-up.
13. Dismantling & assembling of various valves and actuators.

EN 710: Image Processing & Machine Vision (30)

Image Processing

- Introduction: Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;
- Boundary extraction and representation;
- Morphological operations;
- Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy-based

methods;
- Image Compression: Models, Error free compression, Lossy compression, Standards;

Machine Vision
- Imaging model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflectance, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, Boundary representation,Mathematical Morphology;
- Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, The Generalized Hough Transform;
- High Level Vision: Scene interpretation;
- Texture – Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, Classification and recognition, Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

References:

1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine , Vision,Vikas Publishing House,2003.
6. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004.
7. Davies E.R., Machine Vision Theory Algorithms Practicalities, Academic Press.
8. D.A. Forsyth & J. Ponce, Computer Vision A Modern Approach, Prentice Hall,2003.
9. Horn B.K.P., Robot Vision, The MIT press, 1987.
10. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
11. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

EN 711: Machine Design (25)

Principles of Machine Design:
- Objectives of machine design, general design rules, design methods
- Lightening of' parts and rational design schemes,
- Rigidity of structures, Cyclical/ Contact/ Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs.
- Introduction to inventive problem solving.

Design and Drawing Practices
- Drawing standards, selection of tolerances, fits, and positional tolerances.
- Introduction to Drawing Practices: (matter from various drafting standards),
- Introduction to CAD (including introduction to various drafting and solid modeling softwares)

Sealing Methods
- Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric ‘O’ rings, mechanical seals, labyrinth, valve packings.
- Methods of sealing for high and ultra high vacuum.

Special Dimensional Inspection Techniques
- Description of special dimensional inspection techniques, gaging techniques including composite and paper gauging, Advanced inspection tools including co-ordinate measuring machines and form measuring machines.

Advanced Manufacturing Techniques:
- Precision machining, super finishing, advanced manufacturing
- Micro machining.

References:

1. “Mechanical Engineering Design” by Joseph E. Shigley.
2. “Machinery's Hand Book” (24th edition)
3. “ISO Standards Hand Book” 18.
4. “SKF Bearing Catalogue.”
5. “Relevant IS standards.”
6. “Friction, Wear, Lubrication, Tribology Hand Book” edited by Prof. I.V.Kragelsky & V.V Alisim.

7. "Gear Hand Book by" Dudley.
8. "AGMA Standards 218.01" Dec. 1982.
9. "Industrial Sealing Technology" by H.HUGO BUCHTER

EN 712: Material Science in Nuclear Engineering (ME) (20)

- Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.
- Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X- ray Radiography, etc. for welds.

Corrosion

- Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards

Metallurgy of steels

- Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
- Selection and application of advanced alloys.

Nuclear Materials

- Fabrication, properties and application of Zircaloy, Zr-Nb alloys
- Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications.

Advanced Polymeric materials and Composites

- Physical and Chemical Properties, corrosion, mechanicalproperties
- Equipment design with polymeric materials
- Fabrication principles; standards for design, fabrication and testing.

References:

1. "Introduction to Materials Science for Engineers" - James Shackelford
2. "Physical Metallurgy Principles & Practice" - V.Raghavan
3. "Introduction to Solids" - L.V.Azaroff
4. "Structure and Properties of Materials" - Wulff Series, Wiley Eastern, New Delhi
5. "Materials in Nuclear Application" - C.K.Gupta
6. "Nuclear Chemical Engineering" - Benedict and Pigford

EN 713: Materials Characterisation (20)

Microscopy Techniques

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
  - Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
  - Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High reolution electron microscopy
  - Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, Other modes of operation, Applications in failure analysis, fracture surfaces etc.
  - Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

X-Ray Diffraction and Applications

- Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production and detection of x-rays.
- Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
- Experimental methods in x-ray analysis; Laue methods, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates,

crystal size crystal perfection, crystal orientations:

Chemical Analysis (with applications in materials science).

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

Basics of Analytical Transmission Electron Microscopy,

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, llllcorrections
- Cliff Lorimer factor, thin film correction

Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
- Fundamentals of energy filtering and its uses in life sciences
- Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
- Case studies for metallic bulk samples, life science samples, nano-materials

Physical and Thermal Characterization Techniques

- **Thermal expansion**: Methods and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
- **Thermal Conductivity**: Methods and their principle, advantages and limitations of each method, data of nuclear Fuels
- **TGA/DTA/DSC**: Methods and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
- **Elastic Properties**: Methods and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
- **Hardness**: Different methods and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

EN 714: Membrane Technology (35)

Fundamentals and Overview of Membrane Processes: (5)

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Growth Potential, Classification and description of membrane processes
- Pressure driven membrane processes (MF, UF, NF and RO)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

Novel Membranes

- Features, transport mechanism and application areas
- Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Membrane Bio-reactor, Fuel cell membranes, Membrane sensors, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

Membrane Materials, Preparation and Characterization: (10)

- Material selection
- Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity Molecular weight and molecular architecture
- Membrane preparation techniques- Phase-Inversion, In-situ polymerization, Track-etching, Slip-casting, Sintering
- Membrane Casting Aspects for continuous casting
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of charged membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
- Surface characterization -pore size, roughness, in-homogeneities, and hydrophilicity
- Bulk characterization -porosity, permeation study through flux and solute rejection.

Engineering and Design Aspects of Membrane Technology (10)

- Transport through membranes-Preferential sorption-capillary model,Solution Diffusion model, Irreversible thermodynamics model
- Derivation of basic transport equation for RO membranes

- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants
- Pretreatment considerations, Water chemistry- turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control,Scaling assessment parameters (SDI, MFI)
- Materials of construction
- Process design and system design for water desalination-Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices -pelton wheel, turbo-charger and pressure exchanger
- Effect of operating parameters on membrane performance
- Membrane cleaning and protocols
- Trouble-shooting analysis of operating plants
- Post-treatment techniques
- Membrane autopsy, Reject disposal techniques and brine management.

Membrane Technology Applications (10)

- Techno-economics of membranedesalination plant - seawater / brackish water
- Design aspects of water recovery & recycle from spent streams including sewage Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle
- Hybrid membrane systems, Combo systems -membrane + conventional- for separation application
- Nuclear Desalination
- Membrane based water purification systems-RO/UF application in food processing, pharmaceuticals and Bio-technology
- Fractionation & Value Recovery.
- Zero Liquid Discharge (ZLD)

References

1. Membrane Technology & Applications by Richard W Baker (2008)
2. Membrane Handbook by Ho and Sircar (1992)
3. Transport Phenomena in Membrane by K. Lakshminarayanaiah (1970)

EN 715: Multi-Scale Material Modeling (20)

Introduction

- Spatial and temporal hierarchy of microstructure and dynamics in materials
- Types of models: quantum mechanical, atomistic, mesoscopic, continuum
- Multiscale approaches

Short review and elements of differential equations (numerical solution)

- Differential equations in discrete and continuum simulation methods
- Ordinary differential equations for particle dynamics
- Partial differential equations, conduction/diffusion equation

Atomistic models: Molecular dynamics

- The basics of classical molecular dynamics
- Initial conditions, creating lattice structures, introducing defects
- Defining and maintaining temperature and pressure
- Boundary conditions (periodic, stochastic, conducting, non-reflecting)
- Methods for constant temperature or/and pressure simulations
- Tricks of the trade (neighbor lists, force/energy tables, potential cutoffs, etc.)

Monte Carlo methods

- The basics of Monte Carlo
- Monte Carlo integration, thermodynamic averages
- Importance sampling, Metropolis scheme
- Lattice Monte Carlo, Ising model
- Multi-state Potts models (grain coarsening, recrystallization)
- Kinetic Monte Carlo (surface processes, thin film growth)

Interatomic potentials

- Introduction, Born-Oppenheimer approximation
- Pair potentials and their limitations
- Calculation of elastic constants from potential function

- Potentials for ionic systems, ceramics
- Many-body potentials for metals
- Many-body potentials for covalently bounded systems
- Forces from "first principles"

Analysis of the simulation results

- Equilibrium properties (energy, temperature, pressure, velocity distributions)
- Structural properties (geometrical tessellation, pair correlation functions, atomic level stresses)
- Dynamic properties (diffusion, time correlation functions)

Mesoscopic methods

- Discrete dislocation dynamics
- Strain and stress fields for edge and screw dislocations in an isotropic medium
- The equation of motion in Newtonian Dislocation Dynamics
- Examples from 2D and 3D simulations
- Current problems
- Coarse-grained models

Bridging the scale gaps between different simulation levels

- Simultaneous integration of the models
- Sequential integration of the models (hierarchical approach)
- Examples of combined methods (MD-FEM, MD-MC, etc.)

Modeling at microscale

- Mechanism of ductile fracture and cleavage fracture
- Gurson constitutive law for modeling ductile damage
- Roussiler constitutive law for modeling ductile damage
- Beremin's model for cleavage fracture
- Modeling of material under transition temperature
- Case studies

EN 716: Preparedness & Response to Nuclear Emergencies (35)

- Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
- Radiation Shielding & Study of Criticality parameters and control
- Nuclear Waste Management
- Nuclear Accidents/emergencies
- Transport of Radioactive material
- Radiological accidents/emergencies
- Effects of Hiroshima & Nagasaki bombing
- Detection of Nuclear detonation
- Nuclear weapons: effect (Blast, heat, Radiation and EMP)
- Medical decontamination with demonstration
- Nuclear weapon tests (atmospheric)
- Nuclear & Radiological terrorism (Method to contain and control)
- Chemical warfare & Biological warfare (Method to contain and control it)
- Emergency Response methodology/ Philosophy
- Systems and methodology for Radiological impact assessment
- Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities
- Emergency Monitoring & Shelters
- Civil defence WEB plan for Nuclear attack on major cities
- Monitoring of High radiation field area
- Lab Visits

EN 717: Project Management (25)

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
  - Resources of project.
  - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an

activity, earliest start time EST, latest completion time LCT.
- Scheduling in a project by critical path method, CPM
- Scheduling in a project by Precedence Diagram Method.
- Use of Project Management Software for project planning, scheduling & monitoring.
- Preparation of master control management milestone network, Level-1,2, 3 & 4 network.

- Preparation of Target Plan, updating of progress, monitoring variance & reporting
  - Constraints of project and its effective management
  - Development of Six Monthly Plan and its review process
  - Resource based planning
  - Physical & Financial Monitoring of project, Use of S-curve
  - Capital Budgeting & expenditure control in a project
  - Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis methods, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN 718: Reliability Engineering (ME) (25)

- Reliability Mathematics – Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations,

Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem

- Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
- Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
- Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
- System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
- Application of Reliability - PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

References:

1. Mishra, K.B., “ Reliability Analysis and Prediction”, Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M.,Reliability& Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., “Reliability in Engineering Design”, John Wiley & Sons, 1977.
5. Balaguruswamy, E., “Reliability Engineering” Tata Mcgraw-Hill, 1984.

14. Provan, J.W., “Probabilistic Fracture Mechanics & Reliability”, Martinus Nijhoff, 1987.
15. Nowak, A. S. and Collins, K. R., “Reliability of Structures” McGraw Hill, 2000.
16. Ayyub, B. M. and McCuen, R. H., “Probability, Statistics and Reliability for Engineers”, CRC Press, 1997.
17. Haldar, A. and Mahadevan, S., “Probability, Reliability and Statistical Methods in Engineering Design”,
18. John Wiley and Sons, Inc. 2000.

EN 719: Signal Conditioning, Recovery & EMI Aspects (25)

Review of Analog Signal Conditioning & Recovery Techniques

- Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types ofA/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

Theory of Quantization

- Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti- aliasing filters, fast algorithms for implementation.

Theory of Signal Analysis and Reconstruction

- Function space, orthogonal basis functions, Limitation of Shanon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

Review of EMI Aspects

- Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

EMI Modeling

- Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EN 720: Software Engineering (25)

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools.(3)
- Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods Testing principles, unit testing, integration testing, acceptance testing Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

EN 721: Vibrations (25)

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.
- Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
- Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor;

Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinary.

- Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, aperiodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN 722: Safety and Reliability of Civil Engineering Structures (25)

Introduction to Probability Theory

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, ProbabilityDistributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

Structural Reliability

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment Method, Hasofer Lind Reliability Index, Rackwitz Fiesseler Method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

Probabilistic Safety Assessment

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

Industrial Safety

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

Safety assessment of existing structures:

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

Introduction to decommissioning of structures

References:

1. Hahn, G. J.and Shapiro, S. S. (1994), “Statistical Model in Engineering” Wiley-Interscience.
2. Ranganathan, R. (2000), “Reliability analysis and design of structures”,Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), “A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”, The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety Standard No. AERB/SS/CSE.
6. AERB (1996),“Atomic Energy (Factories) Rules”.

7. AERB (1991), “Safety Guide for Works contract”, Safety Guide No. AERB/SG/IS-1
8. AERB (1996), “The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex”, Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”.
10. Regulatory Guide 1.165 (1997), “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion”, U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (25)

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- BeamWelding Processes
- Arc-Beam Hybrid WeldingProcesses
- Study of welding arc characteristics
- Metal transferduringarcwelding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on themacro-andmicro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high coolingrates
- Phenomena of hot-crackingand coldcracking
- Residualstresses anddistortion duringand afterwelding
- Residual stressmeasurements
- Application ofaboveprinciplesto welding ofcarbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

EN724: Advanced Structural Dynamics and Earthquake Engineering(CE) (30)

I. Introduction to Structural Dynamics and Earthquake Engineering

II. Performance Based Design of structures, systems and components subjected to earthquake loading

Concepts of performance bases, Seismic demand, Capacity of structures, systems and components, performance levels, energy dissipation and damping.

II. Seismic and Vibration Control

Concepts of seismic and vibration control, Passive control using Yielding dampers, friction dampers, tuned mass dampers, Tuned liquid damper, etc., Semi active and active control strategies.

III. Base Isolation Techniques

Concepts of vibration and seismic isolation, laminated rubber bearings, Lead plug bearings, Friction Isolation System etc.

V. Testing and Modal analysis

Need of testing, Methods of testing, qualification of systems by testing, data processing using FFT and Wavelets, modal analysis for frequency, mode shapes and damping. Causes and types of experimental error, statistical analysis of data.

VI. Seismic and Vibration Instrumentation

Measurement Methods and Applications: Measurement of displacement, velocity, acceleration, pressure, forces, strain and optical methods of measurements; Data Acquisition and Processing.

Types of inputs: analog and digital signals, calibration and uncertainty, Measurement System: Performance characteristics, linearity, dynamic range, sensitivity, stability, accuracy, bandwidth, noise, repeatability, hysteresis- threshold- resolution, readability and span.

VII. Fluid-structure interaction techniques

Coupling of fluid with structure, Dimensionless numbers in fluid-structure interactions, Added mass and added stiffness, Fluid sloshing, Flow induced vibration, Flow over bluffed bodies, Vortex shedding.

VIII. Multibody Dynamics

Rigid-Body Kinematics, Kinematics for General Multibody Systems, Modelling of forces in multibody systems, contact forces, friction effect, Equations of Motion of Multibody Systems.

Numerical integration methods for free standing objects, spring-mass system with friction, Runge Kutta methods, error estimation, Computer programs.

Text / Reference Books

1. A. K. Chopra, “Dynamics of structures”, Prentice Hall, 4th edition, 2007.
2. S. S. Rao, “Mechanical vibration”, Prentice Hall, 5th edition, 2014.
3. Holman, “Experimental Methods for Engineers”, 6e, McGraw-Hill, 1994.
4. Doeblin, Engineering Experimentation, McGraw-Hill, 1995.
5. Hans-Joachim Bungartz Michael Schäfer, “Fluid-Structure Interaction Modelling, Simulation, Optimization”, Springer-Verlag Berlin Heidelberg 2006.
6. Soong, T.T. and G.F. Dargush, “Passive Energy Dissipation Systems in Structural Engineering”, Wiley & Sons, New York, 1997
7. Farid Amirouche, “Fundamentals of Multi Body Dynamics, Theory and Applications”, Springer Science, 2006

NON-SUBJECT ASSIGNMENTS

EN 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

EN 592.1: Process Control Trainer (15)

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

Expt 1

Introduction to typical process under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.

Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

Expt 2

Optimisation of process control - using ultimate sensitivity method.

Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.

Optimum gain and integral / differential time constants are calculated using empirical formulae.

Expt 3

Feed forward control configuration - study of process response in comparison with normal feedback control.

Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

Expt 4

Smart Differential Pressure transmitter.

Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.

Re range transmitter using HART communicator.

Re configure transmitter for linear and square root characteristics.

Expt 5

Final control element - Linear pneumatic control valve.

Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.

Virtual instrumentation and wireless data communication between controller and PC.

EN 592.2: Nuclear Detectors (15)

A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.

NaI(Tl) γ- Ray Scintillation Detector

This experiments imparts training on the use of NaI(Tl) detector using known γ- Ray sources (Co^{60} & Cs^{137}) , plotting of calibration curves and identification of unknown sources.

α-Particle spectroscopy using a Solid State Detector

This experiment imparts training on the use of the Solid State Detector using known α-Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup. **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter , testing counting statistics of the counter and studying absorption behaviour of β-rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN 593: Mini-Project Work (300)

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.). Project runs on a part time basis for 11 weeks from mid May to Mid July.

BACK TO MAIN

IGCAR

INTEGRATED Ph.D. (DUAL DEGREE)
ENGINEERING SCIENCES
(PROGRAM CODE: ENGG05)

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
ME1	Code Design for Pressure Vessels and Piping	30	4
ME4	High Temperature Design and Inelastic Analysis	25	2
ME6	Computational Fluid Dynamics	30	4
ME8	Finite Element Method	30	4
ME10	Advanced Heat and Mass Transfer	30	4
ME13	Reliability Engineering	20	2
ME14	Manufacturing Technology	40	4
Total		**205**	**24**

SPECIALISED/ELECTIVE COURSES

(Any three of the seven listed courses)

Course Code	Course Name	Hours	credits
ME3	Machine Design	25	2
	Structural Integrity Assessment Methods and NDE	30	4
	Vibration Engineering and condition Monitoring	20	2
ME5	Seismic Design of Nuclear Reactors and Facilities	20	2
	Plant Dynamics	20	2
	Experimental Mechanics	20	2
ME15	Process Control and Instrumentation	20	2

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-001-P	Project	Duration : 9 Weeks	
2.	02ENGG04-001-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

1. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
2. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
3. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
4. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
5. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
6. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
7. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity

2 **Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor

3 **Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors

4 **Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation

5 **Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions

6 **Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization

B BASIC REACTOR PHYSICS-STATIC

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety
Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down
Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
7. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology (NRST)

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flowmeter: Electromagnetic pumps and flowmeter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6.	Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7.	Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Code Design for Pressure Vessel & Piping (ME1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11.	Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India

3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Finite Element Method (ME8) (30 hours)

S.No.	Course content
1.	Introduction to FEM as applied to solid mechanics. Energy principles in structural mechanics and principles of minimum potential energy
2.	Element Shape and Shape Functions: Generalised co-ordinates. General requirements of shape functions; Lagrangian and Hermitian interpolation functions – CO, C1 continuity; Natural coordinate system; Derivation of shape functions for Bar, Beam, Plane, Brick and Plate elements.
3.	Bar Element: Derivation of elemental stiffness matrix and load vector; Transformation from element to global coordinate system; Assembly of Global stiffness matrix and load vector; Solution of typical 2D-plane Truss problems to evaluate Displacements and Member forces/stress; Thermal stress evaluation in Bars/Truss.
4.	Beam Element: Derivation of elemental stiffness matrix and load vector; Solution of simple Beam problems to evaluate Deflections/rotations; BM/SF distribution and determination of stresses, Shear deformation in beams. Curved Beam Element: Derivation of elemental stiffness matrix and load vector; Derivation of stiffness matrix for elbow.
5.	Axisymmetric Thin Shell Element: Strain-displacement and stress-strain relationship; Derivation of stiffness matrix and load vector for 2 noded axisymmetric thin shell element. 2D Plane Elements – 3 Noded Triangular Element: Derivation of elemental stiffness matrix and load vector, Plane Stress/Plane Strain & Axisymmetric elements: Evaluation of Strain/Stress.
6.	2D Isoparametric Element – 4, 8 and 12 noded quadrilateral Element: mapping of parent element to global space; Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of stiffness matrix for plane & axisymmetric elements; Evaluation of strain/stress at Gauss points.
7.	Introduction and Application of 3D Elements: Strain displacement and stress-strain relationship; Tetrahedron, Triangular prism and Hexahedron elements.
8.	Plane Bending Elements: Thin and Thick plate theory; Elements based on Kirchoff's Theory; Elements based on Mindlin Theory; Shear locking and Reduced Integration.
9.	Shell Element: Strain-displacement and stress-strain relationship; Flat plate and curved shell elements; 4 and 8 noded degenerated thick shell Elements, basic assumptions, degree of freedom, shape functions and shear locking.
10.	Incompatible Displacement Model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral element.
11.	Introduction to Nonlinear Problems. Meshing and Errors: Finite Element Modeling and Discritization Criterion, Adaptive meshing, classification of FEM stresses per ASME code, sources of potential error in the finite element solution

Books Suggested:

1.Finite Element Procedures-K.J.Bathe, Prentice Hall, 1996.
2.Concepts and Applications of Finite Element Analysis, R.D.Cook,D.S.Malkus & M.E.Plesha, 4th Ed., Prentice-Hall India, 2003.
3.An introduction to the Finite Element Method-J.N.Reddy, 2nd Ed., McGraw Hill Education (ISE editions)-1993.
4.Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.1, Butterworths-Heinemann,2000.
5. Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.2, Butterworths-Heinemann,2000.

6.The Finite Element Methods: its basics and fundamentals- O.C.Zienkiewicz ,R.L.Taylor &J.Z.Hu, Elsevier,2005.
7.The Finite Element Method: Linear,Static and Dynamic Finite Element analysis-T.J.R.Hughes, Dover Publication,2000.
8.Fundamentals Finite Element Analysis and Applications-M.Ashghar Bhatti, John-Wiley & Sons, NJ,2005.

3. Advanced Heat and Mass Transfer (ME10) (30 hours)

S.No.	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes & Bemoulli equations.
2.	**Laminar Boundary Layer and Forced Convective Heat:** Formulation of differential equation for hydrodynamic and thermal boundary layer. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory. Convective heat transfer for intemal and extemal flows. Low and high Prandtl number limits and different thermal boundary conditions Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method.
3.	**Turbulent Flow and Heat Transfer:** Reynolds decomposition for turbulence**.** Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical. correlations for calculating heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
4.	**Turbulence Modeling:** Eddy diffusivity models: k-£ and k-w) models, RNG based k- £ model. Reynolds stress models: algebraic & differential models. Low Reynolds number models Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
5.	**Natural Convection:** Basic Equations of natural convection. Boussinesq approximation. Derivation of Dimensionless groups from basic equations. Analytical approximations
6.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Moment, porosity, permeability etc.., homogenization method, continuity equation & energy equation, introduction to 2 phase flows & heat transfer in fluid flows.
7.	**Heat Transfer With Phase Change** : Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post dryout heat transfer. Various models available for calculation of heat transfer coefficient.. Critical Flow. Models for single - phase and two-phase critical flow.
8.	**Radiation heat transfer:** Radiation heat transfer. Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Books suggested:

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.

3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

4. Computational Fluid Dynamics (ME6) (30 hours)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme
B.	**Numerical Solution of Complete Fluid Flow and Energy Equation:**
1.	Formulations of governing equations used in numerical simulation:
2.	Stream function-temperature formulation
3.	Stream function-vorticity-temperature formulation
4.	Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5.	Primitive-Variable (P-V-T) formulation
6.	Pressure velocity coupling for incompressible flow.
7.	Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8.	Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9.	Simple grid generation techniques for structured grid:
10.	Elliptic. parabolic and hyperbolic equation method
11.	Grid adaptation
12.	Domain decompositions in CFD and heat transfer
13.	SIP and preconditioned conjugate gradient methods for solution

14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Books suggested:

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9^{th} Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

5. Reliability Engineering (ME13) (20 hours)

S.No.	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.\
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY.

6. Manufacturing Technology (ME14) (40 hours)

S.No. **Course content**

Curriculum for Metal Forming

1. **Uniaxial tensile test**:
   a. Engineering stress, engineering stain, true stress, true strain;
   b. Extraction of plastic stress-plastic strain data from load – elongation data of uniaxial tensile tests; Hollomon type and Voce type constitutive relations;
   c. Tensile instability and significance of strain harkening exponent;
   d. Determination of strain rate sensitivity index and the significance of strain rate sensitivity;
2. Stress matrix and the derivation of the Cauchy relation from the law of conservation of linear momentum; concept of principal stress;
3. Small strain matrix and rotation matrix obtained from the displacement functions;
4. **Elements of the theory of plasticity**:
   a. Decomposition of stress matrix to hydrostatic and deviatoric matrices;
   b. Yield surfaces as a function of the second and third invariants of the deviatoric matrix with von Mises and Tresca criteria being examples; concept of equivalent stess;
   c. Normality flow rule and convexity of the yield surface; concept of equivalent strain

Curriculum for Materials Joining

1. **Welding Processes**
   a. Fusion Welding Processes: Arc Welding Processes like SMAW, GTAW, GMSE, GVSE etc. and Beam welding process like EB welding and Laser Welding
   b. Solid state Welding Process like Friction Welding, Friction Stir Welding, Diffusion bonding, Explosive welding
   c. Resistance Welding Processes
2. **Thermal Cycle during welding**
   a. Weld Thermal Cycle, Dependence of bead shape with welding speed, prediction of weld thermal cycle
3. **Residual Stress and Distortion**
   a. Generation of residual stress, Effect of residual stress on performance, removal of residual stresses, measurement of residual stresses
   b. Origin of Distortion, Control of distortion

7. High Temperature Design & Inelastic Analysis ME4: (25 hours)

S.No. **Course content**

1. Introduction: Modes of failure, material selection, criteria to assess creep effect, creep law, creep-fatigue interaction, thermal striping
2. Design Practice: Loading category, primary, secondary and peak stress intensity, allowable stress intensity (S_m), assessment of basic wall thickness, strain limits

3. Analysis: strain range under multi axial state of stress, Nuber's rule, triaxiality, elastic followup, fatigue damage, allowable numbers of cycle, creep damage, creep life prediction, creep rupture strength, creep fatigue interaction, ratcheting, efficiency diagrams and creep buckling
4. Fracture mechanics, creep crack growth, introduction to RCC-MR A16
5. In elastic Analysis: General principles for constitutive models, non unified model (plastic + creep), flow rule, creep strain hardening, classified models, viscoplastic material model, non-linear kinematic hardening, isotropic hardening, plastic strain memory, finite element Implementation, automatic time integration

Books Suggested:

1.Creep Analysis – H.Krauss
2.Mechanical Metallurgy-G.E. Dieter
3.Creep in Structures-A.R.S.Ponder and Drkhayhurst
4.Advances in Creep Design-Ed.A.I.Smith and A.M.Nickelson
5.ASME Section3 Subsection NH-1
6.French Design Code-RCCMR-Subsection RB

SPECIALISED/ELECTIVE COURSES

1. Machine Design (25 hours)

S.No.	Course content
1.	Principles of Machine Design: Objectives of machine design, general design rules, design methods, variable loads, Lightening of parts and rational design schemes, Rigidity of structures, Cyclical/Contact/Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs. Introduction to inventive problem solving.
2.	Design and Drawing Practices: Drawing standards, selection of tolerances, fits, and positional tolerances. Introduction to Drawing Practices: (matter from various drafting standards), Introduction to CAD (including introduction to various drafting and solid modelling softwares)
3.	Sealing Methods: Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric `O' rings, mechanical seals, labyrinth, valve packings. Methods of sealing for high and ultra high vacuum.
4.	Special Dimensional Inspection Techniques: Description of special dimensional inspection techniques, gauging techniques including composite and paper gauging, advanced inspection tools including co-ordinate measuring machines and form measuring machines.
5.	Advanced Manufacturing Techniques: Precision machining, super finishing, advanced manufacturing, Micro machining.

Books suggested:

1) Mechanical engineering design (In SI Units) - Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2) Design Of Machine Elements Edition 7 - Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3) Machine Elements in Mechanical Design - Mott (R L), Columbus, Charles E Merril, 1985.
4) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.

5) Mechanical Engineering Design (In SI Units) – Joseph E Shigley & Charles R. Mischke, New Delhi, Tata Mcgraw Hill, 2001.
6) Design of Machine Elements - Ed. 7 – Spoots M F, Shoup T E, New Jersey, Prentice Hall 1998
7) Machine Elements in Mechanical Desgin – Moot R L, Columbus, Charles E Merril, 1985.
8) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.
9) Fundamentals of machine design – Oriov, Mir Publishers, Moscow.
10) Fluid power applications – Anthony Esposito, Pearson education
11) Precision engineering manufacturing – Murthy R.L., New Age International
12) MEMS and Microsystems design and manufacture – Tai-Ram Hsu, Tata McGraw Hill.

2. Structural Integrity Assessment Methods and NDE (ME3) (30 hours)

S.No.	Course content
1.	Fracture Mechanism in Metals
2.	Linear Elastic Fracture Mechanics
3.	Elastic Plastic Fracture Mechanics
4.	Low Cycle Fatigue
5.	Assessment of Creep damage and creep-fatigue interaction
6.	Creep crack growth models
7.	Experimental determination of fatigue and creep curve CTOD, KIC, KIa, J-R curve and C*
8.	Basis of ASME Sec. XI Reference Curve and its use in Pressurised Thermal Shock
9.	CTOD design method
10.	J-Estimation Schemes and J-based failure assessment diagram
11.	Net Section Collapse Criteria and Reference Stress approach
12.	R-6 method and its application
13.	Thermal background of international assessment procedure
14.	RCCMR code/A-16 method and its application
15.	CEGB codes
16.	Application of R-5/R-6 for design of high temperature components
17.	Failure Assessment Diagram of PD-6493 and BS-7910
18.	J-Estimation Schemes and J-based failure assessment diagram
19.	Leak-Before-Break design method
20.	Analysis of numerical techniques/Computational fatigue, Fracture and creep
21.	Probabilistic Fatigue, Fracture and creep
22.	Bench Mark solutions
23.	Manufacturing and process-induced defects that influence structural integrity -
24.	Principles, capabilities and applications of surface examination NDE techniques
25.	Principles, capabilities and applications of volumetric examination NDE techniques
26.	Quality assurance of nuclear components with relevant codes and standards and quality concepts
27.	Structural integrity, in-service inspection and life assessment of nuclear components using NDE
28.	NDE Lab visit and Practicals

Books Suggested:

1. Practical Non-destructive testing- Baldev Raj, Jayakumar.T. and Thavasimuthu. M., Narosa publishing house, New Delhi, 1997
2. Advances in NDE for structural integrity, - Nichols. R.W., Applied Science Publishers, London, 1982.
3. Non destructive Evaluation: A tool in Design, Manufacturing and Service and Francis – Don E.Bray and Roderick K. Stanley, Taylor, CRC Press, New york, 1996.
4. Non-destructive testing, R. Halmshaw, Edward Arnold, 1991.
5. Electrical and Magnetic Methods for Non-destructive testing, - J. Bllitz, Adam Hilger, Bristol, 1997.
6. Ultrasonic testing of materials, - Josef Krautkramer, Herbert Krautkramer, Springer-Verlag. January 1983.

3. Vibration Engineering and Condition Monitoring (20 hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
7.	Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum,

coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

4. Seismic Design of Nuclear Reactors and Facilities (ME5) (20 hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson’s ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
7.	**Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.

Books Suggested:

1. Chopra, A.K., “Dynamics of Structures, Theory and applications to Earthquake Engineering”, Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures”, New York, McGraw-Hill Book Company.
3. Mariopaz, “Structural Dynamic (Theory and Computation)”, CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., “Numerical Methods in Finite Element Analysis”, Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, “Seismic Analysis of Safety Related Nuclear Structures and Commentary”, ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, “Engineering Seismology”, IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, “Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, “Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites”. AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design”, BIS, New Delhi.

5. Plant Dynamics (20 hours)

S.No.	Course content
1.	**Pressure drop** in fuel Subassembly, friction, local acceleration and elevation pressure drop in wire-wrap. Flow zoning
2.	**Hot spot factors**: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors. Subchannel analysis of fuel subassemblies, mixing parameters, introduction to computer codes.

3. **Event analysis**: General safety features, General Considerations on Design Basis Events, Thermal and Hydraulic Modeling for Analysis, Safety Criteria, Design Criteria for Selection of SCRAM Parameters, Sympathetic Safety Actions, Primary Sodium Flow Halving Time, Maximum Permissible Absorber Rod Speed.

4. **Results of Analysis of Major DBE:** One Primary Sodium Pump Acceleration, Both Primary Sodium Pumps Acceleration, One Secondary Sodium Pump Acceleration, Both Secondary Sodium Pumps Acceleration, Feed water Flow Increase Events, Continuous Withdrawal of One CSR, One Primary Sodium Pump Trip, One Primary Sodium Pump Seizure, Off-Site Power Failure with Emergency Backup for PSP, Primary Pipe Rupture, One Secondary Sodium Pump Trip, One Secondary Sodium Pump Seizure, One Boiler Feed Pump Trip, Loss of Feed Water Flow to Steam Generator, Intermediate Heat Exchanger Sleeve Valve Closure, Loss of Heating in High Pressure Feed water Heaters, Spurious SCRAM. Reactor start-up, BFP Trip and over speeding at full power, Turbine Generator -Trip and subsequent plant operating actions, power setback.

5. **Decay Heat Removal:** Decay Heat Removal through OGDHRS, Decay Heat Removal through SGDHRS, Need for Forced Convection Core Flow, Decay Heat Removal during Station Blackout Situation, Adequacy of SGDHRS Capacity.

6. **Energy Release In Beyond Design Basis Events:** Local Events: Subassembly Accident, Whole Core Events: Pre – disassembly Phase, Disassembly Phase, Mechanical Energy Release / System Response Phase, Analysis of Transient Over Power Accident, Computer Codes, Analysis of Loss of Flow Accident (LOFA), Sodium Void Worth, Consequences of Fuel - Coolant Interaction

Books Suggested:
Material will be provided during the course

6. Experimental Mechanics (20 hours)

S.No.	Course content
1.	Stress & Strain: State of stress, strain, plane stress, plane strain, Thermal stress, Hydrostatic & Deviatoric Component of stress, Elastic stress-strain relationship, Elastic-Plastic strain relations, Von-mises plasticity criteria, plastic flow rule, strain hardening law, perfectly plastic material, Isotropic strain hardening material, kinematic strain hardening, combined strain hardening stress concentration, cyclic stress, Fatigue, Endurance limit, Creep, Larson Miller parameter.
2.	Photo elasticity: Polarisation, polariscope, diffused light and lense polariscope, stress optics law, plane polariscope, circular polariscope, criteria for model material selection, Isochromatic fringe pattern, Iso fringe pattern, scaling model to prototype stress.
3.	3D photo elasticity: locking of model deformations, scaling model and interpretation of the resulting fringe pattern, effective stresses, Birefringent coating, scattered light and its relation to photo elasticity, scattered light polariscope.
4.	Strain measurement methods: strain gage, basic characteristics, types of strain gages, factors in gage selection, electrical resistance strain gage, potentiometer for strain measurement, strain gage circuit, wheat stone bridge

5. Recording Instrument: galvanometer with oscillograph, transient response galvanometer, frequency response of the wheatstone bridge and galvanometer, cathode ray oscilloscope and potentiometer recorder.

Books Suggested:

1.Mechanical engineering design (In SI Units)', Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2.Design Of Machine Elements Edition 7, Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3.Machine Elements In Mechanical Design, Mott (R L), Columbus, Charles E Merril, 1985.
4.Experimental methods for engineers- J.P.Holman, McGraw Hill.
5.Theories of engineering experimentation-Hilbert Schenck, McGraw Hill.

7. Process Control & Instrumentation (Co-ordinator: A. Venkatesan) (20 hours)

S.No.	Course content
1.	Basic Concepts
2.	Units of measurements, Definitions (accuracy, precision, repeatability, span, range, hysterisis, drift, sensitivity, resolution, lag etc.) -- Sensors, transducers, Transmitters, PI diagrams, Symbols., Digital and analog devices.
3.	Sensing, Transmission, Receiving of the following Process Variables
4.	Temperature: classification, thermocouples, RTD, Thermistors, Pyrometers.
5.	Flow: Direct type, inferential type, constant area sensors, differential pressure meters, variable area meters, magnetic, ultrasonic, vortex type flow meters, and mass flow meters.
6.	Level: Direct type (Float, gauge glass, torque tube, piston tube, reflex etc) indirect type (Pressure gauge, purge, d/p with open/closed tanks, Ultrasonic, nucleonic, capacitance & conductivity).
7.	Pressure: Manometers, Bourdon, bellows, diaphragms, D/P Tx, (electronic & pneumatic), strain gauges, load cells.
8.	Analytical: pH, viscosity, conductivity, humidity, isotopic purity, and turbidity.
9.	Control System: Feedback Control theory, Modes of control, generation of control modes, Controllers, feedback & feed forward control, final control elements and valve positioners.
10.	Safety principles: Trip logic, annunciators, simple logic circuits, and smoke/fire detectors.
11.	Current Trends In Instrumentation: Smart transmitters, Instrumentation for a process loop, Paperless recorders, DAS, PLC, DRS, etc.

Books Suggested:

1. Instrument Technology Vol. I to V E.B. Jones.
2. Mechanical & Industrial Measurements, R.K. Jain
3. Automotive Process Control, Donald P. Eckman
4. Measurement Systems Application & Design, Ernest Doebelin.
5. Process Instrument & Control Handbook, Douglas Considine.
6. Instrument Engineers Handbook, Vol. I&II, Dela G. Liptak
7. Instrumentation for Process Measurement & Control, N.A. Anderson

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
ELECTRONICS AND INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
EL2	Reactor Control Engineering	20	2
EL3	Nuclear Instrumentation	20	2
EL4	Reliability Engineering	20	2
EL5	Software Engineering	20	2
EL8	Human Machine Interface for Reactor Control Instrumentation	45	6
EL10	Modern Control of Dynamic Systems	30	4
Total		**155**	**18**

SPECIALISED COURSES

Course Code	Course Name	Hours	Credits
EL6	Artificial Intelligence and Digital Signal Processing	40	4
EL7	Process Instrumentation	35	4
EL9	Embedded and Computer based systems Design	45	6
EL11	Analytical Instrumentation	25	2
Total		**145**	**16**

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-002-P	Project	Duration : 9 Weeks	
2.	02ENGG04-002-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. **Engineering Mathematics (EM) (35 hours)**

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

8. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
9. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
10. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
11. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
12. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).

13. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
14. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

Sl.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

13. Introduction to Materials Science for Engineers - James Shackelford
14. Physical Metallurgy Principles & Practice - V.Raghavan
15. Introduction to Solids - L.V.Azaroff
16. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
17. Materials in Nuclear Application - C.K.Gupta
18. Nuclear Chemical Engineering - Benedict and Pigford
19. Physical Metallurgy, Reed - Hill
20. Heat treatment of steel - Avener
21. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
22. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
23. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
24. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Fast Reactor Physics and Shielding (RP) (35 hours)

S.No.	Course content
A	NUCLEAR THEORY BASICS :
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :** Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units
2	**Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

8. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
9. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
10. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
11. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
12. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
13. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
14. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics and Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

13. Introduction to Health Physics – Herman Cember
14. Introduction to Radiation Protection – Alan Martin
15. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
16. Nuclear Radiation Detection - W.J. Price
17. Radiation Detection and Measurement - G.F. Knoll
18. Biological Effects of Radiation – J.E. Coggle
19. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
20. Atoms, Radiation and Radiation Protection by James E. Turner 1986
21. Problems and solutions in Radiation Protection by James E. Turner, 1988
22. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
23. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
24. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) – (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :**
	Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology (NRST)**

1 **Properties of Sodium:** Physical and chemical properties, (hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

11. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
12. Steam Power Station, G.A. Gassort.
13. Power Plant Engineering & Economics, Strosal & Vapet.
14. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
15. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
16. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
17. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
18. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
19. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
20. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Reactor Control Engineering (EL2) (20 hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (EL3) (20 hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (EL4) (20 hours)

S.No.	Course content
12.	**Introduction: Reliability Engg. Applied to C&I Systems** Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors. Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems. Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
13.	**Reliability Maths/Statistics:** • Mathematical and statistical expressions required for reliability study. • Types of failures in electrical, electronic and computer components • Failure probability concept, statistical distribution models_ • Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions • Chi-square distribution and its use in confidence and risk factors • Baye's theorem • Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software. • Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions. • Derivation of exponential reliability expression_ • R(t)=[exp-(lt)] for electronic components and systems. • Examples to solve

14. **Fault Tolerance and Systems Reliability:**

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model

Example from C&I system in the NPPs

15. **QA/QC Concepts in Brief:**

- QA/QC Concepts in the components, systems procurement, manufacture and
- Site installation for C&I systems in the NPPs.

16. **Environmental Qualification and Reliability Testing:**

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

17. **PSA/PRA Concepts in NPPs:**

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

18. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Software Engineering (EL5) (20 hours)

S.No.	Course content
1.	Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work- products of different phases
2.	Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics, CASE tools.
3.	Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalization, composition, polymorphism. Modeling structure and behavior, Use case diagrams, class diagrams, state diagrams, sequence diagrams, architectural and detailed design., Modeling real-time software. Introduction to Object Oriented Languages. CASE tools.
4.	Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities.
5.	Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods. Testing principles, unit testing, Integration testing, acceptance testing., Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing.
6.	Software Configuration Management: Configuration items (with examples), baselines, libraries, version control
7.	Software Engineering Standards

Books suggested:

1. Software Engineering by Roger S. Pressman, McGraw Hill International Students Edition
2. Software Engineering by Ian Sommerville, 5th Edition, Addison Wesley
3. An Integrated Approach to Software Engg. by P. Jalote, Springer/Narosa Publishers
4. Unified Modeling Language User Guide by G. Booch, J. Rumbaugh, I. Jacobson, Addison Wesley
5. Real-time UML, second edition, Bruce P. Douglass, Addison Wesley

5. Human Machine Interface for Reactor Control Instrumentation (EL8) (45hours)

S.No.	Course content
A .	**Reactor Instrumentation:**
1.	Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification
2.	RPS & RRS for FBRs : Core Temperature Monitoring System, Diversified Safety Logics, Control Logics for CSRDM & DSRDM
3.	Supervision Systems : Startup systems, Discordance supervision systems for SCRAM signals & CSRs, Alarm Generation system, ESR & PDA
4.	Component Handling Systems: I & C for Rotatable plugs, Transfer Arm, IFTM, CTM, Under Water Trolley and Storage Bays, HMI in HCR for Component handling and fuel movement monitoring.
5.	Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, low selector, high selector, median selector, voting logics, Interfaces with electrical Control gear.
6.	C & I Cables : Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
7.	Incident monitoring & mitigation systems : RCB Isolation, I&C for SGDHR, Seismic Instrumentation, Post Accident monitoring system, Video monitoring system
8.	Special systems: Fire Alarm System, Physical protection systems, Biometric Sensors, etc.
9.	Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station, DDCS for PFBR. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards, PLCs for package systems.
10.	PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

11. Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

B. Human Machine Interface (HMI)

1. Overview of plant automation.
2. Design of HMI, Soft Console versus Conventional control panels.
3. Guidelines for design of HMI displays.
4. Case study of a commercially available Professional HMI package.
5. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package
6. Practical.

Books suggested:

1. Intellution Ifix documentation
2. NPC Guidelines for development of soft consoles.

6. Modern Control of Dynamic Systems (EL10) (30 hours)

S.No.	Course content
1.	**1.** State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	**.** Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	**.** Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

SPECIALISED COURSES

1. Artificial Intelligence & DSP (EL6) (40 hours)

S.No.	Course content
	A. Introduction to Artificial Intelligence
1.	Introduction – Nature of AI problems
2.	Search – State space search
3.	Robotics – Kinematics and dynamics
4.	Knowledge Representation – Predicate logic
5.	Neural Networks – Feed forward vs Feedback
6.	Fuzzy Logic – membership functions
7.	Reinforcement Learning – Intelligent agents
8.	Genetic Algorithm – Solution representation
9.	Engineering applications including in Robotics
	B. Digital Signal Processing
1.	Introduction: Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, convolution, correlation, sampling theory, aliasing, anti-aliasing filter, quantization noise, signal reconstruction.
2.	Discrete Fourier Transform: Interpretation of DFT, properties of DFT, DFT of real signals, periodic & linear convolution and correlation using DFT.
3.	Fast Fourier Transform: Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, computation of Inverse DFT using FFT algorithm, efficient computation of the DFT of two real sequences and a 2N-point real sequence,

spectrum analysis using the FFT, windows in spectrum analysis, use of FFT algorithm in linear filtering and correlation.

4. Digital filters: FIR and IIR filters, design techniques for FIR and IIR filters, realization of FIR and IIR systems, overview of DSP processors.
5. DSP Applications: Applications of digital signal processing in nuclear and other fields.

Books suggested:

1.Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
2.John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice- Hall of India,1995.
3.Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.

2. Embedded & Computer based systems Design (EL9) (45 hours)

S.No.	Course content
A.	**Microprocessor Based Hardware Design:**
1.	Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Micro-controllers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
2.	Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3.	Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
4.	Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
5.	IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, testability.
6.	Embedded computer system design example.
B.	**Computer Communication and Networks**
	Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.)

C. **Fault Tolerant and Distributed Architectures**

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.

2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. **Real-Time System Design**

1. Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.

2. Overview of LINUX and Embedded NT.

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.

3. Process Instrumentation (EL7) (35 hours)

S.No.	**Course content**
7.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors,

flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.

8. Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
   Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

9. Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

10. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

11. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

12. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type-Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,
    Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

13. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

    Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.

14. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

    Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.

15. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrment Engineer’s Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Fieldbus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

4. Analytical Instrumentation (EL11) (25 hours)

S.No.	Course content
	Measurement related issues
1.	Sensitivity, detection limit, signal-to-noise ratio enhancement
2.	Absorption and Emission Spectroscopy
3.	UV-VIS-IR Spectrophotometry
4.	Atomic Absorption Spectrophotometry
	IR absorption methods for detection of Carbon, Sulphur, Oxygen, Nitrogen
5.	**Fluorescence Spectrometry**
6.	Generation of X-Rays
7.	X-Ray Fluorescence Spectrometry
8.	X-Ray Diffraction Spectrometry
9.	Laser florescence
10.	**Mass Spectrometry**
	Applications and importance of mass spectrometry
	Various types of ion sources
	Various types of mass analysers
	Various methods of detection
	Computer based automation and measurements
11.	**Thermo analytical methods**
	Thermal analysers-DTA and TG
	Differential Scanning Calorimeters
12.	**Electro analytical instruments**
	Voltametry, amperometry and Coulometry
	Conductivity and pH

Books Suggested:

1. Instrumental methods of analysis, - Willard & Others, Pub: CBS, New Delhi, 7th Ed.
2. Principles of instrumental analysis, - Douglas A.Skoog and James J. Leary, Saunders College Publishing, Harcourt Brace College Publishers. (IGCAR Acc. No. 063944)

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
CHEMICAL ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING (CHEMICAL)
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE1	Nuclear Chemical Engineering	35	4
CE2	Chemical Engineering Thermodynamics	40	4
CE3	Transport Phenomena	40	4
CE4	Multi Phase Flow Systems	40	4
CE5	Code Design for Pressure Vessels and Piping	25	2
CE6	Computational Fluid Dynamics and Heat Transfer	40	4
CE7	Advanced Chemical Reaction Engineering	25	2
Total		**245**	**24**

SPECIALISED COURSE
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE8	Process Analysis and Control	25	2
CE9	Advanced Mass Transfer	25	2
Total		**50**	**4**

ELECTIVE COURSES
(One course amongst the three to be chosen)

Course Code	Course Name	Hours	credits
CEEL	Preparedness &Response to Nuclear Emergencies	30	4
	Artificial Intelligence Methods &Applications	30	4
	Membrane/ Separation Process and Technology	30	4

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-003-P	Project	Duration : 9 Weeks	
2.	02ENGG04-003-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers. B-splines,Bezier curves, Response surface method, different levels of factorial design.

Book suggested

15. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
16. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
17. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
18. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
19. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
20. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
21. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
9.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
10.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
11.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
12.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
13.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
14.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
15.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
16.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

25. Introduction to Materials Science for Engineers - James Shackelford
26. Physical Metallurgy Principles & Practice - V.Raghavan
27. Introduction to Solids - L.V.Azaroff
28. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
29. Materials in Nuclear Application - C.K.Gupta
30. Nuclear Chemical Engineering - Benedict and Pigford
31. Physical Metallurgy, Reed - Hill
32. Heat treatment of steel - Avener
33. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
34. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
35. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
36. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

15. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
16. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
17. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
18. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
19. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
20. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
21. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.

Course content

1. **Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity.

   Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.

2. **Biological effects of Radiation:**

   Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).

3. **Radiation Protection and Regulations:**

   Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India.

   Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.

   Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.

   Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.

4. **Radiation protection and measurement (External and Internal):**

   Control of external exposures (with problems in each case).

   Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources.

   Routes of intake of radioactive material,

   Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

25. Introduction to Health Physics – Herman Cember
26. Introduction to Radiation Protection – Alan Martin
27. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
28. Nuclear Radiation Detection - W.J. Price
29. Radiation Detection and Measurement - G.F. Knoll
30. Biological Effects of Radiation – J.E. Coggle
31. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
32. Atoms, Radiation and Radiation Protection by James E. Turner 1986
33. Problems and solutions in Radiation Protection by James E. Turner, 1988
34. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
35. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
36. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. **Thermal Power Reactors :**

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. **Fast Power Reactors :**

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology**

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

21. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
22. Steam Power Station, G.A. Gassort.
23. Power Plant Engineering & Economics, Strosal & Vapet.
24. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
25. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
26. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
27. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
28. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
29. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
30. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.

9. Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.

10. Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.

11. Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.

12. Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements

2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.

3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types

4. Design criteria, Loadings to be considered, Analysis method and validation methodology

5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features

7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Nuclear Chemical Engineering (CE1) (30 Hours)

S.No.	Course content
1.	**An Introduction to Nuclear Chemical Engineering** General Introduction and course schematics
2.	**Production of Nuclear Materials** Production of nuclear fuels (i.e.)uranium, thorium and zirconium form ores. Alternate sources for uranium Isotope separation technologies for uranium and water Fuel fabrication technologies for various types of reactors Less common nuclear materials like Zr, Hf, Th, Be,V, Nb and Ta
3.	**Solvent Extraction of Nuclear Materials** Introduction to archival extractants and flowsheets Science and technology of primary extractant (TBP) Alternate extractants for fuel reprocessing applications Extractants for nuclear waste management applications Classical and novel nuclear solvent extraction equipment Criticality and its prevention. Other safety aspects
4.	**Nuclear Fuel Reprocessing** PUREX, Advanced PUREX, SuperPUREX processes Reprocessing of thermal reactor (PHWR and AHWR) Fuels Reprocessing of fast reactor (FBTR & PFBR) Fuels UREX process and its variants Supercritical Fluid Extraction based Superdirex Process Pyrochemical and other non-aqueous processes for reprocessing
5.	**Nuclear Waste Management** Characterization of nuclear wastes Conditioning and remediation. Post-PUREX and Post-UREX processes for isolation of important radionuclides (TRUEX, UNEX, ARTIST, SETFICS, SESAME etc.) Decontamination and decommissioning
6.	**Modeling and Simulation in Nuclear Chemical Engineering** Generation of SX data by conventional & **AKUFVE** techniques Modeling of solvent extraction data Computer codes for simulation of nuclear SX Simulation of solvent extraction process flowsheets Experimental design based variation analysis of flowsheets

Books Suggested:

1. Benedict M., Pigford T.H. and Lewi H. Nuclear Chemical Engineering, McGraw Hill. 2nd ed. (1981)
2. Long, J.T. , Engineering for Nuclear Fuel Reprocessing, American Nuclear Society, IL (1978)

3. Schulz. W.W, Navratil, J.D. and Talbot A.E., Science and Technology of Tributyl Phosphate, Vol.1, CRC Press Inc., Boca Raton, FL (1984)
4. Schulz. W.W, Burger, L.L.,Navratil, J.D. and Bender K.P., Science and Technology of Tributyl Phosphate, Vol.3, CRC Press Inc., Boca Raton, FL (1984)
5. Knief, R.A. Nuclear Energy Technology, Hemisphere Publishing corporation, NY, (1981)
6. Vilani, J., Isotope Separation, (IGCAR library)
7. Selected IGCAR Reports Concurrent literature on AFCI, UREX and allied processes

2. Chemical Engineering Thermodynamics (CE2) (30 Hours)

S.No.	Course content
1.	Classical thermodynamics - the scope of classical thermodynamics, basic concepts and definitions. Laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures.
3.	Multicomponent systems: the chemical potential, fugacity, activities, and activity coefficients.
4.	Solubilities of gases in liquids, solids in gases and in liquids.
5.	Vapour liquid equilibria at low and high pressure. (Van Laar, Peng-Robinson equations). Thermodynamics of super critical fluid
6.	Liquid-Liquid equilibria.
7.	Models for Non ideal, Non-electrolyte solutions and ionic liquids.
8.	Solution thermodynamics
9.	Phase Equilibrium: Phase rule, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations, Equilibrium in systems with supercritical components, phase stability applications.
10.	Chemical Reaction Equilibria: Equilibrium constants for Homogeneous and heterogeneous reactions.
11.	Statistical Thermodynamics

Books Suggested:

1.Denbigh, K. G., The Principles of Chemical Equilibrium, Cambridge, 1971.

2.Tester, J. W. and Modell, M., Thermodynamics and its Applications, 3rd ed., Prentice-Hall, 1997.

3.Bejan, A., Advanced Engineering Thermodynamics, Wiley, 1988.

3. Transport Phenomena (CE3) (40 Hours)

S.No.	Course content
1.	Phenomenological description of continuum approach. Reynolds transport theorem. Basic laws of conservation of mass, momentum and Energy and Multicomponent systems.

2. Transport properties. Modeling of Engg systems and the specification of boundary conditions. Shell balances, Navier-Stokes equations; Momentum, Heat and Mass transfer in steady and unsteady viscous flows; turbulent flows; shell and differential thermal energy balances; steady and unsteady conduction; laminar, forced and natural convection; shell and energy balances of mass of species; diffusion under various driving forces, diffusion with chemical reaction; convective diffusion in dilute solutions; integral balances. Transport coefficient and the macroscopic treatment of momentum, Energy and mass transport in complex system.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Multi-phase flow systems (CE4) (30 Hours)

S.No.	Course content
1.	Multiphase flows and Classification of Multiphase, Flow Patterns (gas-liquid, liquid-liquid and gas-solid and gas-liquid-solid) - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum and energy transfer for different models: Multi-dimensional and flow regime specific models.
2.	Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. (Gas-liquid mixture transport in horizontal and vertical pipe.), vapour-liquid flow, flow boiling, sub-cooled boiling, critical heat flux.
3.	Applications of two-phase flow in the design of steam generators, thermo-syphon evaporators, condensers with non condensibles and air lift pumps. Hydrodynamic of liquid-liquid flow design variables such as holdup, characteristic velocity and pressure drop.
4.	Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. (Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile and pressure drop for turbulent slurry flow.)
5.	The phenomena of fluidization and its industrial application. Characteristics of particles. Principle of fluidization and mapping of various regimes. Two phase theory of fluidization. Bubbles in fluidized bed. Entrainment and Elutriation. Fast fluidized bed. Mixing, segregation and gas dispersion. Heat and mass transfer in fluidized bed. Solid-liquid fluidized bed and three phase fluidized bed. Design of fluidized bed reactors

Books suggested:

1. Wallis, G.B. - " One Dimensional Two phase flow", McGraw Hill Book Co., New York, 1969.
2. Govier, G.W. and K.Aziz., - " The flow of Complex Mixtures in Pipes ", Van Nostrand Reinhold Co., New York, 1972.
3. Brodkey, R.S. - " The Phenomena of Fluid Motions ", Addison - Wesley Publishing Co., New York, 1967.
4. Gad Hestsroni, (Ed.in Chief) - " Handbook of Multi Phase Systems ", Hemisphere Publishing Corporation, Washington and McGraw-Hill Book Company London, 1982.
5. Two-phase flow in pipe lines and heat exchangers – D.Chisholm, Longman Inc, NewYork.
6. Fluidization Engineering- Author: Daizo Kunni and Octave Levenspiel, Butterworth-Heinemann
7. Fluidized bed technology in Materials Processing**, -**Author: C. K. Gupta and D. Sathiyamoorthy, CRC Press.
8. Chemical Reaction Engineering, - Octave Levenspiel,Wiley Eastern Limited.
9. Handbook of separation techniques for Chemical Engineers, - Philip A. Schweitzer,: McGraw- Hill

5. Code Design for Pressure Vessels & Piping (CE5) (25 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.

6. Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.

7. Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.

8. Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.

9. Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.

10. Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

6. Computational Fluid Dynamics & Heat Transfer (CE6 & CE610) (40 Hours)

Syllabus for CE6 : Computational Fluid Dynamics (30 hrs.)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme

B. Numerical Solution of Complete Fluid Flow and Energy Equation:

1. Formulations of governing equations used in numerical simulation:
2. Streamfunction-temperature formulation
3. Stream function-vorticity-temperature formulation
4. Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5. Primitive-Variable (P-V-T) formulation
6. Pressure velocity coupling for incompressible flow.
7. Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8. Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9. Simple grid generation techniques for structured grid:
10. Elliptic. parabolic and hyperbolic equation method
11. Grid adaptation
12. Domain decompositions in CFD and heat transfer
13. SIP and preconditioned conjugate gradient methods for solution
14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Syllabus for CE610 : Heat Transfer (10 hrs.)

C. Laminar Boundary Layer and Forced Convective Heat:

1. Formulation of differential equation for hydrodynamic and thermal boundary layer
2. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
3. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
4. Convective heat transfer for internal and external flows
5. Low and high Prandtl number limits and different thermal boundary conditions
   Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

D. Turbulent Flow and Heat Transfer:

Reynolds decomposition for turbulence
Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder
Calculation of friction factor and drag coefficient
Analytical and semi-analytical correlations for calculating heat transfer coefficients
Analogy between heat and momentum transfer
Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models
Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

E. Natural Convection:

Basic Equations of natural convection
Boussinesq approximation
Derivation of Dimensionless groups from basic equations
Analytical approximations
Numerical solution of approximate equations

F. Reactor Heat Transfer:

Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.

Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.

Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.

low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.

Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.

Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies

G. Heat Transfer With Phase Change :

Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.

Basic equations of two phase flow; Homogenous & separated flow models for two hase flow; void fraction & phase velocity ratio (Zivi's model)

Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)

Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.

Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept.
Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
Critical Flow: Models for single – phase and two-phase critical flow.

Books suggested:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.

4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

7. Advanced Chemical Reaction Engineering (CE7) (30 Hours)

S.No.	Course content
1.	Stoichiometry rates and thermodynamics of chemical reactions. Influence of concentration and temperature. Reaction mechanism. Generalized balance equation for reactive systems.

2. Collection and analysis of rate data: differential method, Integral method, Graphical method, polynomial fit method, Methods of initial rates, Methods of excess, Methods of half life. Kinetics of homogeneous and heterogeneous reactions.

3. Conservation equations for chemically reacting mixtures; heterogeneous catalytic reactions.

4. Chemical reactions and processes of transport: external diffusion effects on heterogeneous reactions, diffusion and reaction in porous catalysts.

5. Design and analysis of chemical reactors: Isothermal and non-isothermal reacting systems, catalytic and non-catalytic reactions systems.

6. Uniqueness and multiplicity of steady states, stability analysis.
Non-ideal reactors: distributions of residence time for chemical reactors, models for non-ideal reactors.

7. Modeling of multiphase reactors: fixed, fluidized, trickle bed, slurry etc.

Books Suggested:

1. Aris R., Elementary Chemical Reactor Analysis, Prentice-Hall 1969.
2. Foggler, H. S., Elements of Chemical Reaction Engineering, Prentice Hall of India, 1994.
3. Froment G.F. and Bischoff K.B., Chemical Reactor Analysis and Design, John Wiley, 1994.
4. Smith J.M. - " Chemical Engineering Kinetics ", McGraw-Hill, 1981.

SPECIALISED COURSES

1. Process Analysis and Control (CE8) (25 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.
2.	Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3.	Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.

4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

2. Advanced Mass Transfer (CE9) (25 Hours)

S.No.	Course content
1.	Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Film, Penetration & Surface Renewal models, Solvent extraction theory
2.	Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors. Adsorption and ion exchange equipment.
3.	Membrane separation and other advanced mass transfer processes. Process intensification approaches. (few hours for seminar by TSO's).

Books suggested:

1. Transport phenomena in liquid extraction – G.S. Laddha and T.E. Degaleesan. McGraw Hill, 1978.
2. Separation process principles – J.d. Seader, Ernest J.Henley. John Wiley & Sons. 2nd Ed. 2005.
3. Mass transfer – Thomas K.Sher wood, Robert L.Pigford, Charles R. Wilkey. McGraw hill.
4. Mass transfer operations - Robert E. Treybal. Mcgraw-hill (1980)
5. Handbook of solvent extraction – The. C. Lo. Malcolm, H.I. Baird, Carl Hanson (editor), Krieger Pub. Co. Reprint edition (Feb 1991).

ELECTIVE COURSES

1. Preparedness & Response to Nuclear Emergencies (CE-EL) (30 Hours)

S.No.	Course content
1.	Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
2.	Radiation Shielding & Study of Criticality parameters and control
3.	Nuclear Waste Management
4.	Nuclear Accidents/emergencies
5.	Transport of Radioactive material
6.	Radiological accidents/emergencies
7.	Effects of Hiroshima & Nagasaki bombing
8.	Detection of Nuclear detonation

9. Nuclear weapons: effect (Blast, heat, Radiation and EMP)

10. Medical decontamination with demonstration

11. Nuclear weapon tests (atmospheric)

12. Nuclear & Radiological terrorism (Method to contain and control)

13. Chemical warfare & Biological warfare (Method to contain and control it)

14. Emergency Response methodology/ Philosophy

15. Systems and methodology for Radiological impact assessment

16. Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities

17. Emergency Monitoring & Shelters

18. Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment

19. Civil defence WEB plan for Nuclear attack on major cities

20. Monitoring of High radiation field area

21. Lab Visits

Books suggested:

Material will be provided during the course.

2. Artificial Intelligence Methods & Applications (30 hours)

S.No.	Course content
1.	**Robotics** Forward and Inverse kinematics, Jacobians, Manipulator Dynamics, Trajectory generation, Sensors, Manipulator Control, Force control, Path planning, Mapping & Localisation of Mobile robots, Behavior based control, Robot learning.
2.	**Genetic Algorithm** Introduction to GA and its terminology, GA operators and working principle of GAs. Different selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling and elitism. Constraint handling. Multimodal function optimization. Application of GAs, real-coded GAs. Multiobjective optimization, difference with single objective optimization, concept of Dominance and Pareto-optimality. Multiobjective GAs.
3.	**Fuzzy Logic** Introduction;Need, Historical Development and Perspective of applications. Crisp and Fuzzy Sets, Operations on fuzzy Sets. Fuzzy Arithmetic, Fuzzy relations, Fuzzy logic. Possibility Theory and Uncertainty Based information. Construction of Fuzzy Sets (with examples), Approximate Reasoning.

Applications; Pattern Recognition and Process Control (with examples).

Books Suggested:
Material will be provided during the course.

3. Membrane/Separation Processes and Technology (30 hours)

S.No.	Course content
1.	Type of membranes and membrane processes
2.	Membrane transport theory – solution, diffusion model
3.	Membrane and modules
4.	Concentration polarization – boundary layer film model – concentration polarization in liquid separation processes
5.	Reverse osmosis – membranes and materials, RO membrane categories, membrane modules, fouling control and cleaning
6.	Ultra-filtration – characterization of UF, membrane fouling and cleaning – modules and system design
7.	Other membrane processes – microfiltration, nanofiltration, pervaporation and electrodialysis
8.	Application of membranes in water and wastewater treatment
9.	Application of membranes in radioactive waste management

Book suggested:

1. Membrane Technology and Applications (2nd edition) by Richards W. Baker
2. Membrane Filtration Handbook – Practical Tips and Hints (2nd edition) by Jorgen Wagner
3. Application of Membrane Technologies for Liquid Radioactive Waste Processing – IAEA Technical Report Series No. 431.

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
Materials Science

Course Code	Course Name	Hours	Credits
MS1	Engineering Mathematics	35	4
MS2	Computational Methods	30	4
MS3	Materials and Metallurgy	25	3
MS4	Reactor Physics and Fuel Design	30	4
MS5	Health Physics	25	2
MS6	Metallurgical Thermodynamics	30	4
MS7	Experimental Methods for Materials Research	45	6
MS8	Structural Materials for Nuclear Reactors	45	6
MS9	NDE Science and Technology	30	4
MS10	Physical Metallurgy	45	6
MS11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
MS12	Introduction to Materials Science and Engineering	45	6
MS13	Corrosion Science and Engineering	30	4
MS14	Mechanical Behavior of Engineering Materials	30	4
MS15	Manufacturing Technology	30	4
Total		**505**	**65**

1. Computational Methods (MS2 -45 hours)

S.No	Course content
1.	**Programming:** Introduction to programming with C# as the reference language (C# software will be provided for practice), Getting familiarized with Matlab
2.	**Numerical Techniques:** Overview of standard numerical techniques with wpecial emphasis on statistics and solving ordinary and partial differential equations
3.	**Optimization:** Overview of techniques with special emphasis on non-linear optimi9zation using gradient descent, conjugate gradient and genetic algorithm
4.	**Neural network for predictive applications:** Overview of various neural network architectures, Multilayer perceptron model for prediction, need for neuro-fuzzy models
5.	**Atomistic modeling:** Introduction to Monte-Carlo Simulation, Basics of molecular dynamics, prediction of thermo-physical properties by molecular dynamics, computational challenges
6.	**Introduction to application of FEM:**Introduction to FEM and its application, demonstration of few simple application using Abaqus (FEM software)
7.	**Current status in modeling and simulation:** With respect to mechanical metallurgy

Books Suggested:

1. Sams Teach Yourself C# in 21 Days, B.L. Jones, SAMS publications
2. Numarical Recipes in C++: The art of scientific computing, *W.H. Press et al*, Cambridge University Press
3. Numerical Mathematical Analysis *J.B. Scarborough, MacMillan Publishers*
4. Genetic algorithms in search, optimization and machine learning, *D.E. Goldberg, Addison Wesley*
5. Guide to neural computing applications, *L. Tarassenko, Arnold publishers*
6. Monte Carlo Basics, *K.P.N. Murthy, ISRP publishers*
7. Molecular Dynamics Simulation by *J.M. Haile, John Wiley and sons*

2. Fast Reactor Physics and Fuel Design (MS4/CH8- 30 hours)

S.No.	Course content
1.	**Basic Nuclear Physics Concepts:** Properties of nuclei. Nuclear forces, Nuclear models. Nuclear decay, Liquid drop model and nuclear stability, Nuclear reactions including fission, Compound nucleus formation, Microscopic cross-section, Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	**Chain Reaction:** four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.

5. **Reactor Kinetics:**Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.

Books Suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C. Edlund. Van Nostrand, 1952.
2. Introducation to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Physics of Nuclear Reactors, Jakeman D., English Universities Press, 1966.
4. A.E. Walter and A.B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981.

3. Metallurgical Thermodynamics(MS6- 30 hours)

S.No.	Course Content
1.	**Classical thermodynamics -** the scope of classical thermodynamics, basic concepts and definitions. First and second laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures. The chemical potential, fugacity, activities, and activity coefficients, Phase rule
3.	Solubilities of gases in liquids, and solids
4.	**Solution thermodynamics**: Integral and Partial Molar Thermodynamic Properties, Solution Models, Ideal Solution, Regular Solution, Real Solutions
5.	**Phase Equilibrium and Stability**: Phase equilibria in multicomponent systems, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations,
6.	**Chemical Reaction Equilibria**: Equilibrium constants for Homogeneous and heterogeneous reactions.
7.	Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Pourbaix Ellingham Diagrams, Phase Diagrams,
8.	**Experimental Methods**: Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.

Books Suggested:

1.D. Gaskell, Materials Thermodynamics, Talyor and Reid, 1981.
2. O. Kubaschewski, C.B. Alcock and P.J. Spencer, Materials Thermochemistry, Pergamon, 1985

4. Experimental Methods for Materials Research (MS7-45 hours)

S.No	Course Content
1	Vacuum Techniques (3): Fundamentals, Creation & Pressure Measurements, units, Pumps – fore Vacuum, high Vacuum and UHV
2	Thin Film synthesis methods- Physical, Chemical and MBE

3. X-RAY TECHNIQUES - techniques based on measuring the energy or angular distribution of scattered x-rays,

1.1 Wide angle elastic scattering (XRD): Atomistic – form factors; unit cell structure factors, Bragg equation, reciprocal lattice, Laue equations; Expwrimental methods- transmission, reflection, thin film, in-situ; Otjer information-particle size distributions.

1.2 Inelastic scattering- x-ray absorption spectroscopy: Basics- edges and extended fine structure; XANES and EXAFS quantitation; Surface sensitivity; Experimental methods

1.3 Small angle scattering-SAXS: Basics- what SAXS sees; Mathematical modeling;

1.4 X-ray fluorescence spectroscopy: Basics- core hole formation, fluorescence yield, transport ("ZAF"); Experimental realization – Bulk analysis; lab and synchrotron x-ray sources; Surface analysis – TXRF; Microscopy – x-ray beam manipulation.

4. **ELECTRON MICROSCOPIES:**

2.1 Transmission electron microscopy (TEM/STEM):

Electron interactions in solids-elastic and inelastic scatterin, phase change; Contrast generation- bright field, dark field, "high-resolution"; Images-information and resolution; Diffraction; Beam damage; Experimental methods hardware, specimen preparation; Inelastic scattering- electron energy loss; Emitted x-rays – elemental analysis, sensitivity, spatial resolution; STEM

2.2. Scanning electron microscopy:

Beam transport in bulk solids; Signals and images- backscattered and secondary electrons; Diffraction- channeling patterns – EBSD; X-ray generation and transport, detection and analysis; Other useful signals; Experimental methods;

EPMA Electron probe micro-analyzer

2.3. LEELS

5. ION BEAM TECHNIQUES

techniques using ions or neutrals made from them as the bombarding species

3.1. Ion beams – production-ion guns; manipulation- ion, filters

3.2. Rutherford (Nuclear) Backscattering Spectroscopy- (RBS):

High energy ions in solids- electronic and nuclear (Rutherford) stopping; Quantitative description; Experimental methods – energy spectroscopy

3.3. Nuclear reaction analysis – elemental specificity – depth profiling

3.4. PIXE (Proton Induced X-ray Emission) Signal to noise ratio – trace element analysis

3.5. Surface Mass Spectriscopy-SIMS:

Ejection of matter by bombardment: sputterin; Fate of ejected materials subsequent reaction, charge state; Mass dedtection – quad, magnetic sector, ToF; experimental issues

6. ELECTRON SPECTROSCOPIES -

techniques based on measuring the energy distribution of emitted electrons

4.1 Photoelectron spectroscopy:

Basics- energy balance, element identification; Not-so Basics- relaxation, chemical states, satellites; Surface sensitivity; Quantitation; UPS- the unfamiliar cousin

4.2 Auger Electron Sepctroscopy:

Electron excitation- why bother ? The Auger spectrum- energy balance; Chemical effects; Quantitation; Imaging- meaning of maps.

4.3 Experimental methods;

Surface of real-world things; Below the surface- profiling, variable energy; Hardware and software; samples and handling.

7. PROXIMAL PROBE MICROSCOPIES

Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM): Basics; Experimental methods; Spectroscopy in Scanning Probe Microscopy

8. NUCLEAR SPECTROSCOPY

Positron annihilation, Mossbauer – Application to defects, radiation damage defects in metals and alloys

9. **VIBRATIONAL SPECTROSCOPIES**

7.1 Vibrations in molecules and solids – normal coordinates, group frequencies

7.2 Infrared spectroscopy;

IR absorption – dipole scattering, selection rules; Optical arrangements-transmission, specular reflectance, diffuse reflectance, attenuated total reflectance, microscopy, in-situ; Signal collection and Fourier transform processing, data analysis

7.3 Raman: Energy transfer, selection rules; Normal, resonance, surface-enhances, Fourier transform, UV

10. **8.RESONANCE ABSORPTION SPECTROSCOPIES**

8.1 Nuclear Magnetic Resonance (NMR):

Fundamentals; Experimental Techniques; Magnetic Resonance Imaging

8.2 Electron Paramagnetic Resonance (EPR): Fundamentals; Experimental Techniques

BOOKS FOR STUDY AND REFERENCE:

1. Cullity Addision, B.D., "Elements of X-ray Diffraction", Wesley Publishing Co., 1967.
2. Williams (D B), Carter (C B), Transmission Electron Microscopy: A Textbook For Materials Science, New York, Plenum, 1996
3. J.R. Tesmer et al 'Handbook of modern ion beam materials analysis' (MRS, Pittsburgh,1995)
4. L.C. Feldman, J.W. Mayer 'Fundamentals of surface and thin film analysis' (North-Holland, N.Y, 1986)
5. Prutton, M., "Surface Science and Technology, Volume27, "Analytical techniques for thin films", Academic Press, Inc.Newyork, 1991.
6. Bacon, G.E., "X-ray and Neutron Diffraction", Pergamon Press, 1966.
7. Concise Encyclopedia Of Materials Characterization Ed. Cahn (R W) and lifshin (E) Ed Oxfod, Pergamon, 1993
8. Advances in Materials Characterization Ed. G. Amarendra, Baldev Raj, M.H. Manghnani, University Press (India), 2007

8. Structural Materials for Nuclear Reactors (MS8)(Coordinator: –45hrs)

S.No.	**Course Content**
1.	Three stage Nuclear Power Program (Importance of Material Selection)
2.	**Thermal Reactors:** Concept, Selection of Materials – Core and out of core, Processing of Materials, Properties/Performance of Materials
3.	**Fast Breeder Reactors:** Concept, Selection of Materials for different systems, Brief description of different systems, Core materials, Design criteria for clad and wrapper, Radiation damage, Evolution of materials for clad and wrapper, Material performance, Material processing and fabrication, Structural materials, Design criteria, Materials processing and fabrication, Steam generator materials, Design criteria, Selection of materials, Materials processing and fabrication, Properties of materials and performance
4.	**Materials in Reprocessing Applications,** Closing of nuclear fuel cycle, Design concept of reprocessing plant component, Selection of materials, Processing and fabrication, Evaluation of properties and performance
5.	**Materials in Waste Storage Applications**

Books Suggested:

1. Materials research: Current scenario and future projections, Chidambaram R, Banerjee S Ed, Allied Publishers, New Delhi, 2003
2. High temperature reactor materials (workshop La Jolla,CA March18-21,2002), Allen T, Oak Ridge, U.S.Department of Energy, 2002.
3. Nuclear materials: Issues and concerns Vol 2., Bhaskara Rao D Discovery Publishing House, New Delhi, 2001.
4. Materials R & D for PFBR: Compilation of articles: (Eds) S.L. Mannan and M.D. Mathew, IGCAR, Kalpakkam, 2003.
5. An overview of R&D on fast reactor fuel cycle, Baldev Raj, Int. J. Nuclear Energy Science and Technology, Col.1, Nos.2/3, 2005, pp.164-177.
6. Selection of materials for PFBR, S.L. Mannan, S.C. Chetal, Baldev Raj, S.B. Bhoje, Trans IIM, Vol..56, No.2, April 2003, pp.155-178.
7. Development of fuels and structural materials for fast breeder reactors, Baldev Raj, S.L. Mannan, P.R. Vasudeva Rao and M.D. Mathew, Sadhana, Vol.27, Part 5, October 2002, pp. 527-558
8. Input of the atomic energy programme on special materials development in India, C. V. Sundaram, Trans IIM, vol. 41, No.5, Oct 1988, p.407.
9. Recent trends in fast breeder reactor materials, C.V. Sundaram, P. Rodriguez and S. L. Mannan, IE (I) Journal –MM, Vol.67, Sept. 1986, pp.1-11.
10. Radiation effects in nuclear reactor materials – correlation with structure, P. Rodriguez, R. Krishnan and C.V. Sundaram Bull. Mater. Sci. Vol. 6, No.5, May 1984, PP.339-367.

Nuclear Reactor Materials, C.O.Smith, Addison Wesley, 1967

9. NDE Science and Technology (MS9 - 30 hours)

S.No.	Course Content
1.	**Introduction to NDE:**Importance and need for NDE, classification of techniques, origin of defects; material processing related-casting, forging, rolling, welding etc., and service related-fatigue, creep, corrosion, irradiation etc. Detection, characterisation, sensitivity, reliability, accuracy,
2.	**Surface NDE:**Principle, instruments & sensors, capabilities, applications and limitations of visual, liquid penetrant, magnetic particle, eddy current and flux leakage techniques
3.	**Volumetric NDE:**Principle, instruments & sensors, capabilities, applications and limitations of radiography and ultrasonic techniques. Gamma, Micro-focal, LINAC and real-time radiography and tomography. IRIS, TOFD, SAFT, MEMS, Non-linear ultrasonics related to ultrasonics.
4.	**Dynamic NDE:**Acoustic emission, infrared radiography, intelligent processing of materials and continuous monitoring.
5.	**Digital NDE:**Forward and inverse problems, signal processing, numerical modeling, imaging, automation, probability of detection (POD), multiple NDE, data fusion and robotics.
6.	**Industrial NDE:**NDE for quality assurance, structural integrity, material characterization, condition monitoring and in-service inspection, reference standards for calibration, codes & standards, selection of NDE techniques
7.	**Practicals:** 1. Ultrasonic testing – detection of defects in weld/HAZ and measurement of thickness

2. X-radiography of welds and interpretation of radiographs
3. Eddy current testing of plates and heat exchanger tubes for defects
4. ***Seminar***: Preparation and submission of report on a topic in advanced NDE. Presentation and viva-voce

Books Suggested:

1. A practical NDT – Baldev Raj, T. Jayakumar and M. Thavasimuthu, Narosa, New Delhi, 1996.

2. ASNT Volumes on Visual, penetrant, magnetic particle, eddy current, ultrasonic, radiography, acoustic emission, thermography and other techniques, ANST, Ohio, Coloumbus.

3. Grandt, A. F. Jr., Fundamentals of Structural Integrity: Damage Tolerant Design and Non-destructive Evaluation, John Wiley & Sons, Inc. Hoboken, NJ, 2004.

4. Bray, D.E. and R.K. Stanley, 1997, Nondestructive Evaluation: A Tool for Design, Manufacturing and Service; CRC Press, 1996.

5. Peter J. Shull, Nondestructive Evaluation: Theory, Techniques, and Applications, Marcel Dekker Inc., 2002.

10. Physical Metallurgy (MS10- 45 Hrs)

S.No.	Course Content
1.	Structure and Properties of Materials
2.	**Crystalline solids:** Introduction: Engineering materials, materials cycle, application and selection criteria of materials. Significance of microstructure; crystalline defects:- dimensions, origin and their effect on properties; amorphous structure.
3.	**Phase diagrams**: Origin, construction, interpretation and application of binary phase diagrams with reference to a few important metallic and ceramic systems. introduction and classification of phase transformations, calculation of phase equilibria based on thermodynamic principles
4.	Correlation between Free energy, selection of a Phase and order parameter, different thermodynamic classification of phase transformations, order of a transformation
5.	**Diffusional transformations:** Diffusion in solids: phenomenological approach and atomistic approach. Nucleation and growth theories of vapour to liquid, liquid to solid, and solid to solid transformations; homogeneous and heterogeneous strain energy effect during nucleation; interface-controlled growth and diffusion controlled growth; overall transformation kinetics. Principles of solidification, evolution of microstructures in pure metals and alloys. Precipitation from solid solution: types of precipitation reactions, crystallographic description of precipitates, precipitation sequence and age hardening, spinoidal decomposition.
6.	**Iron-carbon alloy system:** iron-carbon diagram, nucleation and growth of pearlite, cooling of hypo-eutectoid, eutectoid, and hyper-eutectoid steels, development of microstructures in cast irons. Heat treatment of steels: TTT and CCT diagrams
7.	**Diffusionless transformations:** martensitic transformation, hardenability, role of alloying elements in steels. Bainitic transformation, Widmanstatten transformation, Massive transformation. Order-disorder transformation.

8. Diffusion, rate theory, mechanisms of, measurement techniques
9. Phase transformations in some nuclear non-ferrous metals and alloys
10. Characterization of microstructure – microscopy techniques, X-ray spectroscopy and diffraction.
11. **Metallographic techniques**: Optical metallography, image analysis, quantitative phase estimation.
12. Properties of X-rays: continuous and characteristics x-rays, absorption, filter, production and detection of X-ray Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.
13. **Electron optical methods**: (a) Scanning electron microscopy and X-ray microanalysis including electron probe microanalysis, electron optics, electron beam specimen interaction, image formation in the SEM; (b) Transmission electron microscopy and analytical transmission electron microscopy: Electron diffraction, reciprocal lattice, analysis of SAD patterns; different electron diffraction techniques, atomic resolution microscopy, analytical devices with TEM, field ion microscopy, scanning tunneling microscopy, advanced techniques.
14. **Introduction to novel materials and processes**: composites, intermetallics, cermets, metallic foams, intelligent materials, Dependence of their properties on structure, Nanocrystalline Materials: Synthesis, Structure and Properties.: Amorphous Materials; Metallic glasses, Glass forming ability, Bulk Metallic Glasses, Properties; Quasi crystalline Materials; Structure, Synthesis, Properties;
15. **Advanced Processes**: Rapid solidification processing, Laser surface Modification, Mechanical Alloying, Rapid prototyping, Self propagating High temperature synthesis, inert gas condensation etc.
16. **LABORATORY** Microstructures of alloys of Fe, Al, Cu and Ti for each type of transformation at different levels of resolution; Crystal structure by diffraction techniques; Defects of different dimensions; Advanced processes – Laser Ablation, Magnetron Sputtering and Plasma and Chemical deposition methods.

11. Fuel Cycle Physics& Introduction to Fuel Cycle (MS11/PY11 - 30 Hrs)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.

8. Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9. U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10. Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11. Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12. Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13. Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14. Isotopic separation operation of bred uranium in thorium cycles to remove U-232.
MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Introduction to Materials Science & Engineering (MS12/CH4-40 hours)

S.No.	Course content
1.	**Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.
2.	**Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.
3.	**Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.
5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.
6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.
7. **Phase Diagrams &Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley &Sons, N.Y., 2003.
7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

13. Corrosion Science and Engineering (MS13/CH13 - 30 hours)

S.No.	Course content
1.	Thermodynamics of Aqueous Corrosion: Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.
2.	Kinetics of Aqueous Corrosion: Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.
3.	Forms of Corrosion: General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion. Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.
4.	Corrosion in Reactor and Reprocessing Plants: Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.
5.	Prevention and Control of Corrosion: Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.
6.	**Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.
7.	**Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, “Corrosion and corrosion control – An introduction to corrosion science and engineering”, Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, “Corrosion Engineering”, Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.

4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, "Corrosion and corrosion protection handbook", USA, 1983.

14. Mechanical Behaviour of Engineering Materials (MS14- 30 hours)

S.No.	Course Content
1.	**Engineering Materials:** Alloys, intermetallics, ceramics, composites, polymers.
2.	**Basic Crystal Structure of Materials**: Unit cell, packing fractions, planes and directions, slip systems
3.	**Defects in Materials:** Point defect, line defect (dislocation), surface defects (grain boundary, twins, stacking faults), volume defects
4.	**Dislocation:** Types, Burger's vector, stress field and energy, stacking faults, dislocation glide and slip systems in crystal, interaction between dislocations, interaction between dislocations and point defects, dislocation pile up, dislocation climb, dislocation sources, multiplication of dislocations.
5.	**Elastic Behaviour of Materials:** Stress and strain at a point and their relationship
6.	**Plastic Behaviour of Materials:**
7.	**Tensile Deformation:** single crystal, yield point, CRSS, polycrystalline materials (Schmidt's factor), grain size effect-Hall-Petch relation, thermally activated deformation, constitutive equation for plastic deformation, strain hardening and dynamic strain ageing (DSA).
8.	**Strengthening Mechanism:**Strain hardening, strengthening from grain boundary, solid-solution strengthening, order-disorder strengthening, precipitation strengthening, dispersion strengthening, strengthening by point defects, martenisitic strengthening, and composite materials.
9.	**Creep:** Creep curve, mechanisms of creep deformation, activation energy for creep deformation, structural changes during creep, deformation mechanism map, super plasticity, presentation of creep data, prediction of long-term creep properties, irradiation creep, grain boundary sliding, nucleation, growth and coalescence on inter granular cavities, effect of impurity segregation on cavitation, creep fracture of weld joint, design of creep deformation and fracture resistance materials.
10.	**Fatigue:** Types of loading, high cycle fatigue, low cycle fatigue, thermo-mechanical fatigue, creep-fatigue interaction, fretting fatigue and corrosion-fatigue of various engineering materials, effect of surface treatment and coating, fatigue behaviour of welds, characterization of fatigue deformation and damage, fatigue under combined stresses, notch sensitivity, design criterion, life prediction techniques, alloy design against fatigue.
11.	**Fracture Mechanics:** Ductile to brittle transition, Griffith's law, strain energy release rate, introduction to linear and non-linear fracture mechanics, fracture toughness, fatigue and creep crack growth, material design against fracture.

Books Suggested

1. Physical Metallurgy Principle – R. E. Reed-Hill
2. Modern Physical Metallurgy – R. E. Smallman
3. Mechanical Metallurgy – G. E. Dieter
4. Plastic Deformation of Metals – R. K. W. Honeycomb
5. Introduction to Creep – W. W. Evans
6. Fatigue of Materials - S. Suresh, CambridgeUniversity Press.
7. Deformation and Fracture Mechanics of Engineering Materials – R. W. Hertzberg

15. Manufacturing Technology (MS15 - 30 hours)

S.No.	Course content
1.	**Nuclear materials and their melting practices**: Selection criteria for in-core, structural and steam generator materials, Radiation damage, Properties of nuclear materials. Principles of Vacuum melting & casting processes, including general descriptions of vacuum induction melting, vacuum arc re-melting and electro-slag refining.
2.	**Hot and cold working processes and tube making processes**: Fundamentals of mechanical processing, defects during manufacturing, Various techniques for producing seamless pipes, design of tooling for hot extrusion and principles of pilgering and Various presses and their characteristics.
3.	**Special metal forming processes**: High velocity forming processes like explosive forming, pertroforge forming, electro magnetic and hydraulic forming, comparison of HVF methods, Super-plastic forming.
4.	**Powder metallurgy** : Introduction, characterization of metal powders. Manufacturing of metal and composite powders. Compaction and sintering of metal powders. Secondary operations. Applications of typical P/M components.
5.	**Computer aided design:** Role of computers in design and manufacture, Solid modeling – techniques and algorithms for modelling – data structures for solid models; Surface modeling – curves and surface representation – composite surfaces – application to computer aided manufacture; Current developments in CAD – feature based modeling – Design by feature – function, feature linkages – Application of feature based models. Parametric modeling.
6.	**Metal joining principles and processes**: Fusion and non- fusion welding processes, modern welding processes, design of welded joints, Introduction to residual stresses and distortion in welds.
7.	**Weldability of materials**: Welding of austenitic stainless steels, ferritic steels, weldability tests, dissimilar welding and selection of weld consumables and welding defects, principles of post weld heat treatment and stress relieving.
8.	**Welded Fabrication**: Codes and Standards, Procedure and performance Qualification, Evaluation of the welded joints, NDT of welds.
9.	**Hard facing Technology**: Introduction, Need for hard facing, Hard facing processes, Hard facing in nuclear power plants.
10.	**Heat Treatment**: Annealing, normalizing, quenching and tempering, Precipitation hardening, Recrystallisation annealing, Importance of heating and cooling rate and hold time in heat treatment, Heat Treatment furnaces.

Books Suggested:

1.Metal Forming Handbook, Schuler, Springer Verlag, Berlin, 1998.
2.Welding Technology for Engineers, Baldev Raj, Shankar (V) And Bhaduri (A K), Narosa Publishing House, New Delhi, 2006.
3.Fundamentals of Metal Forming, Wagoner (R H), John Wiley & Sons, New York, 1997.
4.CAD/CAM from Principles To Practice, Chris Mcmahon And Jimmie Browne, Addison – Wesley, 1993.
5.Manufacturing Technology: Foundry, Forming And Welding, Rao (P N), Tata Mcgraw-Hill, New Delhi, 1987

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING I

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (MECHANICAL/CHEMICAL)

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE1	Code Design for pressure vessel and piping	30	4
2.	FRE2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	30	4
3.	FRE3	Transport Phenomena	30	4
4.	FRE4	Reliability Engineering	20	2
5.	FRE5	Process Design and Control	30	4
6.	FRE6	Vibration Engineering and Condition Monitoring	20	2
7.	FRE7	Seismic Design of Nuclear Reactors and Facilities	30	4
8.	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**210**	**26**

MODULE III- OPERATIONS

S. No	*Code*	*SUBJECT TITLE*	*HOURS*	*CREDITS*
1.	FRE9	Plant Dynamics and Control	25	3
2.	FRE10	Turbine Generator Fundamentals	25	3
3.	FRE11	Mechanical and Electrical Equipments	25	3
4.	FRE12	Maintenance Engineering	25	3
5.	FRE13	Regulatory Framework for NPPs	25	3
6.	FRE14	Practical's	**6 Weeks**	**12**
		Total	**125**	**27**
		Total	**510**	**74**
1.	Viva Voce	**Grand Total**		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

31. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
32. Steam Power Station, G.A. Gassort.
33. Power Plant Engineering & Economics, Strosal & Vapet.
34. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
35. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
36. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
37. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
38. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
39. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
40. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. **Coolant circuits**

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.

2. **Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3. **Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4. **Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5. **Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6. **Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7. **Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8. **Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities
8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II - CORE ENGINEERING (MECHANICAL/CHEMICAL)

1. Code Design for Pressure Vessel and Piping (FRE1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical, spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures. Thermal stresses in plates and shells.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc (WRC-297)
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Design of tube sheets as per TEMA and ASME Sec VIII Div. 1.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Difference between Sec. VIII Div.1 & Sec III-NB.
12. Introduction to design codes (structure of RCC-MRx) both insignificant and significant creep. Service levels and design class. Introduction to shell and piping design. Thin Shell Design Against Buckling as per RCC-MR Appendix A-7, Elastoplastic instability under monotonic loading – linear elastic analysis, Elastoplastic instability under cyclic loading - elastic linear analysis -negligible creep, Elastoplastic instability in significant creep - simplified method.

Books suggested:

11. Harvey J F , 'Pressure vessel design' CBS publication
12. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
13. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
14. American standard code for pressure piping , B 31.1
15. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Heat Transfer and Computational Fluid Dynamics (FRE2) (30 Hours)

S.No **Course content**

1. **Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity, momentum and energy equations) with special reference to Navier-Stokes & Bernoulli equations.
2. **Laminar Boundary Layer and Forced Convection:** Formulation of differential equations for hydrodynamic and thermal boundary layers. Different analytical methods for reduction of boundary layer equations and theoretical formulation for boundary layer thickness. Study of jets and flow separation in the light of Boundary Layer Theory. Convective heat transfer in internal and external flows. Low and high Prandtl number limits and different thermal boundary conditions.
3. **Turbulent Flow and Heat Transfer**: Reynolds decomposition for turbulence. Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical correlations for heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy.
4. **Natural Convection**: Basic Equations of natural convection. Boussinesq approximation. Derivation of dimensionless groups from basic equations. Analytical approximations.
5. **Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Law, porosity & permeability, homogenization method, continuity equation & energy equation.
6. **Heat Transfer with Phase Change**: Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling & (b) flow boiling: Heat transfer correlations for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post-dryout heat transfer. Various

models available for calculation of heat transfer coefficient. Critical Flow. Models for single - phase and two-phase critical flows.

7. **Radiation heat transfer**: Radiation heat transfer. Reflection, absorption, transmission and emission; concept of black and grey bodies; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Shape factor & law of reciprocity; Radiation heat transfer between two grey bodies
8. **Numerical Methods in Heat Transfer**: Discretization of conduction equation with Dirichlet & Neumann boundary conditions; Temporal integration: Explicit & Implicit schemes. Discretization of convection-diffusion equations (Upwind & Exponential schemes). Estimation of flow field: stream function-vorticity formulation and primitive variable formulation. SIMPLE family of algorithms. Turbulence Modeling: Eddy diffusivity models: k-ε and k-ω models. Reynolds stress models: algebraic & differential versions. Large eddy simulation and Director numerical simulation.

Books suggested:

AHMT

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974.
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.
3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

CFD

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

3. Advanced Mass Transfer (FRE3) (30 Hours)

S.No. **Course content**

1. **Momentum Transport:**

   1.1 Viscosity and Mechanisms of Momentum Transport: Generalized Newton's Law of Viscosity, Pressure and Temperature Dependence of Viscosity, Molecular Theory of the Viscosity of Gases and Liquids, Viscosity of Suspensions and Emulsions, Convective Momentum Transport.

1.2 Velocity distributions with two independent variables: Time-Dependent Flow of Newtonian Fluids, Flow near Solid Surfaces by Boundary-Layer Theory.

1.3 Macroscopic Balances for Isothermal Flows: Macroscopic mass, momentum, mechanical energy balances; Estimation of viscous loss, Performance of Liquid-Liquid Ejector, Thrust on pipe bends***.***

2. **Energy Transport:**

Fourier's Law of Heat Conduction; Thermal Conductivity, its measurement & its dependence on temperature / pressure. Theory of thermal conductivity of gases, gas mixtures and liquids, Effective thermal conductivity of composite solids, Convective transport of energy.

3. **Mass Transport:**

3.1 Diffusivity and the Mechanisms of Mass Transport: Fick's Law of Binary Diffusion, Diffusivity, its measurement & its dependence on temperature / pressure, Theory of diffusion in gases, binary liquids, colloids etc. Molar transport by convection.

3.2 Concentration Distributions in Solids and Laminar Flows: Diffusion through Gas Films, homogenous / heterogeneous chemical reactions, Diffusion into a Falling Liquid Films.

3.3 Equations of Change for Multi-component Systems: Equations of Continuity for a Multi-component Mixture, Multi-component Equations of Change, Multi-component Fluxes and their applications.

3.4 Concentration Distributions with More than One Independent Variable: Time-Dependent Diffusion, Steady-State Transport in Binary Boundary Layers, Boundary Layer Mass Transfer with complex interfacial motion. Concentration Distributions in Turbulent Flows.

3.5 Interphase Transport in Nonisothermal Mixtures: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions, Combined Heat and Mass Transfer by Free Convection, Effects of Interfacial Forces on Heat and Mass Transfer, Transfer Coefficients at High Net Mass Transfer Rates.

3.6 Other Mechanisms for Mass Transport: Equation of Change for Entropy, The Flux Expressions for Heat and Mass, Concentration Diffusion and Driving Forces, Applications of the Generalized Maxwell-Stefan Equations, Mass Transport across Selectively Permeable Membranes, Mass Transport in Porous Media.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Reliability Engineering (FRE4) (20 hours)

S.No	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.

2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.

4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.

5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.

6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.

7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987

8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.

9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY

5. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.

2. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.
4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

6. Vibration Engineering and Condition Monitoring (FRE6) (20 Hours)

S.No. **Course content**

1. Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2. Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3. Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; A seismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4. Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5. Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6. Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

7. Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

7. Seismic Design of Nuclear Reactors and Facilities (FRE7) (30 Hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

7. **Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.
15. **High Temperature and Creep Fatigue Interaction:** Damage mechanisms and failure modes, Time-dependent and frequency-dependent damage, Cumulative damage rules, Different approaches for life prediction under creep-fatigue conditions: Frequency-modified approach, strain range partitioning (SRP), Ductility exhaustion method, Creep-fatigue interaction Diagram, Thermomechanical fatigue, Codes and Standards

Books Suggested:

1. Chopra, A.K., "Dynamics of Structures, Theory and applications to Earthquake Engineering", Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures", New York, McGraw-Hill Book Company.
3. Mariopaz, "Structural Dynamic (Theory and Computation)", CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., "Numerical Methods in Finite Element Analysis", Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, "Engineering Seismology", IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, "Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites". AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design", BIS, New Delhi.

8. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.

- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.
- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.
- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings, Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.

- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.
- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evolution of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extension of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Independence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.

- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974

11. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

1. **Class room Training**
   a. Reactor System

      Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

   b. Sodium system

      Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

   c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

   d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation.
After classroom training field training will be provided as follows

2. **Field training**
   a. Reactor Operation
   b. Maintenance Activities
   c. Technical Service Activities
   d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING II

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (ELECTRICAL/ELECTRONICS)

S. No.	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE15	Reactor Control Engineering	30	4
2	FRE16	Nuclear Instrumentation	25	2
3	FRE4	Reliability Engineering	20	2
4	FRE5	Process Design and Control	30	4
5	FRE17	Embedded System Design & Human Machine Interface	45	6
6	FRE18	Process Instrumentation	45	6
7	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**215**	**26**

MODULE III- OPERATIONS

S. No	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE9	Plant Control	25	3
2	FRE10	Turbine Generator Fundamentals	25	3
3	FRE11	Mechanical and Electrical Equipments	25	3
4	FRE12	Maintenance Engineering	25	3
5	FRE13	Regulatory Framework for NPPs	25	3
6	FRE14	Practical's	6 Weeks	12
		Total	125	27
		Total	515	74
1	**Viva-Voce**			**2**
		Grand Total		**76**

Fast Reactor Engineering - 2018

MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. El-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP) (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II A- CORE ENGINEERING (ELECTRICAL AND ELECTRONICS)

1. Reactor Control Engineering (FRE15) (30 Hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (FRE16) (25 Hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (FRE4) (20 Hours)

S.No **Course content**

1. **Introduction: Reliability Engineering Applied to C&I Systems**
   Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
   Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
   Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
2. **Reliability Maths/Statistics:**
   - Mathematical and statistical expressions required for reliability study
   - Types of failures in electrical, electronic and computer components
   - Failure probability concept, statistical distribution models
   - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
   - Chi-square distribution and its use in confidence and risk factors
   - Baye's theorem
   - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
   - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions
   - Derivation of exponential reliability expression

- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

3. **Fault Tolerance and Systems Reliability:**
   - Fault tolerance concept for electronic and Computer based C&I systems.
   - Circuit hardware redundancy concept to enhance system reliability, types of redundancy
   - Series, parallel, active, passive, and voting redundancy
   - Redundancy and other fault tolerance methods for software
   - FMEA, FMECA concepts for C&I and Examples to solve
   - Concepts for the analysis of System Reliability, availability, and maintainability.
   - System reliability and availability analysis methods
   - Boolean logic
   - Digraph, cutest-tie set method
   - Fault tree model, and consideration of CCF, CMF, software errors
   - Markov Model

   Example from C&I system in the NPPs
4. **QA/QC Concepts in Brief:**
   - QA/QC Concepts in the components, systems procurement, manufacture and Site installation for C&I systems in the NPPs.
5. **Environmental Qualification and Reliability Testing:**
   - Environmental qualification, testing of the C&I systems
   - Effects of various environments on the electrical/ electronic components
   - Climatic Qualification tests: Temperature, Humidity
   - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
   - Reliability Testing of the electronic components, equipment and C&I systems
   - Reliability screening tests for electronic components
   - Accelerated environmental tests
   - Failure terminated and time terminated tests
   - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
   - Few examples to solve
6. **PSA/PRA Concepts in NPPs:**
   - Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs
   - Explain Event Tree
   - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency
   - Level-1, Level-2, Level-3 PSA studies (Brief introduction only)

7. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier
Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ.
(1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill
Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants
(2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment
(1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier
Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher
(2001),
('Formal Methods' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

5. Embedded System Design and Human Machine Interface(FRE17) (45 Hours)

S.No. **Course content**

Embedded System Design

A. Microprocessor Based Hardware Design:

1. Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16-bit Micro-controllers (e.g. 80196), Overview of 8-bit Atmel Micro-controller (AT89C51), Real Time Clock, DSPs (e.g. TMS320, SHARC family) and ARM processor.
2. Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3. Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play
4. Design Case Study: Single board computer architectures, Remote Terminal Unit, Circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.

B. Computer Communication and Networks

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.);Concept of Fieldbus, fieldbus standards, Industrial networks and Protocols.

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Programmable Logic Controller Design

Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, Relevant communication protocol and standards, PLCs for package systems.

Human Machine Interface

E. Human Machine Interface (HMI)

1. Overview of plant automation, Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
2. Design of HMI, Soft Console versus Conventional control panels, Virtual Control Panel.
3. PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.
4. Guidelines for design of HMI displays.
5. Case study of a commercially available Professional HMI package.
6. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons

7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek& R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.
17. IntellutionIfix documentation
18. NPC Guidelines for development of soft consoles

6. Process Instrumentation (FRE18) (45 Hours)

S.No.	Course content
1.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.
2.	Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors - performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques. Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
3.	Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and

differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

4. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
5. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position
6. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

   Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.
7. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

   Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
8. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

   Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
9. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

   Note:Course Work -35 Hours and Practicals -10 Hours

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication

3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrument Engineer's Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Field bus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

7. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.
- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.

- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal

pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.

- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings,

Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,
Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.
- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.

- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evoluation of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extention of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Indepence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.
- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
-

6. Practicals (FRE 14) (6 Weeks)

12. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

3. **Class room Training**
    a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

4. Field training

a. Reactor Operation

b. Maintenance Activities

c. Technical Service Activities

d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

BACK TO MAIN

IMSc

SYLLABUS FOR

Int Ph.D. in LIFE SCIENCES (Program Code: LIFE05)

Syllabus

Candidates should take all core courses (exemptions can be granted on case-by-case basis but an assessment must be made), as well as at least two electives and experimental components (workshops or lab rotations at collaborating institutes.)

CORE COURSES (Semester 1)		
10-LIFE05-001-C Biology-1 (24 lectures), 100 marks		
1	Basic molecular biology	Biomolecules, DNA, RNA, proteins; genetic code; "central dogma"; gene transcription, translation; packaging of DNA in eukaryotes; introns/exons, splicing
2	Cell biology	Cellular metabolism, cell motility, cytoskeleton, intracellular transport, membrane transport, channels, receptors, signalling, cell cycle
3	Genetics	Mendelian genetics, definitions (genes, loci, alleles), dominance; replication, mitosis/meiosis, linkage/crossover
4	Gene regulation	Transcriptional regulation, miRNA and RNAi
5	Developmental biology	differentiation, early development of drosophila via gradients, gap and pair-rule genes, role of hox genes, Williston's "law", other organisms
6	Evolutionary biology	Molecular evolution, evolution of DNA, genes, proteins and regulation. Molecular mechanisms of evolution -- mutation, recombination, duplication, mobile elements
10-LIFE05-002-C Protein Structure (24 lectures, 100 marks)		
1	Taxonomy	Primary, Secondary and tertiary structure, fold types
2	Protein folding	The Anfinsen experiments, Protein database (PDB), Helix-helix packing in globular proteins, Beta-sheet packing, Folding pathways, thermal denaturation, partially folded intermediates, misfolding and aggregation
3	Membrane proteins	Cell membranes, simple and facilitated diffusion across membranes, membrane protein structural biology, ion channels and receptors, transport via membrane proteins, membrane channels:potassium channel, aquaporins, G-coupled protein receptors, ligand/voltage gated ion channels
4	Enzymes	Biological catalysts, Gibbs free energy, transition state complex, substrate, products, active sites, activation energy barrier, induced-fit hypothesis, cofactors, coenzymes, Michaelis-Menten enzyme kinetics
5	Electrostatics in biology	Continuum methods, solvation and ions, implicit solvent models, Poisson equation, Poisson-Boltzmann equation, solvation free energy
6	Structural characterization	x-ray crystallization, circular dichroism, spectroscopy, NMR, single molecule experiments

7	Homology modelling	Homology Modeling, Visualization
10-LIFE05-003-C Mathematics and statistics for biologists (30 lectures, 100 marks)		
1	Differential equations	introduction to ODEs and PDEs, linear and non-linear, properties, how to solve analytically and numerically; examples -- Hodgkin-Huxley, reaction-diffusion equations, Volterra equations
2	Essentials of linear algebra	vectors, matrices, eigenvalues and eigenvectors; orthogonal bases of functions, Sturm-Liouville theory and differential equations; Fourier series and Fourier transforms
3	Probability theory and statistics	basic concepts -- random variables, mean, variance, moments; conditional probabilities, hypothesis and data, likelihood, Bayes' theorem; probability distributions -- binomial, multinomial, Poisson, normal; the central limit theorem; hypothesis testing, significance testing (orthodox and Bayesian methods); parameter estimation
4	Simulations	Introduction to Markov Chain Monte Carlo for exploring space of hypotheses: ergodicity, detailed balance, convergence. Metropolis and Gibbs sampling
5	Machine learning	decision tree learning, artificial neural networks, support vector machines, Bayesian learning and Bayesian networks
6	Other topics	Game theory, applications to evolutionary biology, agent-based modelling of complex systems
10-LIFE05-004-C Physical Methods for Biologists (37 lectures, 100 marks)		
1	Basic physics of soft matter	What is soft matter, length scales and time scales, biological matter as soft matter, self-organization and self assembly, illustrative examples - DNA, microtubules and/or actin and lipid membranes, coarse-grained representations, interactions and bonding in soft matter systems (including van der Waals forces, hydrogen bonding, electrostatics and screening), what can be measured, energy scales
2	Thermodynamics and statistical mechanics	Thermal equilibrium, the idea of entropy, laws of thermodynamics, free energies, Legendre transformations, different ensembles and relation to computational biology examples, Boltzmann distribution, harmonic oscillator, equipartition theorem, virial theorem, thermodynamics of self assembly, simple ideas of phase transitions, Poisson-Boltzmann theory, dealing with electrostatics
3	Noise, diffusion and drift	Thermal fluctuations and noise, random walk, diffusion equation as continuum limit of the random walk, probability density, continuity equation, Fick’s law, drift-diffusion equation, Stokes-Einstein formula, example of receptor clustering
4	Mechanics of continuous media	Elasticity of isotropic solids, estimates for elastic constants of biological materials, fluids in biology, basics of fluid mechanics, Pascals law, Euler’s equation, viscosity, Reynolds number, Navier-Stokes equation, flow through narrow pipes, dimensionless groups, swimming of microorganisms, hydrodynamic interactions, rheology of biological matter, introduction to viscoelasticity, Maxwell model
5	Polymers, membranes and gels	Simple ideas of polymers and membranes, polymer elasticity, polymer dynamics (Rouse and Zimm model) qualitative discussion, scaling ideas in polymers, semi-flexibility, membrane elasticity, membrane fluctuations, passive gels

6	Out of equilibrium	Active matter, simple examples, what do we need to model them, polymerization forces, cell streaming, molecular motors and models, active gels
7	Other topics	Interfacial tension in biological systems, Laplace pressure, wetting and spreading, osmotic effects, capillary effects in biology, micro-rheology
		for biological systems

CORE COURSES (Semester 2)

10-LIFE05-005-C Biology-2 (25 lectures, 100 marks)

1	Epigenetics	DNA packaging, heterochromatin and euchromatin, methylation, histone tail modifications and gene regulation
2	Basics of neuroscience	Neurons, synapses, neural architecture in various organisms, action potential, Hodgkin-Hoxley equation, firing rates, plasticity, artificial neural networks
3	Introduction to ecology	Ecology and evolution, ecosystems, food webs, large-scale ecology
4	Experimental techniques	PCR, southern/northern/western blots, chromatin immunoprecipitation, microarrays, high-throughput sequencing, ChIP-chip and ChIP-seq, high-resolution microscopy (fluoroscence imaging, confocal, FRET, PALM etc), GFP and reporter gene assays
5	Other topics	Basics of: Intercellular communication, epidemiology, physiology, immunology

10-LIFE05-006-C Biological sequence analysis (30 lectures, 100 marks)

1	Biomolecules	Basics (DNA, RNA, proteins)
2	Probability theory	Basic laws -- joint probabilities, conditional probabilities, likelihood, Bayes' theorem
3	String algorithms	finding common substrings and subsequences: Boyer-Moore algorithm, suffix trees, finding strings with mismatches
4	Sequence alignment	algorithms for pairwise and multiple sequence alignment -- scoring model, Needleman-Wunsch and Smith-Waterman algorithms, BLAST and other heuristic algorithms, significance of scores, structural alignment
5	Sequence assembly	assembling short reads, with and without scaffold; ChIP-seq algorithms
6	Markov models	Markov chains, hidden Markov models, Baum-Welch and Viterbi algorithms, profile HMMs and software (HMMer, etc)
7	Transcriptional regulation	Transcription factor binding sites, position weight matrices, sequence logos, motif-finding via expectation maximisation (MEME) and Gibbs sampling
8	Phylogenetic trees	building a tree from pairwise distances, neighbour-joining, parsimony
9	Transformational grammars	regular grammars, context-free grammars; RNA structure analysis

10-LIFE05-007-C Systems Biology (30 lectures, 100 marks)

1	Networks in biology	The diversity of networks across space and time in biological systems Intra-cellular networks: The gene network and protein-protein interaction network Intra-cellular networks: The metabolic network Intra-cellular networks: signaling networks - pathways and	
		enzyme-substrate reaction cascades The signaling network coordination of immune response to infection Reconstructing biological networks from lab experiments Structural analysis of networks: Global properties Structural analysis of networks: Motifs and Modules Dynamics on biological networks: Modeling signaling pathways Inter-cellular networks: Neuronal networks Inter-organism networks: Contact structure and contagion propagation Inter-species networks: Stability-instability of food webs	
2	Patterns in Biology	Temporal patterns: Biological clocks and circadian rhythms Oscillatory activity in Pancreatic beta cells and insulin secretion Pattern formation during development Development in Drosophilia Development of the vertebrate body plan Modeling developmental patterns: Reaction-diffusion models and Turing Patterns Spatial patterns: Linear stability analysis and Fourier modes Autocatalysis and lateral inhibition: Gierer-Meinhardt and related pattern generation mechanisms in biosystems, center-surround principle in retina and cortex Modeling genesis of functional patterns: Ocular dominance columns Development of plants and L-systems modeling Cell differentiation and Random NK Boolean Networks Morphogenesis Fractals in biology: Examples (1/f noise, circulation system), characterization Fractals in biology: Generation mechanisms	
3	Waves in biology	Importance of waves in biology for communication and coordination Intra-cellular waves: Calcium waves, targets and spirals Inter-cellular waves: Waves in the brain, heart and uterus Excitable media models of physiological systems Ionic basis of excitation: Hodgkin-Huxley formalism Simple and complex models of excitability Excitability, Oscillatory and Bistability regimes of systems Wave propagation through inter-cellular gap junctions: Diffusion approximation Genesis and dynamics of spiral waves: kinematic approach Nonlinear dynamical aspects of spiral waves: Restitution and dispersion Excitation-contraction coupling and the role of organ structure in wave dynamics Bidomain models of biological electrical activity Waves in single populations: Fisher waves Waves in interacting populations: Propagating epidemics, spiral waves in host-parasite spatial dynamics	

ELECTIVE COURSES (semester flexible)

10-LIFE05-001-E Biophysics of Macromolecular Structures (32 lectures)

I. Structure and Biophysics of Biomolecules (10 lectures)

Introduction to macromolecular chemistry, building blocks for macromolecular structures, biophysical methods for structure analysis, nucleic acid structure, protein-nucleic acid interactions, membrane proteins, microtubules and other supramolecular assemblies, investigative methods from the atomic to cellular levels, including X-ray crystallography, NMR spectroscopy, molecular dynamics, electron and light microscopy, AFM, single molecule techniques and simulations

II. Kinetics (5 lectures)

Chemical kinetics and application to dynamical processes in proteins, self assembly processes, classical kinetics, transition state theory, unimolecular decomposition, potential energy surfaces, scattering processes and photodissociation processes, enzyme kinetics

III. Biophysical approaches to Biopolymers (6 lectures)

Basics of polymers, protein folding problem, protein aggregation, DNA, DNA electrostatics, DNA force extension relations, RNA folding, polymerization, polymerization forces, dynamic instability, tread-milling and their physical description

IV. Biophysical Approaches to Membranes (5 lectures)

Lipids and Membranes: Structure of various cell membranes, surface tension and curvature energies, Helfrich theory, clustering, phase separation, nanoscale structures i.e. rafts, multicomponent membranes.

SPECIAL TOPICS

V. Kinetics and statistical mechanics of helix coil transitions; physical approaches to the refolding and assembly of multi-subunit proteins; fluorescence spectroscopic studies of macromolecules, molecular basis of enzyme catalysis, antibody structure and function, virus structure and assembly (6 lectures)

10-LIFE05-002-E Simulation Techniques in Biology (32 lectures)

I. Molecular Dynamics (8 Lectures)

Introduction to MD and applications in biology and drug design; Basic Statistical mechanics: Basic thermodynamics, Ensembles (microcanonical, canonical, grand canonical, isothermal-isobaric), Virial theorem, Nose-Hoover chains; Forcefields and interaction potential: Many body potentials, Born-Oppenheimer approximation, electrostatic interactions including Ewald sum, interaction potential for organic molecules; popular forcefields: AMBER, CHARMM, OPLS etc.,;Integration methods and Liouville time operators Phase space concepts, Liouville theorem, Equilibrium solution of Louiville equation, Trotter factorization; Integration algorithms: Verlet, Velocity-Verlet, Gear-Predictor, multiple-time step algorithm, holonomic constraints (RATTLE/SHAKE)

II. Monte Carlo Simulations (6 lectures)

Importance Sampling, Random variables and stochastic processes,lattice models, Random walks, Gibbs sampling, sampling errors, configurational-bias Monte Carlo method, Markov chain Monte Carlo, Advanced Monte Carlo methods: Parallel tempering, simulated annealing

III. Reaction Diffusion (4 Lectures)

Predator Prey Models, Reaction Kinetics, diffusion-limited reactions, Population dynamics, Reaction-diffusion Equations

IV. Brownian/Stochastic simulations (8 lectures)

Stochastic reaction-diffusion models:Compartment-based reaction-diffusion algorithm, reaction-diffusion master equation, pattern formation; Diffusion:

Brownian motion, On/Off-Lattice models, diffusion to adsorbing surfaces, reactive boundary conditions, Einstein-Smoluchowski relation; Stochastic models of transport processes in cells: Fokker Planck Equations, Brownian rachet models, Chapman

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Kolmogorov equation, Gillespie algorithm, chemical master equation

SPECIAL TOPICS

V. Free energy methods (3 lectures)

Potential of mean force, umbrella sampling, Adaptive bias force method,

thermodynamic integration

VI. Binding and Docking (3 lectures)

Enzyme-substrate recognition process, Search Algorithms (simulated annealing, steepest descent, genetic algorithms), Scoring Functions, Applications of Docking, Softwares for docking

10-LIFE05-003-E **Population Biology, Ecology and Evolution (30 lectures)**

1. Single species population (10 lectures)

Continuous and discrete-time models of population growth (Logistic and related models)
Models of age-structured populations
Population dynamics in the presence of noise
Time-series analysis of data
Flies: Model experimental organism for studying population dynamics
Modeling migration of populations
Territorial behavior
Fundamentals of game theory
Evolution of cooperation between individuals
Spatial dynamics of strategies (Example: Spatial Prisoners Dilemma)

2. Interaction between multiple populations (10 lectures)

Introduction to food webs and ecological interactions between species
Predator-prey interactions: Lotka-Volterra and related models
Functional response
Competition
Cooperation
Multiple prey and predators: Generalized Lotka-Volterra and related models
Stability vs complexity in ecosystems: Single trophic level
Stability vs complexity in ecosystems: Multiple trophic levels
Experimental techniques for studying impact of diversity on stability
The robustness of complex ecological networks

3. Evolution and population genetics (10 lectures)

Fundamentals of population genetics: Random mating and Hardy-Weinberg principle
Classical mathematical genetics: Single locus with multiple alleles
Classical mathematical genetics: Multiple loci
X-linked genes; Linkage and its distribution
The molecular basis of classical genetics
Fitness landscapes and mathematical models of evolution
The major transitions in evolution
Mutation and natural selection
Random genetic drift
Neutral theory of evolution
Coevolution and evolutionary game theory
Evolutionary ecology

<u>10-LIFE05-004-E</u> **Computational Neuroscience (30 lectures)**

1. Neurons, Synapses, Gap Junctions and Small Circuits (10 lectures)
   - Introduction to the biological components of the nervous system
   - Types of Neurons and Glial cells
   - Neuronal activity: Action potential and Graded potential
   - Ion channels and electrical activity of neurons
   - Dynamics of graded potential neurons (Example: retina)
   - Dynamics of action potential neurons, spikes and spike trains
   - Dynamics of inter-neuron communication: Synaptic transmission
   - Dynamics of inter-neuron communication: Gap junctions
   - Introduction to GENESIS/NEURON simulation platforms
   - Neuron-Glial interaction
   - Small neuronal circuits and motifs

2. Systems Neuroscience (10 lectures)
   - Introduction to the computational perspective for studying the brain
   - Introduction to Neural Network Models: McCulloch-Pitts paradigm
   - Associative Memory and the Hopfield Network
   - Storage capacity and stability of memories in Hopfield Network: Mean-field theory
   - Learning: Donald Hebb’s Hypothesis, Long-Term Potentiation and STDP
   - Perceptron and related models: learning to generalize
   - Dynamics of Learning: Hebbian and Competitive principles
   - Information theory and neuro-communication
   - Development of the nervous system in a growing organism
   - Evolution of the nervous system: from single cells to the brain
   - Invertebrate neuroscience: C. elegans as a model organism
   - Modeling the nervous system of invertebrates
   - Sensory-motor integration in the nervous system

3. Vision and cognitive neuroscience (10 lectures)
   - Introduction to Sensory Processing in the Nervous System
   - Components of the Visual System
   - Dynamics of Early Visual Processing at Retina
   - Receptive fields and centre-surround principle (Mach bands, etc.)
   - Processing at the Primary Visual Cortex and Higher Brain Areas
   - Modeling edge detection, shape from texture and motion detection
   - Visual binding: Synchronization of neuronal activity
   - Optical illusions as tool for studying vision
   - Information theory of vision
   - Introduction to cognitive neuroscience
   - Experimental tools of cognitive neuroscience: fMRI, PET, etc.
   - Linguistic ability: A model system for cognitive neuroscience

10-LIFE05-005-E **Modeling of Infectious Diseases (28 lectures)**

1. Genomics & evolutionary biology of pathogens (8 lectures)

Dynamics of molecular evolution
Vertical and horizontal gene transfer
Genomic landscape of pathogens, vectors and humans (Example: malaria); Coevolution and Red queen hypothesis
Gene regulation, pathogenesis and immune response
Evolution of virulence

2. The biology and modeling of host-pathogen interactions (8 lectures)

The immune system: design, phylogeny and ontogeny
The functional anatomy of immune response
Analysis of idiotypic network interactions
Systems biology principles for intra-cellular sigaling in immune response
Systems-level modeling of Mycobacterium tuberculosis host-parasite protein-protein interactions
Micro-edipdemiology: population dynamics of viruses and host cells, May-Nowak and related models; application to HIV

3. Epidemiology: data analysis and mathematical modeling (12 lectures)

Epidemics: Dynamics and basic reproductive ratio R0
Estimation of R0 from data - statistical technqiues
Immunization and other public health intervention strategies
SIR model of epidemics: derivation and solution
Variants of SIR model: SEIR, SIS and SIRS
Modeling vector-borne diseases
Host-parasite models (example: Nicholson-Bailey model)
Cellular automata models
Eco-epidemiological models
Contact network: structure and dynamics
Agent-based models of infection propagation

BACK TO MAIN

IMSc

INTEGRATED Ph.D. (Dual Degree) MATHEMATICAL SCIENCES (Program Code: MATH05)

COURSEWORK AND SYLLABI FOR THE PH.D. AND INTEGRATED PH.D. PROGRAMS IN MATHEMATICS AT IMSC

All courses in mathematics carry 8 credits except for the seminar course which carries 4 credits and the research methodology course which is a pass/fail course with no credits earned.

The Ph.D. program requires a total of 9 courses including the seminar course and the research methodology course (for a total of 60 credits).

The I.Ph.D. program requires 13 courses including the seminar course and the research methodology course along with a 28 credit master's thesis (for a total of 120 credits).

The courses are chosen from among the courses listed below along with other courses offered from time to time either at IMSc or at other institutes with which HBNI has an MoU such as CMI. Topics courses in mathematics may be repeated for credit and will be shown on the transcript with suffixes such as I, II, III etc.

10MATH04-001-C ALGEBRA I - 8 CREDITS

Group theory
- Group actions: Orbits, stabilisers, transitivity
- Lagrange, Cauchy, Sylow theorems in the language of group actions
- Direct and semidirect products
- symmetric and alternating groups

Matrices, determinants and linear maps
- Linear maps and matrices, dual = transpose
- determinants
- Equality of row, column and determinantal rank over a commutative ring

Representations of a single endomorphism
- Minimal and characteristic polynomials, eigenvalues and eigenvectors
- Rational and Jordan canonical forms
- S-N decomposition

Bilinear forms and spectral theorems
- Preliminaries and quadratic maps
- Symmetric forms, orthogonal basis, Sylvester's theorem
- Hermitian forms, polarization, Cauchy-Schwarz inequality
- Spectral theorems, polar decomposition

Basic category theory
- Categories and functors
- Universal properties
- Sums, products and limits

Rings and modules over a PID
- Finitely generated abelian groups
- PID $\Rightarrow$ UFD, R UFD $\Rightarrow$ $R[X]$ UFD, Gauss' lemma

- Irreducibility criteria
- Modules over a PID

Tensor products

- Of vector spaces, modules over a ring, basic properties
- connection with Hom, of algebras
- tensor, symmetric and exterior algebras and connection with the determinant

10MATH04-002-C ALGEBRA II - 8 CREDITS

Group theory

- simple, solvable and nilpotent groups
- Jordan-Holder theorem

Galois theory

- Finite extensions, algebraic extensions, algebraic closure
- Splitting fields and normal extensions
- separable extensions
- Finite fields
- Inseparable extensions
- Galois extensions
- Examples and applications
- Cyclotomic fields
- Independence of characters, norm and trace
- Cyclic extensions
- Solvable and radical extensions

Instructor's choice from among the following suggested topics or others.

Semisimplicity

- Schur's lemma and semisimple modules
- Jacobson density theorem, DCT
- Structure of semisimple rings
- Structure of simple rings

Representations of ftnite groups

- Maschke's theorem
- Characters
- Class functions
- Orthogonality relations

Commutative algebra and Dedekind domains

- Prime, maximal ideals, Zariski topology, CRT
- Localization and its properties
- Integral extensions
- Dedekind domains - characterizations
- Unique factorisation - failure and restoration

10MATH04-003-C ANALysis I - 8 crEDiTs

Measure Theory

- Measurable spaces, Caratheodory's theorem and construction of measures, Lebesgue measure, Riesz representation theorem for compact metric spaces
- Measurable mappings, various convergence concepts like almost sure, convergence in measure.
- Integration, MCT, DCT.
- Product measures, Fubini's theorem.
- Radon-Nikodym theorem, Lebesgue decomposition theorem.
- L^p spaces: Basic theory, Holder's inequality, Minkowsky inequality, completeness, their duality.
- (*) Analysis on $\mathbb{R}^n$; convolutions; approximate identity; approximation theorems; Fourier transform; Fourier inversion formula; Plancherel theorem.

Note: Topics marked with asterisk are optional.

10MATH04-004-C ANALysis II - 8 crEDiTs

Elementary functional analysis

- Topological vector spaces; Banach spaces; Hilbert spaces.
- bounded linear transformation;linear functionals and dual spaces.
- Hahn Banach theorem and it's geometric meaning.
- Category theoem and it's applications like open mapping theorem, uniform boundedness principle, closed graph theorem.
- Weak and Weak-* topologies, Banach-Alaoglu's theorem.

Instructor's choice from among the following suggested topics or others.

Distribution Theory

- The spaces $D(\Omega)$, $E(\Omega)$, for Ω open in IR^n.
- $S(\mathbb{R}^n)$ and their duals, convolution, Fourier transform.
- Paley-Wiener theorems; fundamental solutions of constant coefficient partial differential operators.

Banach Algebras and Spectral Theory

- Banach algebras, spectrum of a Banach algebra element, Holomorphic functional calculus, Gelfand theory of commutative Banach algebras.
- Hilbert space operators, C*-algebras of operators, commutative C*-algebras.
- Spectral theorem for bounded self-adjoint and normal operators. formulation).
- Spectral theorem for compact operators,(*) application to Peter-Weyl theorem.

Note: Topics marked with asterisk are optional.

10MATH04-005-C Topology I - 8 credits

Point-set topology

- Quotient topology including the construction of standard topological spaces such as surfaces and real and complex projective spaces as quotient spaces
- The notion of attachment of a cell to a topological space
- Group actions and orbit spaces
- Topologies on function spaces
- Baire category theorem
- Arzelà-Ascoli theorem

Fundamental groups and covering spaces

- Fundamental groups, covering spaces and their relationship
- Free groups, free products of groups
- Seifert-van Kampen theorem - examples and applications

Introduction to homology

- Definition of homology groups
- Homotopy invariance of homology groups
- The first homology group as the abelianization of the fundamental group
- Review of homological algebra necessary to introduce the Mayer-Vietoris sequence
- Mayer-Vietoris sequence and its applications in computing homology groups of surfaces, complex projective spaces, real projective spaces etc.

Applications of fundamental groups and homology groups

Instructors choice among the following topics or other topics at this level.

- Jordan curve theorem
- Winding number of a closed curve
- Brouwer's fixed point theorem
- Fundamental theorem of algebra
- Nielsen-Schreier theorem

10MATH04-006-C Topology II - 8 credits

Instructors choice among the following topics. It is suggested that one topic from the first two and basic notions of differential topology be covered in addition to some of the advanced topics.

Homology theory

- Quick review of homology theory
- Relative homology and the associated long exact sequence
- Excision theorem and its applications
- Characterisation of homology theory by the Eilenberg-Steenrod axioms
- Homology with coefficients

Cohomology theory and introduction to homotopy groups

- Basic notions of cohomology
- Universal coefficient theorem
- Künneth formula
- Cup product and the cohomology ring, Borsuk-Ulam theorem

Basic notions of differential topology

- Differentiable manifolds, tangent bundle, vector fields, flows
- Differential forms and de Rham cohomology
- Integration on manifolds
- Stokes theorem
- Poincaré duality using differential forms.

Advanced topics

- Higher homotopy groups and the Hurewicz theorem
- H-spaces, suspensions, fibre bundles
- Cap product and various forms of duality with integral coefficients
- Bott periodicity theorem
- Topics in differential geometry such as:
  - Smooth vector bundles
  - Notions of connection, curvature and parallel transport
  - Definition of Riemannian manifold
  - Gauss-Bonnet formula
  - Notion of geodesic and Hopf-Rinow theorem
- Obstruction theory and introduction to characteristic classes:
- Topics in Morse theory such as:
  - Definition and genericity of Morse functions
  - Lemma of Morse
  - Cell structure associated to a Morse function and Morse homology
  - Morse-Smale-Witten complex

10MATH04-007-C COMPLEX ANALYSIS - 8 CREDITS

- Analytic function, Cauchy-Riemann equations, power series, exponential and logarithmic function
- Cauchy theorem on a disc, Integral formula, power series and Laurent series expansion Product development, Weierstrass theorem, Homotopy version of Cauchy's theorem, Liouville's theorem, residue theorem, Argument principle
- Maximum modulus principle, Schwarz lemma, Phragmen-Lindelof method
- Conformal mapping, Mobius transformation, Automorphisms of the disc and upper half plane, Riemann mapping theorem
- Harmonic functions, Dirichlet problem, Mean value property
- Analytic continuation, Monodromy theorem
- (optional) Introduction to Hyperbolic geometry
- (optional) Elliptic functions, Gamma and Zeta functions

10MATH04-008-C CREDIT SEMINAR - 4 CREDITS

The topic of the seminar will be chosen by the student in consultation with an assigned faculty member. The student will read recent research papers as assigned by the faculty member, and present the results in a formal seminar.

10MATH04-009-C Research Methodology - Pass/Fail

An introduction to the methods and techniques of academic research through a project and presentations - both oral and written.

The following courses are advanced level research courses whose content will be decided by the instructor based on current research and the requirements of the individual students.

10MATH04-001-E Topics in analytic number theory - 8 credits

Course content varies according to instructor's choice. Possibilities for topics are: introduction to arithmetic functions, convolution and Mobius inversion for-mula, basic asymptotic formulas for arithmetic functions, characters and Fourier analysis on finite abelian groups, theory of Dirichlet series, primes in arithmetic progression, Riemann zeta function, Poisson summation and functional equation, The prime number theorem, error term in prime number theorem, its oscillation and the Riemann hypothesis, equivalent formulations of Riemann hypothesis, zero-free regions, explicit formula and Siegel's theorem, introduction to sieve methods, Brun and Selberg sieve, large sieve and the Bombieri-Vinogradov theorem and Vinogradov's three prime Theorem.

10MATH04-002-E Topics in algebraic number theory - 8 credits

Course content varies according to instructor's choice. Possibilities for topics are: Dedekind domains, ramification, different and discriminants, decomposition and inertia groups, quadratic fields and genus theory, classification of primitive quadratic characters, Gauss sums and quadratic reciprocity, geometry of numbers, finiteness of class number and explicit computations, regulators and Dirichlet's unit theorem, cyclotomic fields and inverse Galois problem for abelian number fields, Artin symbol and splitting in cyclotomic fields, Dedekind zeta function, the analytic class number formula and introduction to the Chebotarev density theorem

10MATH04-003-E Topics in commutative algebra - 8 credits

Course content varies according to instructor's choice. One possibility is a course covering the second half of Matsumura's text including topics such as: regular sequences, Koszul complex, Cohen-Macaulay rings, Gorenstein rings, regular rings, UFDs, complete intersections, local flatness criterion, generic freeness, derivations and differentials, separability, I-smoothness, Cohen's structure theorems and applications of complete local rings.

10MATH04-004-E Topics in modular forms - 8 credits

Course content varies according to instructor's choice. Possibilities include: Introduction to $SL_2(\mathbb{R})$ and its action on the Poincare upper half-plane $\mathcal{H}$, discrete subgroups Γ of $SL_2(\mathbb{R})$ and their cusps, the modular group $SL_2(\mathbb{Z})$, Topology, measure theory and complex structure on $\mathcal{H}/\Gamma$ and its compactification, Modular functions, modular forms and cusp forms on $SL_2(\mathbb{Z})$, examples : Eisenstein Series and the delta Function, finite dimensionality of space of modular forms, the Miller basis and the $\mathbb{Z}$-structure on the space of modular forms, growth of Fourier coefficients of cusp forms, introduction to Ramanujan's conjectures, theory of Hecke operators and Petersson inner-product on the space of cusp forms, application to Ramanujan's conjectures, the L-function of modular forms, congruence subgroups, modular forms and cusp forms on congruence subgroups, spectral theory of automorphic forms, introduction to Galois representations and Deligne's theorem, Lehmer's conjecture and the Atkin-Serre Conjecture.

10MATH04-005-E Topics in elliptic curves - 8 credits

Course content varies according to instructor's choice. Possibilities for material to be covered include selected topics from Elliptic functions by Lang, The arithmetic of Elliptic curves by Silverman, Elliptic curves by Milne or Elliptic curves by Husemoller. Another possibility would be to prove Mazur's theorem which is a well-known and important result covering elliptic curves and abelian varieties, and the moduli of elliptic curves.

10MATH04-006-E Topics in algebraic curves - 8 credits

Course content varies according to instructor's choice. Possibilities for material to be covered include selected topics from An invitation to arithmetic geometry by Lorenzini, Algebraic Curves by Fulton or lectures notes of Joseph Oesterle. Topics such as the basics of algebraic varieties over the complex numbers (with focus on dimension 1), singularities of curves (what are they and when is a curve nonsingular), desingularization of curves by normalization, the relationship between nonsingular algebraic curves and complex manifolds of dimension 1, nonsingular projective algebraic curves and function fields, the Riemann-Roch theorem, and also some of its applications.

10MATH04-007-E Topics in diophantine geometry - 8 credits

Course content varies according to instructor's choice. Some possibilities are: introduction to Global fields, absolute values on global fields, theory of heights, rational points on conics. local-global principle and application to quadratic forms, affine and projective varieties, morphisms and rational maps, explicit arithmetic on function fields and their zeta-functions, divisors on curves, The Riemann-Roch theorem, elliptic curves over global fields, endomorphism rings of Elliptic curves, CM and non-CM curves, ehe Mordell-Weil group and rank of an elliptic curve and local-global principle on elliptic curves and the Tate-Shaferevich group.

10MATH04-008-E Topics in transcendental number theory - 8 credits

Course content varies according to instructor's choice. Possibilities are: Liouville's theorem and Liouville Numbers, elements of rational approximation, transcendence of e and π, irrationality of $\zeta(3)$, introduction to algebraic independence, Lindemann-Weierstrass theorem, Schanuel's conjecture and Ax's theorem for formal power series, the Schneider-Lang Theorem, Hilbert's seventh problem and the Gelfond-Schneider theorem, Baker's Theorem and applications, six exponential theorem, introduction to heights and Roth's Theorem, the p-adic Baker theorem (by Brumer) and introduction to Leopoldt's conjecture and the p-adic subspace theorem and applications.

10MATH04-009-E Topics in algebraic groups - 8 credits

Course content varies according to instructor's choice. One possibility is to cover the basic theory of linear algebraic groups over an algebraically closed field up to the classification of the reductive groups by means of root data, developing the necessary background from algebraic geometry as and when needed. Thus covering preliminaries from algebraic geometry, linear algebraic groups: definition and first properties, commutative algebraic groups, derivations, differentials, and Lie algebras, topological properties of morphisms applied to this context, Parabolic subgroups, Borel subgroups, and solvable subgroups, Weyl group, roots, and root datum and reductive groups and their classification: isomorphism and existence theorems.

10MATH04-010-E Topics in infinite dimensional Lie algebras - 8 credits

Course content varies according to instructor's choice. Some possibilities are: generalized Cartan matrices and their associated Lie algebras, symmetrizability, the invariant bilinear form, the Weyl group, classification of indecomposable GCMs, finite, affine and indefinite types, affine Kac-Moody algebras, roots, the affine Weyl group, realizations of untwisted and twisted affine Kac-Moody algebras in terms of loop algebras, representation theory: integrable representations, category $\mathcal{O}$, proof of the Weyl-Kac character formula, highest weight integrable representations, weights, representations of affine Kac-Moody algebras.

10MATH04-011-E Topics in functional analysis - 8 credits

Course content varies according to instructor's choice. Some possibilities are: analytic Fredholm theory, compact and Fredholm operators, Atkinson's theorem, Gelfand duality, properties of the analytic index, Toeplitz operators on Hardy spaces, Pseudo-differential operators and Elliptic regularity, Fourier transforms and Sobolev spaces on R^n, Symbol calculus and Pseudo-differential operators, Ellipticity and Pseudo-differential operators on smooth manifolds, construction of parametrices, Elliptic regularity theorem, Ellipticity and Fredholm property of Dirac operators on closed manifolds.

10MATH04-012-E Topics in non-commutative geometry - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Vector bundles, K-theory for topological spaces, Serre Swan theorem, K_0 and $K_1$for a C*-algebra, homotopy invariance, split exactness, half-exactness, stability of K-theory, inductive limits and K-theory, Bott periodicity, Six term exact sequences, computations with them, Pimsner-Voiculescu exact sequence, Thom isomorphism, Hilbert C*-modules, KK groups, Geometric index theory, Vector bundles, connections and curvature on Riemannian manifolds, structure equations of Cartan, invariant forms and characteristic classes in de Rham cohomology, Chern-Gauss-Bonnet theorem and idea of proof, topological index and statement of the Atiyah-Singer index theorem

10MATH04-013-E Topics in Lie groups - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Introduction to Lie algebras, definitions, examples, abelian, nilpotent, solvable lie algebras, semisimple lie algebras, representation of Lie algebras, structure of general Lie algebras over characteristic zero field : statement of the Levi decomposition, statement of Ado's theorem, Introduction to real differentiable manifolds, and various standard objects associated with it, statement of the Frobenius theorem on integrability, definition of real Lie groups, examples, associated Lie algebra, the exponential map and its properties, closed subgroup theorem, continuous homomorphisms, definition of Lie subgroups and examples, association of lie subgroups and lie subalgebras, covering Lie groups, simply connected lie groups and association with real Lie algebras, the adjoint representation, the manifold structure of the left or right coset space with respect to a closed subgroup and the (subgroup)-principal bundle structure of the Lie group with respect to the projection to the coset space, Construction of left invariant Haar measure using left invariant differential forms, formula for modular function, compact Lie groups, Peter-Weyl theorem, embedding compact groups in linear Lie groups, Weyl group, conjugacy of maximal tori in connected compact Lie groups, Centralizers of tori, basic structure of semisimple Lie groups, existence of compact real forms of complex semi-simple Lie algebras, Cartan decomposition both at the Lie algebra and Lie group level, Iwasawa decomposition.

10MATH04-014-E Topics in algebraic geometry - 8 credits

Course content varies according to instructor's choice. One possibility is an introduction to the language of schemes, properties of morphisms, and sheaf cohomology. So that the students gain an understanding of the basic notions and techniques of modern algebraic geometry.

10MATH04-015-E Topics in differential geometry - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Definition of smooth manifolds, atlas, examples, tangent spaces, inverse and implicit functon theorems for manifolds, vector fields, flow, completeness of the flow function, integrability and Frobenius theorem, differential forms, pullback by functions, exterior derivative, orientations, manifolds with boundary, Stokes theorem, DeRham cohomology, computations using Mayer Vietoris, Riemannian metrics and geodesics.

10MATH04-016-E Topics in partial differential equations - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Examples of partial differential equations, Strategies for studying PDE., Well posed problem, Brief introduction to classical solutions, weak solution and regularity, Transport equation, Laplace's equation, Heat equation and wave equation, Problems associated to these equations, notion of fundamental solution etc., Non-linear first order PDE, Hamilton Jacobi equations, calculus of variations, Hamilton's ode, Legendre transforms, etc., Theory of linear partial differential equations: Sobolev spaces, weak derivative, Sobolev inequalities, Elliptic equations, Weak solutions, the existence of weak solutions, regularity, maximum principles, eigenvalues and eigenfunctions of elliptic operators, compactness, etc.

10MATH04-017-E Topics in mathematical physics - 8 credits

Course content varies according to instructor's choice. One possibility is to cover classical and quantum mechanics covering topics such as: review of Galilean group, mechanical system with one degree of freedom, mechanical system consisting of motion of a point in three dimensional space and motion of system of n points, review of calculus of variation, Lagrange's equation, Hamilton's equations, Liouville's theorem, Symplectic structures on phase spaces and Noether's theorem, D'Alembert's principle, Symplectic manifolds, Hamiltonian mechanics on symplectic manifolds, moment map, postulates of quantum mechanics, mathematical aspects of Schrödinger's equation, review of Lie group, Lie algebra and their representations with main focus on groups like $U(1)$, $SO(3)$, $SU(2)$, Spin groups in 3 and 4 dimensions, Spin $\frac{1}{2}$ particle in magnetic field, review of Fourier transforms, position and momentum space, Dirac notation, Heisenberg's uncertainty principle, Hydrogen atom, quantization, canonical quantization, The Groenewold-van Hove no-go theorem, canonical quantization in n–dimensions, quantization and symmetries.

10MATH04-018-E Topics in algebra - 8 credits

Course content varies according to instructor's choice. One possibility is a course in commutative algebra covering prime ideals and maximal ideals, nilradical and jacobson radical, prime avoidance and the Chinese remainder theorem, extension and contraction of ideals, modules, submodules and quotient modules, direct sum and direct product, finitely generated modules and Nakayama lemma, exact sequences, tensor products, restriction and extension of scalars, exactness properties of the tensor product, algebras, tensor product of algebras, localization, local properties, extended and contracted ideals in rings of fractions, primary decomposition, integral extensions, lying over, going-up theorems, integrally closed domains and the going-down theorem, valuation rings, Noetherian and Artinian modules, Noetherian rings, Hilbert basis theorem, primary decomposition in Noetherian rings, Artinian rings and their structure, discrete valuation rings and Dedekind domains, fractional ideals, completions, filtrations, topologies, and completions, graded rings and modules, associated graded ring, dimension theory, Hilbert functions, dimension theory of Noetherian local rings, regular local rings, transcendental dimension, relation to algebraic varieties and algebraic geometry.

10MATH04-019-E Topics in operator algebras - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Banach algebras, spectrum, spectral radius formula, C*-algebras, Gelfand Naimark theorem, continuous functional calculus, GNS construction, positivity, measurable functional calculus, von Neumann algebras, Kaplansky density theorem, double commutant theorem, finite-dimensional C*-algebras, representation theory of the C*-algebra of compact operators, Toeplitz algebra, Coburn's theorem, group C*-algebras, crossed products, amenability, groupoid C*-algebras.

10MATH04-020-E Topics in representation theory - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Lie algebras: definition and basic properties, ideals, subalgebras, homomorphisms, nilpotent and solvable Lie algebras, Lie's and Engel's theorems, semisimple Lie algebras, the Killing form, Cartan's criterion, abstract Jordan decomposition, classification of finite dimensional semisimple Lie algebras, Dynkin diagrams, the Weyl group, isomorphism and conjugacy theorems, representations, Verma modules, category $\mathcal{O}$, irreducible highest weight modules, complete reducibility, Weyl character formula, Freudenthal weight multiplicity formula, Kostant and Steinberg formulas.

10MATH04-021-E Topics in algebraic combinatorics - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Partially ordered sets and Mobius inversion, generating functions, permutations and statistics, Robinson-Schensted correpondence, partitions, Young's lattice, hook-length formula, Representation theory of symmetric groups, similarity classes of matrices and orthogonal polynomials

10MATH04-022-E Topics in topology - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Definitions and basic construction of homotopy groups, Whitehead's theorem, Hurewicz's theorem, stable homotopy groups, fibrations and obstruction theory, Bott's periodicity theorem, H-cobordism theorem, construction and applications of characteristic classes.

10MATH04-023-E Topics in symplectic geometry - 8 credits

Course content varies according to instructor's choice. Possibilities include: Motivations of sympletic Geometry from Hamiltonian mechanics, neighbourhood theorems, compatible almost complex structure, and the contractibility of the space of almost complex structures, integrability of almost complex structures, Newlander-Nirenberg theorem, Hamiltonian circle actions on symplectic manifolds, moment maps, Fubini-Studi form on projective space, Kähler forms as Hessians of plurisubharmonic function on complex manifolds, introduction to pseudoholomorphic curves, outline of proof of Gromov's non-squeezing theorem.

10MATH04-024-E Programming for mathematicians - 8 credits

Course content varies according to instructor's choice. Some possibilities are: Basic python syntax, Iterables and generators, Object oriented programming, introduction to Sage, the Numpy library, the Networkx library, graphics with Sage and Matplotlib and a Programming project.

BACK TO MAIN

Harish-Chandra Research Institute

Doctoral Program in Physics

The Ph.D. program consists of course work and projects for the first three semesters, followed by research work leading to a Ph.D. degree.

Curriculum and detailed course content

SYLLABUS FOR

INTEGRATED Ph.D. in PHYSICAL SCIENCES (PROGRAM CODE: PHYS05)

Course Structure

The Masters program consists of four semesters of pedagogical lectures

No	COURSE CODE	Semester I	No	COURSE CODE	Semester II	No	COURSE CODE	Semester III	No	COURSE CODE	Semester IV
1	08PHYS05-001-C	Classical Mechanics	6	08PHYS05-006-C	Numerical Methods	11	08PHYS05-011-C	Condensed Matter I	16	08PHYS05-016-C	Particle Physics
2	08PHYS05-002-C	Quantum Mechanics I	7	08PHYS05-007-C	Quantum Mechanics II	12	08PHYS05-012-C	Quantum Mechanics III	17	08PHYS05-017-C	Elective II
3	08PHYS05-003-C	Electrodynamics	8	08PHYS05-008-C	Statistical Mechanics	13	08PHYS05-013-C	Quantum Field Theory I	18	08PHYS05-018-C	Elective III
4	08PHYS05-004-C	Mathematical Methods I	9	08PHYS05-009-C	Electronics	14	08PHYS05-014-C	Mathematical Methods II	19	08PHYS05-019-C	Project
5	08PHYS05-005-C	Laboratory I	10	08PHYS05-010-C	Laboratory II	15	08PHYS05-015-C	Elective I	20	08PHYS05-020-C	Laboratory III

Elective I : Choose one from — Advanced Statistical Mechanics, Fluid Mechanics, General Relativity, Non-linear Dynamics, Quantum Information and Computation I.

Elective II and III : Choose two from — Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure, Quantum Field Theory II, Quantum Information and Computation II, Quantum Optics, Soft Matter, Ultra Cold Atoms.

Semester I

(1) Classical Mechanics

- A rapid review/summary of Newtonian mechanics
- Calculus of variations: Concept of variation - Euler equation - Applications - Variation subject to constraints and Lagrange multipliers.
- The Lagrangian formulation: Generalised coordinates and velocities - The principle of least action and the Lagrange equations of motion - Extension to constrained systems.
- Conservation laws: Symmetries and Noether's theorem.
- Integration of the Lagrange equations of motion: Motion in one dimension - The two body problem, reduced mass and the equivalent one-dimensional problem - Motion in a central field - Kepler's problem - Scattering.
- Small oscillations: Free, damped and forced oscillations in one dimension - Resonance - Damped and forced oscillations - Parametric resonance.
- Rigid body motion: Angular velocity - The inertia tensor and angular momentum of a rigid body - The equations of motion- Eulerian angles - Motion of tops - Motion in a rotating frame - Coriolis force.
- The Hamiltonian formulation: Hamiltonian and Hamilton equations - Poisson brackets - Dynamics in the phase space - Hamilton-Jacobi equation - Separation of variables and solutions - Action-angle variables - Adiabatic invariants.
- Elements of non-linear dynamics: Differential equations as dynamical systems - Lyapunov exponents.

Textbooks:

1. Mathematical Methods of Classical Mechanics, V I Arnold,
2. Classical Mechanics, T W B Kibble and F H Berkshire,
3. Classical Mechanics, H Goldstein,
4. Classical Mechanics, L D Landau and L M Lifshitz,
5. Introduction to Dynamics, I. Percival and D. Richards.

(2) Quantum Mechanics I

- Basic notions: states, operators, time evolution
- One-dimensional problems: harmonic oscillator, periodic potential, Kronig-Penny model;
- Three-dimensional problems: central force potential, the hydrogen atom
- Charged particle in an electromagnetic field: gauge invariance, Landau levels
- Symmetries and conservation laws in QM: Degeneracies, Discrete symmetries
- Angular momentum in quantum mechanics: raising and lowering operators, angular momentum addition, Clebsch-Gordon coefficients; Tensor operators and Wigner-Eckart theorem
- Time-independent perturbation theory: non-degenerate and degenerate cases, Stark and Zeeman effects
- Semiclassical (WKB) approximation and variational methods

Textbooks:

1. Introduction to Quantum Mechanics, D. J. Griffiths,
2. Quantum Mechanics, B. H. Bransden and C. H. Joachain,
3. Principles of Quantum Mechanics, P.A.M. Dirac,
4. Modern Quantum Mechanics, J. J. Sakurai,
5. Quantum Mechanics, E. Merzbacher,
6. Quantum Mechanics, L. I. Schiff,
7. Quantum Mechanics (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz.

(3) Classical Electrodynamics

- Special theory of relativity and electrodynamics: Lorentz transformation of electromagnetic fields, Lorentz covariant formulation of electrodynamics; gauge invariance, Maxwell equations from action principle.
- The electrostatic limit of Maxwell equations, multipole expansion, uniqueness, boundary value problems, solution of Poisson equation.
- The magnetostatic limit of Maxwell equations, applications.
- Electrodynamics: motion of charges in external fields; electromagnetic waves in vacua and propagation through continuous media; energy-momentum of electromagnetic field and Poynting theorem.
- Advanced and retarded Green functions; Lienard-Wiechert potentials; dipole radiation and Larmor's formula; spectral resolution and angular distribution of radiation from a relativistic point charge; synchrotron radiation; Rayleigh and Thomson scattering; collision problems; Bremsstrahlung and Cerenkov radiation.
- Scattering of electromagnetic waves: Rayleigh and Thomson scattering, radiation damping.

Textbooks:

1. Introduction to Electrodynamics, D.J. Griffith,
2. Classical Electrodynamics, J.D. Jackson,
3. Electrodynamics of Continuous Media, Vol. 6 of Course of Theoretical Physics, L.D. Landau and E.M. Lifshitz.

(4) Mathematical Methods I

- Vector Analysis: operations with vectors, scalar and vector fields, gradient, curl and divergence. Line, surface, and volume integrals, Curvilinear coordinate systems, Elements of tensors.
- Vector Spaces, linear transformations, scalar product and dual space, bases, linear operators, eigenvalues and eigenfunctions, unitary and hermitian operators
- Complex Analysis: functions of a complex variable, analytic functions, integral calculus, contour integrals, Taylor and Laurent series, singularities, residues, principal values, Riemann surfaces, conformal mapping, analytic continuation

- Ordinary differential equations: linear ODEs, Green functions, second order differential equations: classification of singularities and local solutions, special functions
- Elements of statistics: probability, random walk. Probability distributions.

Textbooks:

1. Mathematical Methods in Physics, J. Mathews, R. L. Walker,
2. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag,
3. Mathematical Methods for Physicists, G. B. Arfken, H. J. Weber, F. E. Harris,
4. Fundamentals of Mathematical Physics, E. A. Kraut,
5. Complex Variables, M. J. Ablowitz and A. S. Fokas.

(5) Laboratory I

- Forced Oscillations-Pohl's Pendulum:
- Coupled Pendula and Chaotic oscillator:
- Photoelectric effect:
- Normal and Anomalous Zeeman Effect:
- Michelson Interferometer:
- Mach-Zehnder Interferometer:
- Faraday Effect:
- Millikan Oil-drop Experiment:
- Electron Diffraction:
- Fine Structure:

Semester II

(6) Quantum Mechanics II

- Scattering theory and applications
- Schrodinger and Heisenberg pictures; postulates of quantisation
- Time dependent perturbation theory, Interaction picture, Fermi golden rule
- Path integrals: propagators, amplitudes as path integrals, Semiclassical methods revisited
- Quantum mechanics of many particles, identical particles and symmetries of the wave-function, scattering of identical particles
- Relativistic quantum mechanics, Klein-Gordon and Dirac equations and their solutions, gyromagnetic ratio of the electron, relativistic corrections to the Schrodinger equation
- Entangled states and Bell inequalities

Textbooks:

1. Principles of Quantum Mechanics, P.A.M. Dirac,
2. Quantum Mechanics and Path Integrals, R. P. Feynman and A. R. Hibbs,
3. Modern Quantum Mechanics, J. J. Sakurai,
4. Quantum Mechanics, E. Merzbacher,
5. Quantum Mechanics, L. I. Schiff,
6. Quantum Mechanics (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz

(7) Research Methodology and Numerical Methods

- Research Methodology including quantitative methods, communication skills, seminar presentation and review of research papers
- Introduction to programming languages: F77, F90 or C
- Errors in numerical calculations.
- Numerical linear algebra, eigenvalue and eigenvectors.
- Interpolation techniques.
- Generation and use of random numbers.
- Sorting and searching.
- Differentiation and Integration (including Monte Carlo techniques)
- Root finding algorithms
- Optimisation, extrema of many variable functions.
- ODEs and PDEs: including FFT and finite difference methods, integral equations.

Textbooks:

1. Research Methodology: Methods and Techniques, C.R. Kothari,
2. Numerical Mathematical Analysis by J. B. Scarborough,
3. Computer oriented numerical methods, V. Rajaraman,
4. Data reduction and error analysis for the physical sciences, P. R. Bevington and D. K. Robinson,
5. An Introduction to Error Analysis, J.R. Taylor.

(8) Statistical Mechanics

- Basics: phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
- Non interacting classical systems: few level systems, ideal gases, oscillators.
- Non interacting quantum systems: method of second quantisation, electrons in metals, relativistic electron systems, electrons in a strong magnetic field, lattice vibrations and phonon physics, photons, blackbody radiation, Bose condensation.

- Interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
- Phase transitions: symmetry breaking and long range order, mean field approach, Landau theory, 2nd and 1st order transitions, Landau-Ginzburg functional, illustrative examples, estimate of fluctuations.

Textbooks:

1. Statistical Mechanics, K. Huang,
2. Statistical Mechanics, R. K Pathria,
3. Fundamentals of statistical and thermal physics, F. Reif.

(9) Electronics

- Circuit theory: lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive networks, node and loop analysis, Thevenin and Norton's theorem, time domain response of RL, RC and RLC circuits, frequency domain response, impedance, filters and transfer function.
- Analog electronics: discrete devices, characteristics and operation - diode, Zener diode, LED, photodiode. Simple diode circuits. Bipolar junction transistor (BJT): biasing, h parameters, small and large signal response, amplifiers. Field effect transistors.
- Operational amplifiers: device properties, integrator, differentiator, RC active filter, negative and positive feedback, oscillators.
- Digital electronics: logic gates, truth table, multiplexer, combinatorial circuits, flip-flop, counters, programmable logic devices, microprocessors.

Textbooks:

1. Electronic Principles, A. P. Malvino and D. J. Bates,
2. Digital Electronics, A. P. Malvino and A. P. Leach,
3. Integrated Electronics, J. Millman and C. C. Halkias.

(10) Laboratory II

- Coupled Oscillator Circuits:
- Thermal Equation of State and Critical point:
- Lock-in Amplifier and Signal Processing:
- OpAmps I: Amplifiers & Negative Feedback:
- OpAmps II: Limitations & Applications:
- Diodes: Clamps, Rectifiers, Power supplies
- Transistors I: Switch, Common Emitter Amplifier, Push-pull Follower
- Transistors II: Characteristics, Comparators, MoSFET, CMoS Inverter
- Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
- Flip-flops: as Memory element, Shift Register, Counters

- Microcontroller I: Programming to MCU, using the port for input
- Microcontroller II: Some Applications, Seven Segment Display

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Semester III

(11) Condensed Matter Physics I

- The building blocks - atoms to solids: atomic physics, Coulomb effects, crystal fields in solids, local moments and band electrons, lattice vibrations, electron-lattice coupling, electron-electron interactions.
- Structure: characterizing structures - crystalline/amorphous/liquids, classification of periodic structures, reciprocal space, x-ray and neutron diffraction.
- Electronic structure: free electrons - spectrum, density of states, thermodynamics, band electrons - nearly free electron and tight binding limits, consequences for thermodynamics and transport.
- Physics of metals: specific heat, susceptibility, impurity scattering, basic transport theory. Response to magnetic fields: Landau quantization, quantum Hall effect.
- Phonons: Debye and Einstein model, spectrum of a real lattice, thermodynamics of phonons, anharmonic effects, Debye-Waller factor.
- Magnetism: spin paramagnetism, itinerant-vs-localised electrons, Stoner and Heisenberg models, mean-field theory, spin waves.
- Superconductivity: phenomenology, pairing interaction, BCS theory, Ginzburg-Landau theory and type II superconductors.

Textbooks:

1. Condensed matter physics - N. W. Ashcroft and N. D. Mermin,
2. Solid State Physics - C. Nayak,
3. Solid State Basics - S. Simon,
4. Introduction to many body physics - T. Giamarchi, A. Lucci and C. Berthod,
5. Lessons from nano-electronics - a new perspective on transport - S. Datta.

(12) Quantum Mechanics III

- Atomic physics: One electron atoms - spin-orbit interaction, fine structure, Lamb shift, Zeeman effect, Stark effect.

- Two electron atoms: spin wave functions, approximate handling of electron-electron repulsion. Coupling of angular momenta, multiplet structure, gyromagnetic effects. Hyperfine and nuclear quadrupole interactions.
- Many electron atoms: central field approximation, Thomas-Fermi and Hartree-Fock methods.
- Molecular physics: Born-Oppenheimer approximation, molecular structure, rotation and vibration of diatomic molecules, hydrogen molecular ion, vibrational-rotational coupling, effect of vibration and rotation on molecular spectra. Electronic structure- molecular orbital and valence bond theories.
- Atoms and light: transition rates, dipole approximation, Einstein coefficients, radiative damping, optical absorption, ac Stark effect.
- Cold atoms: Doppler cooling, magneto-optical trap, ion traps, dipole force, evaporative cooling, optical lattice.
- Collective effects: Feshbach tuning of interactions, Bose condensation of alkali atoms, BCS-BEC crossover, the unitary Fermi gas. Imaging cold atoms.
- Computing with atoms: qubits and their properties, entanglement, quantum logic gates, decoherence and error correction.

Textbooks:

1. Theoretical Atomic Physics, H. Friedrich,
2. Atomic Physics, C. Foot,
3. Physics of Atoms and Molecules, B. H. Bransden and C. H. Joachain,
4. Molecular Quantum Mechanics, P. Atkins and R. Friedman.

(13) Quantum Field Theory I

- Non-relativistic quantum field theory: quantum mechanics of many particle systems; second quantisation; Schrodinger equation as a classical field equation and its quantisation; inclusion of inter-particle interactions in the first and second quantised formalism
- Irreducible representations of the Lorentz group, connection to quantum fields
- Symmetries and conservation laws: examples in non-relativistic and relativistic field theories; translation, rotation, Lorentz boost/Galilean transformation and internal symmetry transformations; associated conserved charges
- Free Klein-Gordon equation: classical action and its quantisation; spectrum; Feynman rules for computing n-point Green functions of elementary and composite operators.
- Interacting Klein-Gordon field: Feynman rules for computing Green functions; physical mass of the particle from the analysis of two point Green functions; S-matrix and its computation from n-point Green functions; relating S-matrix to cross-section.
- Quantisation of free Dirac fields: spectrum; Feynman rules
- Quantisation of free electromagnetic field: role of gauge invariance; gauge fixing; physical state condition; spectrum; Feynman rules

- Quantum electrodynamics: coupling Dirac field to electromagnetic field; gauge invariance; quantisation; Feynman rules for computing Green functions; Spectrum and S-matrix from the Green functions.

Textbooks:

1. An introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder,
2. Quantum Field Theory, C. Itzykson and J-B Zuber,
3. Relativistic Quantum Fields, J. D. Bjorken and S. Drell.

(14) Mathematical Methods II

- Integral transforms, Fourier transforms, inversion and convolution, Laplace transforms
- Advanced topics in ODE, Partial differential equations: classification of second order PDEs, Laplace and Poisson equations, applications to electrostatics, Heat equation, Wave equation
- Group theory, definitions and examples of groups. Homomorphism, isomorphism and automorphism, Permutation groups
- Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group. Symmetries in physical systems, Young Tableau.

Textbooks:

1. Mathematics for Physicists, P. Dennery and A. Krzywicki,
2. Introduction to Topology, Differential geometry, and group theory to physicists, S. Mukhi and N. Mukunda,
3. Classical Groups for physicists, B. G. Wybourne,
4. Group Theory, P. Ramond.

(15) Elective I

Choose any one of the following topics, Advanced Statistical Mechanics, Fluid Dynamics, General Theory of Relativity, Techniques in Nonlinear Dynamics, Quantum Information and Computation I.

• Advanced Statistical Mechanics

- Critical phenomena : Liquid-gas transition and Van der Waals equation of state, Classical spin systems, Transfer matrix for one dimensional systems, Order parameters, Mean field approach, Landau theory, Universality, Critical exponents, Scaling hypothesis, Estimating fluctuations
- Renormalisation : Hubbard-Stratanovich transformation and the Ginzburg-Landau-Wilson functional,Self-consistent approximation, Basic ideas of renormalisation

group, Real space RG in one and two dimensions, Spherical limit, Wilsonian RG and ε-expansion, Field theoretic RG, Two dimensions and BKT transition

- Equilibrium dynamics : Conserved and broken symmetry variables, Hydrodynamic approach, Dynamical critical phenomena
- (Extra module : one of the following two) :
- Non-equilibrium phenomena : Fluctuation-dissipation, Linear response, Kubo formula, Langevin and Fokker-Planck descriptions
- Stochastic thermodynamics : Non-equilibrium work theorems (Jarzynski, Crooks, …), Non-equilibrium steady-states, Stochastic heat engines, Examples from colloidal systems and molecular motors

Textbooks:

1. Field Theory and Renormalisation Group, D. J. Amit,
2. Modern Theory of Critical Phenomena, S. K. Ma,
3. Lectures on Phase Transition and The Renormalisation Group, N. Goldenfeld,
4. Quantum Field Theory and Critical Phenomena, J. Zinn-Justin.

• Fluid Mechanics

- Ideal Fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity
- Viscous Fluids: Viscosity, Navier-Stokes equation, Reynolds number, laminar flow, exact solution to the eq. of motion.
- Turbulence: Stability of flows, instabilities, quasi-periodic flows, Strange attractors, turbulent flows, jets, free shear layers, wakes, boundary layers
- Thermal Conduction in fluids: eq. of heat transfer, conduction in incompressible fluid, law of heat transfer, convection, convective instability in static fluid
- Compressible flows
- Relativistic Fluid dynamics: eq. of motion, energy-momentum tensor, eq. for flow with viscosity and thermal conduction.

Textbooks:

1. Fluid Mechanics, L. D. Landau and E. M. Lifshitz,
2. An Introduction to Fluid Dynamics, G. K. Batchelor,
3. Relativistic Fluid Dynamics, A. Anile and Y. Choquet-Bruhat.

• General Theory of Relativity

- Review of Lorentz transformations and special theory of relativity.
- Tensors and their transformation laws; Christoffel symbol and Riemann tensor; geodesics; parallel transport along open lines and closed curves; general properties of the Riemann tensor.

- Equivalence principle and its applications: gravity as a curvature of space-time; geodesics as trajectories under the influence of gravitational field; generalisation to massless particles; gravitational red-shift; motion of a charged particle in curved space-time in the presence of an electric field; Maxwells equation in curved space-time.
- Einsteins equation, Lagrangian formulation, Einstein-Hilbert action.
- Schwarzschild solution: construction of the metric and its symmetries; motion of a particle in the Schwarzschild metric; Schwarzschild black hole; white holes and Kruskal extension of the Schwarzschild solution: construction of the metric and its symmetries; Motion of a particle in the Schwarzschild metric; precession of the perihelion; bending of light; horizon, its properties and significance.
- Precession of the perihelion; bending of light; radar echo delay.
- Initial value problem; extrinsic curvature; Gauss-Codacci equations;
- Linearised theory, gravitational waves, field far from a source, energy in gravitational waves, quadrupole formula
- Elementary cosmology: principles of homogeneity and isotropy; Friedman-Robertson-Walker metric; open, closed and flat universes; Friedman equation and stress tensor conservation, equation of state, big bang hypothesis and its successes.

Textbooks:

1. General Relativity, S. Weinberg,
2. Lecture Notes on General Relativity, S. Carroll,
3. Introducing Einstein's Relativity, R. D'Inverno,
4. General Relativity, R. M. Wald.

• Nonlinear Dynamics

- Long time behaviour of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.
- Periodic orbit for conservative systems, periodic orbits for dissipative systems (limit cycles) and their stability, Bifurcations and centre manifolds.
- Different kinds of perturbation theory for calculating periodic orbits, Renormalisation group aided perturbation theory, Poincare Bendixon theorem, chaos and strange attractors.
- Maps, fixed points, cycles and stability, bifurcations , period doubling, intermittency and quasi periodicity, universal behavior at the onset of chaos , renormalization group and scaling behaviour.
- Partial differential equations, patterns, Galerkin truncations and reduction to dynamical systems.

Textbooks:

1. Chaos in Dynamical Systems, E. Ott,

2. Arithmetical Chaos, E. B. Bogomolny, B. Georgeot, M.-J. Giannoni, C. Schmit,
3. Nonlinear Dynamics and Chaos, S. H. Strogatz.
4. Deterministic Chaos, H. G. Schuster.

- ## Quantum Information and Computation I

- Quantum formalism: states, evolution, measurements.
- Multipartite quantum systems: description and manipulation of bipartite systems and beyond.
- Entanglement: quantification and detection in bipartite and multipartite systems.
- Quantum communication: no-cloning theorem, quantum teleportation, quantum dense coding, multipartite communication protocols.
- Quantum cryptography: essential classical cryptography, BB84, B92, Ekert, and secret sharing protocols.
- Quantum computation: quantum algorithms, universal gates.
- Interface of quantum information with other sciences.
- Experimental realisations.

Textbooks:

1. Quantum Computation and Quantum Information, M. Nielsen and I. Chuang,
2. Lecture Notes of J. Preskill, available at http://www.theory.caltech.edu/~preskill/ph229/
3. Quantum information, G. Alber et al (Editors),
4. Lectures on Quantum Information, D. Bruss and G. Leuchs,
5. Quantum Theory: Concepts and Methods, A. Peres,
6. The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation, D. Bouwmeester, A. Ekert, and A. Zeilinger.

Semester IV

(16) Particle Physics

- Experimental methods: fixed target and collider experiments, particle detectors.
- Role of symmetries: charge conjugation, parity, time reversal, isospin and SU(2), quark model and SU(3).
- Introduction to relativistic kinematics: Mandelstam variables, phase space, calculation of cross-sections and decay widths.

- Basics of quantum electrodynamics: electron-positron annihilation, electron-muon scattering, Bhabha scattering, Compton scattering.
- Deep inelastic scattering: Bjorken scaling, parton model, scaling violation, introduction to quantum chromodynamics and tree level processes.
- Introduction to weak interactions: parity violation, V-A theory, pion and muon decay, neutrino scattering.
- Standard Model: Glashow-Salam-Weinberg model, neutral current, physics of W, Z and Higgs, CKM mixing and CP violation.
- Neutrino physics, neutrino oscillation

Textbooks:

1. Quarks and Leptons: F. Halzen and A. Martin,
2. An Introductory Course of Particle Physics: P. B. Pal,
3. Dynamics of the Standard Model: J. F. Donoghue, E. Golowich and B. R. Holstein,
4. Field Theory and Particle Physics: B. De Witt and J. Smith.

(17) Elective II and (18) Elective III

Choose any two of the following topics,

Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure Calculations, Quantum Field Theory II, Quantum Optics, Soft Matter, Ultra cold Atoms.

• Astrophysics

- Introduction to celestial objects, coordinates and the concept of time. Radiation transfer. Equations of radiation transfer, Black-body/thermal radiation, Opacity and optical depth, solutions of the radiation transfer equations in limiting cases, Rosseland mean opacity.
- Thermal Bremsstrahlung emission, synchrotron emission. Self-absorption and the emergent spectrum. Thomson scattering. Compton and Inverse-Compton scattering. Scattering in a region with magnetic field, Faraday rotation Introduction to fluid dynamics. Convection instability and transfer of energy from cores of stars. Supersonic motion, shocks.
- Introduction to Magneto-hydro dynamics, flux freezing, Generation and amplification of magnetic fields in astrophysical situations.
- Stellar structure. Mass-radius relation for main sequence stars, Minimum and maximum mass for nucleosynthesis, Hertzsprung-Russell diagram, Evolution of a star on the HR diagram. Novae and Supernovae, End points of stellar evolution. Inter-stellar medium. Phases of interstellar medium. Thermal, photoionisation, chemical and pressure equilibrium, Star formation, feedback and the evolution of ISM.

- Orbits around massive bodies, Tidal disruption, restricted 3 body problem, Roche limit. Orbits in external potentials, potential-density pairs. An overview of models for galaxies. Accretion of matter on to a point mass, spherical accretion, Eddington limit.
- Introduction to Cosmology, Friedmann models, equations. Hubble's law. A brief overview of the thermal history of the universe.

Textbooks:

1. Theoretical Astrophysics-I, T. Padmanabhan,
2. Theoretical Astrophysics-II, T. Padmanabhan,
3. An Introduction to Modern Astrophysics, B. W. Carroll and D. A. Ostlie,
4. Astrophysics for Physicists, A. Roy Choudhuri.

• Condensed Matter Physics II

The course will consist of any two of A-D:

Part A: Mesoscopics and spintronics:

- Foundation: low dimensional systems: quantum Wells, wires and quantum dots, 1D and 2D heterostructures, coupled wells and superlattices.
- Charge Transport: transmission and its relation to conductance, Landauer theory, transmission function, S matrix and Green functions. Non-equilibrium Green functions and Landauer-Buttiker theory. Noise in Charge transport, scattering theory of shot noise.
- Spintronics: introduction to spintronics.(Datta-Das spin transistor) equilibrium and non-equilibrium spin currents, spin Hall effect, coupled charge and spin transport, TMR, spin shot noise, entanglement generation and its detection.

Part B: Electronic structure:

- Physics in low dimensions: surface states, reconstructions, adsorption, atomic wires and clusters.
- Electron-electron interactions: Hartree-Fock approximation, electron gas, density functional theory.
- Anharmonic effects in crystals: thermal expansion, lattice thermal conductivity, umklapp processes.
- Phonons in metals: Kohn anomaly, dielectric constant, temperature dependence of electrical resistivity.
- Dielectric properties of insulators. Plasmons, magnons etc.

Part C: Mesoscopics and interacting systems:

- Quantum Hall effect
- Quantum dots and quantum wires, Kondo effect
- Fermi liquid theory and non-Fermi liquids
- Bosonization and Luttinger liquids.
- Quantum spin systems

Part D: Correlated electrons:

- Mott physics: electron localization, magnetic order, doped phase, physics in the cuprates.
- Kondo systems: physics of the single impurity, dense systems Kondo and Anderson lattice, heavy fermions, quantum criticality.
- Metallic magnets: ferromagnetism in strongly repulsive systems, the transition metals, spin-fermion systems, the double exchange model, the classical Kondo lattice.
- Electron-phonon coupling: the classical theory, polaron formation, many electron systems, polaron ordering, physics in the manganites.
- Superconductivity: the BCS-BEC crossover, superconductivity in repulsive systems, competition with magnetism, effect of disorder.

Textbooks:

1. Condensed matter field theory - A. Altland and B. Simons,
2. Field theories of condensed matter physics - E. Fradkin,
3. Electronic transport in mesoscopic systems - S. Datta,
4. Composite fermions - J. K. Jain,
5. Topological insulators and topological superconductors - B. Bernevig and T. Hughes.
6. Aromaticity and Metal Clusters, Ed. P. Chattaraj
7. Introduction to Cluster Dynamics, P.-G. Reinhard and E. Suraud
8. Surface Science, an Introduction by Oura et al.
9. Principles of Surface Physics, F. Bechstedt
10. Physics at Surfaces, A. Zangwill

• Cosmology

- Friedman-Robertson-Walker metric, Friedman equation and stress tensor conservation, equation of state: matter, radiation, cosmological constant, experimental evidence for dark matter and dark energy.
- Age of the universe, cosmological horizon, expansion rate.
- Thermal history of the universe, formation of hydrogen and origin of CMBR, decoupling of neutrinos, nucleosynthesis, recombination.
- The horizon problem, possible resolution via inflation, slow roll condition and slow roll parameters, reheating, inflationary origin of density perturbation.
- Early history, electroweak baryogenesis via leptogenesis, dark matter.

- Theory of cosmological perturbations: gauge invariant scalar and tensor perturbations, spectral index, ratio of tensor to scalar fluctuation and Lyth bound, transition from quantum to classical perturbation: horizon exit and reentry, from density fluctuation to CMB fluctuations via Boltzmann transport equation, origin of the acoustic peak, and origin of CMB polarisation, E and B modes.

Textbooks:

1. Cosmology, S. Weinberg,
2. Physical Foundations of Cosmology, V. Mukhanov,
3. Particle Physics and Inflationary Cosmology, A. Linde.

• Introduction to Electronic Structure

- Review of QM: variational method, identical particles, many fermion wave functions.
- First-principles Hamiltonian and Born-Oppenheimer approximation.
- Treating electron-electron interactions: Hartree-Fock approximation, exchange energy, correlation energy.
- Density functional theory: Thomas-Fermi method, Hohenberg-Kohn theorems, Levy constrained search formulation, Kohn-Sham formulation, exchange-correlation energy, LDA and GGA functionals, spin density functional theory.
- Solution of the Kohn-Sham equations, basis sets - LCAO: STO-NG, 4-31G, 6-31G etc, quality of basis sets, polarisation functions, spin-restricted calculations, Roothan equations.
- Spin unrestricted calculations. Plane wave basis set.
- Pseudopotentials and PAW in conjunction with plane waves.
- Structure optimisation, Hellman-Feynman theorem.
- Simple practical applications: band structure of standard solids, metals and semiconductors, optimisation of lattice constants, cohesive energies and other simple properties.
- Possible advanced topics: hybrid functionals, van der Waals interactions, density functional perturbation theory, phonon band structure, electron-phonon coupling. CI, CCSD methods, QMC.

Textbooks:

1. Density Functional Theory of Atoms and Solids, R. G. Parr and W. Yang,
2. Modern Quantum Chemistry, A. Szabo and N. S. Ostlund,
3. Electronic Structure of Materials, R. Prasad,
4. Electronic Structure, R. Martin.

• Quantum Field Theory II

- Path integrals for scalar and fermionic fields: generating functional, Feynman rules, loop diagrams.
- Renormalisation of scalar and Yukawa theories: power counting, regularisation, renormalisable and non-renormalisable theories, Green functions at 1 loop of some prototypical theories, basics of renormalisation group (running coupling), 1PI effective actions.
- Spontaneous symmetry breaking and Goldstone's theorem.
- Path integrals for the Maxwell field, gauge fixing.
- Renormalisation of QED: 1 loop diagrams, Landau pole.
- Non-abelian Gauge Theories: Classical theory of non-abelian gauge theories, Quantization of non-abelian gauge theories by path integral methods, Non-abelian gauge theories at one loop and asymptotic freedom, Spontaneous symmetry breaking in non-abelian gauge theories.

Textbooks:

1. An introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder,
2. Quantum Field Theory, C. Itzykson and J-B Zuber,
3. Quantum Field Theory: A Modern Primer, P. Ramond.

• Quantum Information and Computation II

- General evolution and Decoherence theory.
- Master equations (Markovian and Non-Markovian, Various measure of nonmarkovianity).
- Advanced entanglement theory (GM, GGM, newly proposed measures etc).
- Quantum Correlation beyond Entanglement (Quantum Discord, Geometric discord, Work-Deficit etc).
- Resource theory in QI (Entanglement, Quantum Coherence, Reference Frame, Asymmetry etc).
- Quantum Thermodynamics.
- Advanced topics in quantum channels.
- Quantum information and condensed matter systems.

Textbooks:

1. Lecture Notes on the Theory of Open Quantum Systems by D. A. Lidar,
2. The Theory of Open Quantum Systems by H.-P. Breuer, F. Petruccione,
3. Classical and Quantum Computation, A. Yu. Kitaev, A. H. Shen, and M. N. Vyalyi.

• Quantum Optics

- Introduction: Quantization of the electromagnetic field, Fock states, coherent states, squeezed states, basic atom-photon interaction, density-matrix formalism.
- Theory of coherence; Semiclassical theory of atom-photon interaction.
- Quantum theory of atom-photon interaction.
- Quantum theory of dissipation.
- Quantum information in continuous variable systems; Quantum state engineering.
- Quantum operations based on beam splitters, mirrors, squeezing and homodyne and heterodyne measurements and nonlinear operations such as parametric down converters.
- Photon addition and subtraction operations; Elements of cavity QED.

Textbooks:

1. Quantum Optics, M. O. Scully and S. Zubairy,
2. Introductory Quantum Optics, C. C. Gerry and P. L. Knight,
3. Quantum Optics, D. F. Walls and G. J. Milburn,
4. Quantum Information with Continuous Variables of Atoms and Light, N. J. Cerf, G. Leuchs and E. S. Polzik (eds.),
5. Quantum information with continuous variables, S. L. Braunstein and P. van Loock.

• Soft Matter

- Forces, energies and timescales in soft matter, van der Waals force, hydrophobic and hydrophilic interactions. Basic phenomenology of liquid crystals, polymers, membranes, colloidal systems. Phase behaviour, diffusion and flow, viscoelasticity.
- Order parameter, phase transitions: mean-field theory and phase diagrams, elasticity, stability, metastability, interfaces.
- Colloidal systems: Poisson-Boltzmann theory, DLVO theory, sheared colloids, stability of colloidal systems, measurement of interaction.
- Polymers: model systems, chain statistics, polymers in solutions and in melts, flexibility and semi-flexibility, distribution functions, self-avoidance, rubber elasticity, viscoelasticity, reptation ideas.
- Membranes: fluid vs. solid membranes, energy and elasticity, surface tension, curvature, de Gennes-Taupin length, brief introduction to shape transitions.
- Experimental tools and numerical approaches: Stokes limit, Rouse and Zimm Model for polymers, membranes, relaxation, computational studies, multiscale modelling.
- The intent is to train students in the applications of classical statistical mechanics in areas like fluids, colloids, membranes polymers. This includes training in the mathematical tools as well as the phenomenology.

Textbooks:

1. Soft Matter Physics, M. Kleman and O. D. Lavrentovich,
2. Soft Condensed Matter, R. L. Jones,
3. Principles of Condensed Matter Physics, P. Chaikin and T. C. Lubensky (Cambridge),
4. Statistical Mechanics of Surfaces, Interfaces and Membranes, S. A. Safran,
5. Soft Matter Physics, Ed, M. Daoud and C. E. Williams,
6. The Structure and Rheology of Complex Fluids, R. Larson,
7. Intermolecular and Surface Forces, J. Israelachvili.

• Ultra-Cold Atoms

- Spatial, time, and energy scales in cold atom physics.
- Experimental background: trapping and cooling, Feshbach resonance, optical lattices, cold atom spectroscopies.
- Basic theory: many particle physics, mean field theory, phase transitions, perturbation theory.
- Continuum bosons: bosons in free space, weak interactions, Bogoliubov theory, BEC in trapped systems, Gross-Pitaevski equation.
- Continuum fermions: fermions in free space, trapped fermions, Fermi liquid theory, weak attraction - BCS instability, strong attraction - BEC of pairs, the unitary Fermi gas, Stoner instability.
- Optical lattices: Hubbard model - Bose/Fermi cases, superfluid-Mott transition for repulsive bosons, BCS-BEC crossover for attractive fermions, Mott transition in repulsive fermions.
- Spin systems: quantum, S = 1/2, magnetism on unfrustrated and frustrated lattices. Entanglement in many body systems: pure states, mixed states, area laws, tensor network states.
- Special topics: population imbalance, Anderson localisation, gauge fields, quench dynamics.
- The course combines elements of atomic physics with many body theory to model collective phenomena in cold atomic gases. The students would learn of the application of quantum statistical mechanics and many body theory in the context of interacting Bose and Fermi gases.

Textbooks:

1. Many Body Physics with Ultracold Gases, Les Houches Lectures, Ed, C. Salomon, G. Shlyapnikov and L. F. Cugliandolo,
2. Ultracold Quantum Fields, H. T. C. Stoof, K. B. Gubbels and D. B. M. Dickerscheid,

3. Ultracold Bosonic and Fermionic Gases, K. Levin, A. L. Fetter and D. M. Stamper-Kurn,
4. Bose-Einstein Condensation in Dilute Gases, C. J. Pethick and H. Smith,
5. Bose-Einstein Condensation, L. P. Pitaevskii and S. Stringari,
6. Theory of Ultracold Fermi Gases, S. Giorgini, L. P. Pitaevskii and S. Stringari,
7. Ultracold Atoms in Optical Lattices: M. Lewenstein et al.
8. Cold Atoms and Molecules: Weidenmuller, Zimmerman.

(19)Project

In this semester, every student is supposed to do a project on a theoretical physics topic under the supervision of HRI faculty. Main fields in theoretical physics represented at HRI at the moment are, Astrophysics, Condensed Matter Physics, Particle Physics Phenomenology, Quantum Information and Computation, and String Theory.

(20) Laboratory III

- Ferro to Para Electric Phase Transition (or its Magnetic analogue)
- Raman Spectroscopy
- ESR
- Earth's field NMR gradient
- Bragg Diffraction by Microwaves
- Hall Effect
- G-M counter, Counting Statistics, Gamma ray absorption cross section
- Gamma ray Spectroscopy
- STM with Graphene, HOPG, Gold, Semiconductors and CDW
- Measurement of Speed of Light

Other Electives

• Advanced Particle Physics

- The discovery of the Higgs boson; the Higgs and vacuum stability.
- Issues in collider physics, motivations and outcome of the LHC, motivations for future collider experiments.
- CP-violation, the unitarity triangle, outcomes of B-factory measurements.
- The evolution of parton distribution functions, Altarelli-Parisi equation, applications to LHC physics.
- The motivations for physics beyond the Standard Model current constraints from accelerator and astroparticle/cosmological data, the dark matter issue; supersymmetry, grand unification.

Textbooks:

1. Gauge Theory of Elementary particle physics, T.-P. Cheng and L.-F. Li,
2. Foundations of Quantum Chromodynamics, T. Muta,
3. Collider Physics, V. D. Barger and R. J. N. Phillips,
4. Beyond Standard Collider Phenomenology of Higgs Physics and Supersymmetry, M. C. Thomas.

• Spectroscopic Methods

- Probes for matter on different energy and spatial scales.
- Interaction of electromagnetic radiation with matter, correlation functions in classical and quantum matter, point group symmetries and selection rules.
- Electron spectroscopy in atoms and molecules: single and many electron atoms, simple molecules, vibronic transitions.
- Vibration and rotational spectroscopy: infrared, Raman and microwave methods. Computing the spectrum of simple atomic and molecular systems.
- Probing spin states: electron spin resonance and nuclear magnetic resonance. Mossbauer spectroscopy. Spectra of magnetic ions. Solid state effects on the spectrum.
- Probe of collective effects: X-ray and neutron scattering from condensed matter. Static structure and dynamical correlations. Effect of phonons on lattice dynamical structure factor. Dynamical magnetic structure factor from ferro and antiferromagnetic spin waves. Diffuse magnetic scattering. Dynamics of classical liquids.
- Extended electronic states: angle resolved photoemission spectroscopy, computing the spectrum for weakly correlated electron systems.
- Ultrafast dynamics: control and probe of chemical reactions via femtosecond spectroscopy.

Textbooks:

1. Modern Spectroscopy, J. M. Hollas,
2. Symmetry and Spectroscopy, Harris and Bertolucci,
3. Introductory Raman Spectroscopy, J. R. Ferraro, K. Nakamoto and C. W. Brown,
4. Understanding NMR Spectroscopy, J. Keeler,
5. Theory of Neutron Scattering from Condensed Matter, S. W. Lovesey,
6. Dynamic Light Scattering, Berne and Pecora,
7. Photoemission in High Tc Superconductors, Campuzano, Norman and Randeria, in Bennemann and Ketterson, Superconductivity Vol. 2,
8. Chemical Reactions and their Control on the Femtosecond Time Scale, P. Gaspard and I. Burghardt Femtosecond Laser Spectroscopy, Ed, P. Hannaford.

Quantum Many Body Theory

- Basics: second quantisation, the many body Hilbert space, few particle problems. Green functions: formal definition, Lehmann representation, calculation for quadratic problems, expression of observables in terms of Green functions. Finite temperature: the imaginary time formulation, analytic continuation.
- Perturbation theory: the interaction representation, Wicks theorem, low order expansion and diagrammatic representation, Dyson equation and self-energy, vertex functions and Bethe-Salpeter equation, explicit calculations in the Anderson impurity model.
- Resummations: random phase approximation in the electron gas, ladder summation in dilute hardcore systems, Hartree-Fock and higher order conserving approximations.
- Long range order: self-consistent calculations for broken symmetry phases, static mean field and dynamical calculations, Nambu formulation and Eliashberg theory. Goldstone modes in the ordered phase - metallic antiferromagnets and superconductivity,
- Functional integral methods: representing the partition function, bosons and fermions, quadratic integrals, Hubbard-Stratonovich decomposition of interactions, saddle point, gaussian fluctuations, beyond the gaussian theory, Ginzburg-Landau expansions.

Textbooks:

1. Introduction to Many-Body Physics, P. Coleman,
2. Fundamentals of Many-Body Physics: Principles and Methods, W. Nolting,
3. Quantum Theory of Many-Particle Systems, A. L. Fetter and J. D. Walecka,’
4. Many-Body Physics, G. D. Mahan.

The instructional part of the doctoral program consists of two semesters of pedagogical lectures followed by two projects in the third semester.

Semester V	Semester VI
Elective I	Elective II
Project	Elective III
Mathematical Methods II	Statistical Mechanics
Quantum Field Theory I	Numerical Methods

Elective I : Choose one from — Fluid Mechanics, General Relativity, Non-linear Dynamics, Quantum Information and Computation I, Quantum Mechanics III .

Elective II and III : Choose two from — Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure, Particle Physics, Quantum Field Theory II, Quantum Information and Computation II, Quantum Optics, Soft Matter, Ultra Cold Atoms.

Semester V

08PHYS05-021-C Quantum Field Theory I

Non-relativistic quantum field theory: quantum mechanics of many particle systems; second quantisation; Schrodinger equation as a classical field equation and its quantisation; inclusion of inter-particle interactions in the first and second quantised formalism

Irreducible representations of the Lorentz group, connection to quantum fields

Symmetries and conservation laws: examples in non-relativistic and relativistic field theories; translation, rotation, Lorentz boost/Galilean transformation and internal symmetry transformations; associated conserved charges

Free Klein-Gordon equation: classical action and its quantisation; spectrum; Feynman rules for computing n-point Green functions of elementary and composite operators.

Interacting Klein-Gordon field: Feynman rules for computing Green functions; physical mass of the particle from the analysis of two point Green functions; S-matrix and its computation from n-point Green functions; relating S-matrix to cross-section.

Quantisation of free Dirac fields: spectrum; Feynman rules

Quantisation of free electromagnetic field: role of gauge invariance; gauge fixing; physical state condition; spectrum; Feynman rules

Quantum electrodynamics: coupling Dirac field to electromagnetic field; gauge invariance; quantisation; Feynman rules for computing Green functions; Spectrum and S-matrix from the Green functions.

08PHYS05-022-C Mathematical Methods II

Integral transforms, Fourier transforms, inversion and convolution, Laplace transforms

Advanced topics in ODE, Partial differential equations: classification of second order PDEs, Laplace and Poisson equations, applications to electrostatics, Heat equation, Wave equation

Group theory, definitions and examples of groups. Homomorphism, isomorphism and automorphism, Permutation groups

Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group. Symmetries in physical systems, Young Tableau.

08PHYS05-023-C Project

In this semester, every student is supposed to do a project on a theoretical physics topic under the supervision of HRI faculty. Main fields in theoretical physics represented at HRI at the moment are, Astrophysics, Condensed Matter Physics, Particle Physics Phenomenology, Quantum Information and Computation, and String Theory.

Elective I

Choose any one of the following topics, Fluid Dynamics, General Theory of Relativity, Techniques in Nonlinear Dynamics, Quantum Information and Computation I and Quantum Mechanics III.

08PHYS05-015-E Fluid Mechanics

Ideal Fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity

Viscous Fluids: Viscosity, Navier-Stokes equation, Reynolds number, laminar flow, exact solution to the eq. of motion.

Turbulence: Stability of flows, instabilities, quasi-periodic flows, Strange attractors, turbulent flows, jets, free shear layers, wakes, boundary layers

Thermal Conduction in fluids: eq. of heat transfer, conduction in incompressible fluid, law of heat transfer, convection, convective instability in static fluid

Compressible flows

Relativistic Fluid dynamics: eq. of motion, energy-momentum tensor, eq. for flow with viscosity and thermal conduction.

08PHYS05-016-E General Theory of Relativity

Review of Lorentz transformations and special theory of relativity.

Tensors and their transformation laws; Christoffel symbol and Riemann tensor; geodesics; parallel transport along open lines and closed curves; general properties of the Riemann tensor.

Equivalence principle and its applications: gravity as a curvature of space-time; geodesics as trajectories under the influence of gravitational field; generalisation to massless particles; gravitational red-shift; motion of a charged particle in curved space-time in the presence of an electric field; Maxwells equation in curved space-time.

Einsteins equation, Lagrangian formulation, Einstein-Hilbert action.

Schwarzschild solution: construction of the metric and its symmetries; motion of a particle in the Schwarzschild metric; Schwarzschild black hole; white holes and Kruskal extension of the Schwarzschild solution: construction of the metric and its symmetries; Motion of a particle in the Schwarzschild metric; precession of the perihelion; bending of light; horizon, its properties and significance.

Precession of the perihelion; bending of light; radar echo delay.

Initial value problem; extrinsic curvature; Gauss-Codacci equations;

Linearised theory, gravitational waves, field far from a source, energy in gravitational waves, quadrupole formula

Elementary cosmology: principles of homogeneity and isotropy; Friedman-Robertson-Walker metric; open, closed and flat universes; Friedman equation and stress tensor conservation, equation of state, big bang hypothesis and its successes.

08PHYS05-017-E Nonlinear Dynamics

Long time behaviour of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.

Periodic orbit for conservative systems, periodic orbits for dissipative systems (limit cycles) and their stability, Bifurcations and centre manifolds.

Different kinds of perturbation theory for calculating periodic orbits, Renormalisation group aided perturbation theory, Poincare Bendixon theorem, chaos and strange attractors.

Maps, fixed points, cycles and stability, bifurcations , period doubling, intermittency and quasi periodicity, universal behavior at the onset of chaos , renormalization group and scaling behaviour.

Partial differential equations , patterns, Galerkin truncations and reduction to dynamical systems.

08PHYS05-018-E Quantum Information and Computation I

Quantum formalism: states, evolution, measurements.

Multipartite quantum systems: description and manipulation of bipartite systems and beyond.

Entanglement: quantification and detection in bipartite and multipartite systems.

Quantum communication: no-cloning theorem, quantum teleportation, quantum dense coding, multipartite communication protocols.

Quantum cryptography: essential classical cryptography, BB84, B92, Ekert, and secret sharing protocols.

Quantum computation: quantum algorithms, universal gates.

Interface of quantum information with other sciences.

Experimental realisations.

08PHYS05-019-E Quantum Mechanics III

Atomic physics: One electron atoms - spin-orbit interaction, fine structure, Lamb shift, Zeeman effect, Stark effect.

Two electron atoms: spin wave functions, approximate handling of electron-electron repulsion. Coupling of angular momenta, multiplet structure, gyromagnetic effects. Hyperfine and nuclear quadrupole interactions.

Many electron atoms: central field approximation, Thomas-Fermi and Hartree-Fock methods.

Molecular physics: Born-Oppenheimer approximation, molecular structure, rotation and vibration of diatomic molecules, hydrogen molecular ion, vibrational-rotational coupling, effect of vibration and rotation on molecular spectra. Electronic structure- molecular orbital and valence bond theories.

Atoms and light: transition rates, dipole approximation, Einstein coefficients, radiative damping, optical absorption, ac Stark effect.

Cold atoms: Doppler cooling, magneto-optical trap, ion traps, dipole force, evaporative cooling, optical lattice.

Collective effects: Feshbach tuning of interactions, Bose condensation of alkali atoms, BCS-BEC crossover, the unitary Fermi gas. Imaging cold atoms.

Computing with atoms: qubits and their properties, entanglement, quantum logic gates, decoherence and error correction.

Semester VI

08PHYS05-024-C Statistical Mechanics

Basics: phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.

Non interacting classical systems: few level systems, ideal gases, oscillators.

Non interacting quantum systems: method of second quantisation, electrons in metals, relativistic electron systems, electrons in a strong magnetic field, lattice vibrations and phonon physics, photons, blackbody radiation, Bose condensation.

Interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.

Phase transitions: symmetry breaking and long range order, mean field approach, Landau theory, 2nd and 1st order transitions, Landau-Ginzburg functional, illustrative examples, estimate of fluctuations.

08PHYS05-025-C Research Methodology and Numerical Methods

Research Methodology including quantitative methods, communication skills, seminar presentation and review of research papers

Introduction to programming languages: F77, F90 or C

Errors in numerical calculations.

Numerical linear algebra, eigenvalue and eigenvectors.

Interpolation techniques.

Generation and use of random numbers.

Sorting and searching.

Differentiation and Integration (including Monte Carlo techniques)

Root finding algorithms

Optimisation, extrema of many variable functions.

ODEs and PDEs: including FFT and finite difference methods, integral equations.

Elective II and III

Choose any two of the following topics,

Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure Calculations, Particle Physics, Quantum Field Theory II, Quantum Information and Computation II, Quantum Optics, Soft Matter, Ultra cold Atoms.

08PHYS05-020-EAstrophysics

Introduction to celestial objects, coordinates and the concept of time. Radiation transfer. Equations of radiation transfer, Black-body/thermal radiation, Opacity and optical depth, solutions of the radiation transfer equations in limiting cases, Rosseland mean opacity.

Thermal Bremsstrahlung emission, synchrotron emission. Self absorption and the emergent spectrum. Thomson scattering. Compton and Inverse-Compton scattering. Scattering in a region with magnetic field, Faraday rotation Introduction to fluid dynamics. Convection instability and transfer of energy from cores of stars. Supersonic motion, shocks.

Introduction to Magneto-hydro dynamics, flux freezing, Generation and amplification of magnetic fields in astrophysical situations.

Stellar structure. Mass-radius relation for main sequence stars, Minimum and maximum mass for nucleosynthesis, Hertzsprung-Russell diagram, Evolution of a star on the HR diagram. Novae and Supernovae, End points of stellar evolution. Inter-stellar medium. Phases of interstellar medium. Thermal, photoionisation, chemical and pressure equilibrium, Star formation, feedback and the evolution of ISM.

Orbits around massive bodies, Tidal disruption, restricted 3 body problem, Roche limit. Orbits in external potentials, potential-density pairs. An overview of models for galaxies. Accretion of matter on to a point mass, spherical accretion, Eddington limit.

Introduction to Cosmology, Friedmann models, equations. Hubble’s law. A brief overview of the thermal history of the universe.

08PHYS05-021-E Condensed Matter Physics II

The course will consist of any two of A-D:

Part A: Mesoscopics and spintronics:

Foundation: low dimensional systems: quantum Wells, wires and quantum dots, 1D and 2D heterostructures, coupled wells and superlattices.

Charge Transport: transmission and its relation to conductance, Landauer theory, transmission function, S matrix and Green functions. Non-equilibrium Green functions and Landauer-Buttiker theory. Noise in Charge transport, scattering theory of shot noise.

Spintronics: introduction to spintronics.(Datta-Das spin transistor) equilibrium and non-equilibrium spin currents, spin Hall effect, coupled charge and spin transport, TMR, spin shot noise, entanglement generation and its detection.

Part B: Electronic structure:

Physics in low dimensions: surface states, reconstructions, adsorption, atomic wires and clusters.

Electron-electron interactions: Hartree-Fock approximation, electron gas, density functional theory.

Anharmonic effects in crystals: thermal expansion, lattice thermal conductivity, umklapp processes.

Phonons in metals: Kohn anomaly, dielectric constant, temperature dependence of electrical resistivity.

Dielectric properties of insulators. Plasmons, magnons etc.

Part C: Mesoscopics and interacting systems:

Quantum Hall effect

Quantum dots and quantum wires, Kondo effect

Fermi liquid theory and non Fermi liquids

Bosonization and Luttinger liquids.

Quantum spin systems

Part D: Correlated electrons:

Mott physics: electron localisation, magnetic order, doped phase, physics in the cuprates.

Kondo systems: physics of the single impurity, dense systems Kondo and Anderson lattice, heavy fermions, quantum criticality.

Metallic magnets: ferromagnetism in strongly repulsive systems, the transition metals, spin-fermion systems, the double exchange model, the classical Kondo lattice.

Electron-phonon coupling: the classical theory, polaron formation, many electron systems, polaron ordering, physics in the manganites.

Superconductivity: the BCS-BEC crossover, superconductivity in repulsive systems,

competition with magnetism, effect of disorder.

08PHYS05-022-E Cosmology

Friedman-Robertson-Walker metric, Friedman equation and stress tensor conservation, equation of state: matter, radiation, cosmological constant, experimental evidence for dark matter and dark energy.

Age of the universe, cosmological horizon, expansion rate.

Thermal history of the universe, formation of hydrogen and origin of CMBR, decoupling of neutrinos, nucleosynthesis, recombination.

The horizon problem, possible resolution via inflation, slow roll condition and slow roll parameters, reheating, inflationary origin of density perturbation.

Early history, electroweak baryogenesis via leptogenesis, dark matter.

Theory of cosmological perturbations: gauge invariant scalar and tensor perturbations, spectral index, ratio of tensor to scalar fluctuation and Lyth bound, transition from quantum to classical perturbation: horizon exit and reentry, from density fluctuation to CMB fluctuations via Boltzmann transport equation, origin of the acoustic peak, origin of CMB polarisation, E and B modes.

08PHYS05-023-E Introduction to Electronic Structure

Review of QM: variational method, identical particles, many fermion wave functions.

First-principles Hamiltonian and Born-Oppenheimer approximation.

Treating electron-electron interactions: Hartree-Fock approximation, exchange energy, correlation energy.

Density functional theory: Thomas-Fermi method, Hohenberg-Kohn theorems, Levy constrained search formulation, Kohn-Sham formulation, exchange-correlation energy, LDA and GGA functionals, spin density functional theory.

Solution of the Kohn-Sham equations, basis sets - LCAO: STO-NG, 4-31G, 6-31G etc, quality of basis sets, polarisation functions, spin-restricted calculations, Roothan equations.

Spin unrestricted calculations. Plane wave basis set.

Pseudopotentials and PAW in conjunction with plane waves.

Structure optimisation, Hellman-Feynman theorem.

Simple practical applications: band structure of standard solids, metals and semiconductors, optimisation of lattice constants, cohesive energies and other simple properties.

Possible advanced topics: hybrid functionals, van der Waals interactions, density functional perturbation theory, phonon band structure, electron-phonon coupling. CI, CCSD methods, QMC.

08PHYS05-024-E Particle Physics

Experimental methods: fixed target and collider experiments, particle detectors.

Role of symmetries: charge conjugation, parity, time reversal, isospin and SU(2), quark model and SU(3).

Introduction to relativistic kinematics: Mandelstam variables, phase space, calculation of cross-sections and decay widths.

Basics of quantum electrodynamics: electron-positron annihilation, electron-muon scattering, Bhabha scattering, Compton scattering.

Deep inelastic scattering: Bjorken scaling, parton model, scaling violation, introduction to quantum chromodynamics and tree level processes.

Introduction to weak interactions: parity violation, V-A theory, pion and muon decay, neutrino scattering.

Standard Model: Glashow-Salam-Weinberg model, neutral current, physics of W, Z and Higgs, CKM mixing and CP violation.

Neutrino physics, neutrino oscillation

08PHYS05-025-E Quantum Field Theory II

Path integrals for scalar and fermionic fields: generating functional, Feynman rules, loop diagrams.

Renormalisation of scalar and Yukawa theories: power counting, regularisation, renormalisable and non-renormalisable theories, Green functions at 1 loop of some prototypical theories, basics of renormalisation group (running coupling), 1PI effective actions.

Spontaneous symmetry breaking and Goldstone’s theorem.

Path integrals for the Maxwell field, gauge fixing.

Renormalisation of QED: 1 loop diagrams, Landau pole.

Non-abelian Gauge Theories: Classical theory of non-abelian gauge theories, Quantization of non-abelian gauge theories by path integral methods, Non-abelian gauge theories at one loop and asymptotic freedom, Spontaneous symmetry breaking in non-abelian gauge theories.

08PHYS05-026-E Quantum Information and Computation II

General evolution and Decoherence theory.

Master equations (Markovian and Non-Markovian, Various measure of nonmarkovianity).

Advanced entanglement theory (GM, GGM, newly proposed measures etc).

Quantum Correlation Beyond Entanglement (Quantum Discord, Geometric discord, Work-Deficit etc).

Resource theory in QI (Entanglement, Quantum Coherence, Reference Frame, Asymmetry etc).

Quantum Thermodynamics.

Advanced topics in quantum channels.

Quantum information and condensed matter systems.

08PHYS05-027-E Quantum Optics

Introduction: Quantization of the electromagnetic field, Fock states, coherent states, squeezed states, basic atom-photon interaction, density-matrix formalism.

Theory of coherence; Semiclassical theory of atom-photon interaction.

Quantum theory of atom-photon interaction.

Quantum theory of dissipation.

Quantum information in continuous variable systems; Quantum state engineering.

Quantum operations based on beam splitters, mirrors, squeezing and homodyne and heterodyne measurements and nonlinear operations such as parametric down converters.

Photon addition and subtraction operations; Elements of cavity QED.

08PHYS05-028-E Soft Matter

Forces, energies and timescales in soft matter, van der Waals force, hydrophobic and hydrophilic interactions. Basic phenomenology of liquid crystals, polymers, membranes, colloidal systems. Phase behaviour, diffusion and flow, viscoelasticity.

Order parameter, phase transitions: mean-field theory and phase diagrams, elasticity, stability, metastability, interfaces.

Colloidal systems: Poisson-Boltzmann theory, DLVO theory, sheared colloids, stability of colloidal systems, measurement of interaction.

Polymers: model systems, chain statistics, polymers in solutions and in melts, flexibility and semi-flexibility, distribution functions, self-avoidance, rubber elasticity, viscoelasticity, reptation ideas.

Membranes: fluid vs. solid membranes, energy and elasticity, surface tension, curvature, de Gennes-Taupin length, brief introduction to shape transitions.

Experimental tools and numerical approaches: Stokes limit, Rouse and Zimm Model for

polymers, membranes, relaxation, computational studies, multiscale modelling.

08PHYS05-029-E Ultra Cold Atoms

Spatial, time, and energy scales in cold atom physics.

Experimental background: trapping and cooling, Feshbach resonance, optical lattices, cold atom spectroscopies.

Basic theory: many particle physics, mean field theory, phase transitions, perturbation theory.

Continuum bosons: bosons in free space, weak interactions, Bogoliubov theory, BEC in trapped systems, Gross-Pitaevski equation.

Continuum fermions: fermions in free space, trapped fermions, Fermi liquid theory, weak attraction - BCS instability, strong attraction - BEC of pairs, the unitary Fermi gas, Stoner instability.

Optical lattices: Hubbard model - Bose/Fermi cases, superfluid-Mott transition for repulsive bosons, BCS-BEC crossover for attractive fermions, Mott transition in repulsive fermions.

Spin systems: quantum, S = 1/2, magnetism on unfrustrated and frustrated lattices.
Entanglement in many body systems: pure states, mixed states, area laws, tensor network states.

Special topics: population imbalance, Anderson localisation, gauge fields, quench dynamics.

BACK TO MAIN

INTEGRATED Ph.D. in PHYSICAL SCIENCES (PROGRAM CODE: PHYS05)

Doctoral Programmes in Physics at IMSc

There are two streams leading to the Doctoral degree in Physics at IMSc: the one available to students who have completed their Master's degree prior to joining IMSc (Ph.D.) and the one available to students who join after their Bachelor's degree (Integrated Ph.D.). The Ph.D. program has *two semester compulsory course work* while the integrated Ph.D. has *four semester compulsory course work*. The third and fourth semester course work of the integrated Ph.D. program is the same as the two semester course work of the Ph.D. program.

The courses together with the pre-requisites and reference material, are given below. Integrated Ph.D. students begin with the *rst* semester courses while Ph.D. students begin with the *third* semester courses.

No.	Semester I	No.	Semester II	No.	Semester III
(11)	Classical Mechanics	(21)	Quantum Mechanics II	(31)	Quantum Field Theory I
(12)	Quantum Mechanics I	(22)	Classical Field Theory	(32)	Mathematical Methods II
(13)	Electromagnetic Theory	(23)	Condensed Matter Physics I	(33)	Statistical Mechanics II
(14)	Mathematical Methods I	(24)	Statistical Mechanics	(34)	Particle Physics I

The Fourth semester has *two core courses* (18 credits) and a *project* (12 credits). The core courses di er for students desirous of research in High Energy Physics (HEP) or Low Energy Physics (LEP). These are to be decided in consultation with the monitoring committee.

No.	HEP students	No.	LEP students
(41)	Quantum Field Theory II	(43)	Advanced Condensed Matter Physics
(42a) (42b)	Cosmology-and-Gravitation *or* Particle Physics II	(44a) (44b) (44c)	Nonlinear Dynamics *or* Quantum Information-and-Computation *or* Statistical Field Theory,

The integrated Ph.D. program students earn 123 credits while those of Ph.D. program earn 60 credits at the end of the course work.

Detailed syllabi of the proposed course

The course contents are indicative and will be ne tuned with experience.

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11) Classical Mechanics (four-and-half hours classwork per week, **9 credits**)

- *Lagrangian formulation and the action principle:*

  Configuration space, generalized coordinates Constrained systems, holonomic constraints as coordinate transformations, motion in a central field, including Kepler problem, Rutherford scattering, Small oscillations, normal modes, total time derivatives, non-uniqueness of Lagrangian, Noether's theorem, Conservation laws;

- *Rigid body kinematics and dynamics:*

  Kinematics, rotational kinetic energy, moments of inertia, inertia tensor, Euler angles, angular momentum, Free rigid body motion, axisymmetric tops;

- *Hamiltonian formulation:*

  The Legendre transformation, canonical momentum Poisson brackets, Phase space reduction, cyclic coordinates, Phase space description and evolution, surfaces of section, periodically driven systems, Liouville's theorem, Poincaré recurrence;

- *Canonical transformations, Hamilton-Jacobi theory, perturbation theory:*

  Definition; point transformations; time-independent transformations; symplectic transformations and time-dependent transformations, Invariants of canonical transformations, Generating functions Hamilton-Jacobi equation, action-angle variables, Perturbation theory as a sequence of canonical transformations of a perturbed integrable system;

- *Relativistic mechanics (including Lagrangian formulation):*

  Space-time, 4-vectors, Lorentz transformations, basic relativistic kinematics and dynamics.

Textbooks:

1. L. Landau and E. Lifshitz, *Mechanics : Course of Theoretical Physics*, Vol.1, Pergamon, 1974.
2. W. D. McComb, *Dynamics and Relativity*, Oxford University Press, 1999.
3. V. I. Arnold, *Mathematical Theory of Classical Mechanics*, Springer, 1977.
4. M. Tabor, *Chaos and Integrability in Nonlinear Dynamics*, Wiley, 1989.
5. H. Goldstein, *Classical Mechanics*, Narosa, 1990.
6. I. Percival and D. Richards, *Introduction to Dynamics*, Cambridge, 1991
7. J.V. Jose and E.J. Saletan, *Classical dynamics: A contemporary approach*, Cambridge, 1998.

12) Quantum Mechanics I: (four-and-half hours classwork per week, **9 credits**)

- *Fundamentals of Quantum Theory:*

  The breakdown of classical physics, the polarization of photons, Wave-particle duality: Particle properties of photons and wave properties of electrons, Schrodinger evolution, Hamiltonian, examples: free particle, one-dimensional potential well, potential barrier, harmonic oscillator, etc., Hilbert space formulation of Quantum Mechanics: states, observables, measurement, evolution, collapse of wave function, uncertainty relation and its interpretation, Discrete and continuous spectra, canonically conjugate observables, Schrodinger, Heisenberg and interaction pictures, Virial theorem, Ehrenfest's theorem, semi-classical quantization;

- *Theory of spin-1/2 systems:*

  Stern-Gerlach experiment for the existence of spin Quantum Mechanics of two-level systems

- *Spherically symmetric potentials:*

  Schrodinger equation for spherically symmetric potentials, Orbital angular momentum and spherical harmonics, Hydrogen atom problem and three dimensional harmonic oscillator;

- *Symmetries and conservation laws:*

  What is a symmetry, Wigner's theorem, Continuous transformations, Rotation, Euclidean and Galilean groups, Transformations and invariances;

- *Angular momentum theory in Quantum Mechanics:*

  Orbital and spin angular momenta, Raising and lowering operators, Addition of angular momenta, Clebsch-Gordon coefficients, Schwinger oscillator model, Spherical tensors and Wigner-Eckart Theorem, Spin-orbit coupling,

- *Exactly solvable models:*

  Charged particle in a magnetic field, Landau levels, Quantum Hall e ect;

- *Time-independent perturbation theory:*

  Non-degenerate and degenerate cases, An-harmonic oscillator, Van der Waal's force, Dipole interactions for spin-1/2 systems, Stark e ect, Zeemann e ect;

- *Time-dependent perturbation theory:*

  Approximate solution of Schrodinger equation, Sinusoidal perturbation of two-level system: resonance phenomenon, Coupling with states of continuous spectrum, Fermi's golden rule, Interaction of atom with electromagnetic wave,

Textbooks:

1. C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics*, Vols. I and II, Wiley, 1970.
2. J. J. Sakurai, *Modern Quantum Mechanics*, Addisson Wesley, 1995.
3. Leslie E. Ballentine, *Quantum Mechanics: A Modern Development*, World Scientific, 1998.

13) Classical Electromagnetism: (three hours classwork per week, **6 credits**)

1. *Electrostatics and Magneto-statics :*

   Mathematical preliminaries, boundary value problems using Green function techniques, special techniques for calculating potentials, electrostatics of dielectric media, magnetic vector potential and the gauge problem, Biot-Savart law, magnetic dipole moment and the Larmor precession, magnetic susceptibility and permeability, ferromagnetism;

2. *Maxwell Electrodynamics :*

   Motion of charges in external fields, electromagnetic waves in vacua and propagation through continuous media, gauge transformations, Lorentz covariant formulation of electrodynamics, energy-momentum of electromagnetic field and Poynting's theorem, Lagrangian and Hamiltonian formulation of electrodynamics;

3. *Radiation Theory :*

   Advanced and retarded Green functions, Lienard-Wiechert potentials, dipole radiation and Larmor's formula, spectral resolution and angular distribution of radiation from a relativistic point charge, synchrotron radiation, Rayleigh and Thomson scattering;

4. *Classical Electron Theory :*

   Radiation reaction, acausality and preacceleration, incompleteness of Maxwell electrodynamics;

Textbooks :

1. D. J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall, 1981.
2. L. Landau and E. Lifshitz, *The Classical Theory of Fields*, Pergamon, 1979.
3. J. D. Jackson, *Classical Electrodynamics*, Wiley Eastern, 1986.

14) Mathematical Methods I (three hours classwork per week, **6 credits**)

- *Linear Algebra:*

  Linear Vector spaces, Determinants & Matrices, Special matrices: orthogonal, hermitian, unitary, Eigenvalue problem: matrix diagonalization, Canonical Forms, Infinite-dimensional vector spaces: Hilbert space & Hermitian operators, Numerical solution of linear equations;

- *Complex Analysis:*

  Complex algebra, analytic functions, infinite sequences and series, tests of convergence, Weierstrass theorem, Taylor and Laurent series, classification of isolated singularities, poles & calculus of residues, contour integration, residue theorem and applications;

- *Di erential and Integral Equations:*

  Ordinary di erential equations, linear di erential equations up to second order, orthogonal polynomials and functions, Integral transforms: Laplace and Fourier transforms, partial di erential equations, classification of PDEs, Laplace and wave equations, boundary value problems, Special functions, Integral equations and Green functions, Ideas about nonlinear equations, Approximation methods: WKB approximation (at the level of Mathews-Walker);

Textbooks:

1. J Mathews and R L Walker, Mathematical Methods for Physicists, Benjamin, 1964;
2. G Arfken, Mathematical Methods for Physicists, Academic Press, 1995.

21) Quantum Mechanics II (four-and-half hours classwork per week, **9 credits**)

- *Quantum theory of identical particles:*

  Symmetrization of wave functions, Pauli's exclusion principle, Bosons and fermions, Spin-statistics theorem, Second quantization formalism, Quantum theory of many-electron atoms, Electron gas: application to solids;

- *Approximation methods:*

  WKB approximation, Variational methods, Absorption and stimulated emission of radiation;

- *Scattering theory:*

  Lipmann-Schwinger equation, Born approximation, Partial waves, The optical theorem, Determination of phase-shifts, Hard sphere scattering, Low energy scattering, Resonances;

- *Path integral approach to Quantum Mechanics:*

  Kernel of wave-packet evolution, Feynmann's approach, Examples of free particle and harmonic oscillator, Path-integral approach to spin systems, Aharonov-Bohm e ect, The adiabatic theorem, Berry's phase;

- *Relativistic Quantum Mechanics:*

  Dirac and Klein-Gordon equations and their solutions, Relativistic invariance, Space reflection and time reversal, Idea of spin, Helicity, Hydrogen atom, fine structure of spectral lines;

- *Phase-space description of Quantum Mechanics:*

  Coherent states, squeezed states and thermal states, Wigner's phase-space quasi-probability distribution, Glauber-Sudarshan's P-representation, Husimi distribution, Symplectic transformation and covariance matrix, Non-classical states of light;

- *Foundations of Quantum Mechanics:*

  Density operators formalism, Contradiction of Quantum Theory with local realism, The causality issue.

Textbooks:

1. C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics*, Vols. I and II, Wiley, 1970.
2. J. J. Sakurai, *Modern Quantum Mechanics*, Addisson Wesley, 1995.
3. Marlan O. Scully and M. Suhail Zubairy, *Quantum Optics*, Cambridge University Press, 1997.
4. W. Greiner, *Relativistic Quantum Mechanics: Wave Equations*, Springer, 1997.
5. Leslie E. Ballentine, *Quantum Mechanics: A Modern Development*, World Scientific, 1998.
6. S. D. Bjorken and J. D. Drell, *Relativistic Quantum Mechanics*, McGraw-Hill Science/Engineering/Math, 1998.

22) Classical Field Theory (three hours classwork per week, **6 credits**)

1. *Continuum Mechanics:*

   Coarse graining and continuum limit, The displacement field and strain tensor, The stress tensor and constitutive relations. Hooke's Law, The energy functional, Deformation of thin rods: Stretching, bending and torsion, Equations of motion. Elastic waves, Conservative systems, Lagrangian and Hamiltonian formalisms;

2. *Hydrodynamics:*

   The velocity and density fields. Continuity equation, Pascals Law and the stress tensor, Bernoullis principle, Euler equations. Gravity waves, Viscosity, Navier-Stokes equations. Boundary conditions, examples of flow, low Reynolds number flows, Stokes limit;

3. *Electrodynamics:*

   The electromagnetic field tensor and Bianchi identity, covariant charge density and current, action formalism for electrodynamics, Maxwell's equations and relativistic covariance, Wave solutions. Gauge invariance, Lagrangian and Hamiltonian formalism; [7 Lectures]

4. *Landau-Ginzburg theories:*

   Order parameter field, symmetry breaking, Noether theorem, mean-field theory, Gaussian fluctuations, Goldstone modes, generalized sti ness, topological defects, solitons, vortices, O(N) model, Abelian Higgs model (superconductivity);

5. *Gravitation:*

   Principle of equivalence, curvilinear coordinates, metric, connection, curvature tensor, energy-momentum tensor, Einstein equations;

Textbooks:

1. L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields*, Pergamon Press, 4th Edition, 1980.

2. G. Giachetta, L. Mangiarotti and G. Sardanashvily, *Advanced Classical Field Theory*, World Scientific, 2009.

23) Condensed Matter Physics I (four-and-half hours classwork per week, **9 credits**)

- *Introduction:*

  Length, time and energy scales in condensed matter, soft and hard condensed matter, examples of materials properties, bonding and interactions, van der Waals interaction, hydrogen bonding;

- *Condensed matter systems:*

  Crystals: Lattice, basis, 2-d and 3-d crystals, point and space groups, symmetries, experimental determination of structure, scattering, lattice with basis, Miller indices, structure factor, form factors, defects in crystals;

  Liquids and glasses, Liquid crystals, Polymers, Quasicrystals;

- *Electronic Properties:*

  Jhelium model: Single electron model, density of states, Fermi surface and quasiparticles;

  Thermodynamic properties: Review of thermodynamics, statistical mechanics of non-interacting electrons, Sommerfeld expansion, specific heat, magnetic susceptibility;

  Transport properties: Drude Model, electrical conductivity, thermal conductivity thermoelectric phenomena. Band theory;

  Electrons in periodic potentials, Bloch's theorem, Kronig-Penney model, Brillouin zones, nearly free and tightly bound electrons, Fermi surfaces, band theory, e ective mass, Wannier functions and tight binding, survey of the periodic table;

- *Lattice vibrations:*

  Cohesion of solids, mechanical properties, elasticity, constitutive relations;

  Modes of lattice vibrations. Quantization and phonons. Statistical mechanics of phonon gas, Einstein and Debye models, umklapp processes, thermal expansion, Kohn anomalies, charge-density waves;

  Electron phonon interactions;

- *Semiconductor Physics:*

  Introduction: Valence and conduction bands. Doping and the Fermi level;

  Band diagrams, metal interfaces, work functions, Schottky barrier, diodes and transistors;

  Nano-electronics: heterostructures, quantum wells, quantum wires and quantum dots;

- *Optical Properties:*

  Optical properties of metals, optical properties of semiconductors, direct and indirect band gaps, polarization, Clausius-Mosotti relation, polarons, point defects and color centres, metals at low frequencies, anomalous skin e ect, plasmons, Brillouin and Raman scattering;

- *Superfluidity and Superconductivity:*

  Superfluidity of Helium, BEC, Landau argument, two-fluid model, BEC in atomic gases, superconductivity, phenomenology including Meissner e ect, type-I and type-II superconductors;

- *Magnetism:*

  Atomic magnetism, Hunds rules, Curie's law, Pauli paramagnetism, Landau diamagnetism, quantum mechanics of interacting moments, Heisenberg model, spin waves;

Textbooks:

1. N. Ashcroft and N. Mermin, *Solid State Physics*, Holt, Rinehart and Winston, 1976.

24) Statistical Mechanics I (four-and-half hours classwork per week, **9 credits**)

1. *Fundamental principles :*

   Elements of probability theory, algebra and calculus of random variables, binomial, Poisson and Gaussian distributions, moments and cumulants of probability densities, the central limit theorem, the basic postulate of statistical mechanics, first discussion of ergodicity and mixing;

2. *Thermodynamics:*

   Macroscopic definition of thermodynamic variables, temperature, pressure, work and heat, the Carnot cycle and empirical definition of entropy, free energy and other thermodynamic potentials, convexity of entropy and thermodynamic potentials, thermodynamic potentials as Legendre transforms of the entropy, thermodynamic relations of Maxwell, Gibbs and Duhem, Clausius and Clapeyron, and Clausius and Mosotti, the third law of thermodynamics;

3. *The Gibbs distribution:*

   Gibbs definition of entropy, the Gibbs distribution as maximisation of entropy subject to constraints, connection with Legendre transforms, connection to thermodynamics, the three canonical distributions, the Maxwell-Boltzmann distribution, the probability distribution of a classical and quantum harmonic oscillator;

4. *Non-interacting systems I:*

   Classical ideal gas, the Boltzmann distribution and classical statistics, the counting approach to the Boltzmann distribution, free energy and equation of state of the ideal gas, the law of equipartition, ideal gases with internal degrees of freedom, diatomic and polyatomic gases, the magnetism of an ideal gas;

5. *Non-interacting systems II:*

   Fermi distribution, Bose distribution, counting approach to Fermi and Bose distributions, Fermi and Bose gases of elementary particles, the degenerate electron gas, the specific heat of the degenerate electron gas, magnetism of an electron gas, the degenerate Bose gas, black body radiation;

6. *Non-interacting systems III:*

   Solids at high temperature and the Dulong-Petit law, solids at low temperatures and Einstein's theory of specific heat, the Debye interpolation formula, thermal expansion of solids;

7. *Interacting systems I :*

   Deviations of gases from ideality, van der Waals equation, the conditions of phase equilibrium, the Clausius-Clapeyron equation, the critical point, law of corresponding states, virial and cluster expansions, the method of correlation functions, the Ornstein-Zernike relation;

Textbooks:

1. L. D. Landau and E. M. Lifshitz, *Statistical Physics*, 3rd Edition, Butterworth-Heinmann, 1980.

2. H. B. Callen, *Thermodynamics and an Introduction to Thermo-statistics*, 2nd Edition, Wiley, 1985.

3. D. Chandler, *Introduction to Modern Statistical Mechanics*, Oxford Univ. Press, 1987.

4. M. Plischke and B. Bergersen, *Equilibrium Statistical Mechanics*, World Scientific, 1994.

5. R. K. Pathria, *Statistical Mechanics*, Butterworth-Heinmann, 1996.

6. M. Kardar, *Statistical Mechanics of Particles*, Cambridge Univ. Press, 2007.

7. F. Reif, *Fundamentals of Statistical and Thermal Physics*, Waveland Pr. Inc., 2008.

31) Quantum Field Theory I (four-and-half hours classwork per week, **9 credits**)

First two-third portion of the course is meant for all students, while a bifurcation is made at the end of this for separately orienting students towards HEP and LEP, during the remaining one-third portion of the course. Thus the common section has 32 lectures, the other two parts have 16 to 18 lectures.

1. *QFT I part I:*

   (Common to all students. Knowledge of Relativistic Quantum Mechanics, *i.e.*, Dirac equation and KG equation is expected. Some basic notions of the Lorentz group and Poincare group are also expected)

   - *Elements of Classical Field theory:*
     Lagrangian and Hamiltonian densities, quantization of KG and Dirac and electromagnetic fields, propagators for KG, Dirac and vector (photons) ;
   - *Perturbation theory:*
     Wick's theorem and Wick expansion, Feynman diagrams, cross sections and S matrix. Feynman rules for scalars, spinors and gauge fields (Abelian) ;
   - *Elementary processes in QED:*
     electron positron annihilation, Compton scattering, Bhabha scattering, crossing symmetry etc. ;
   - *Radiative corrections for scalar theory:*
     loop corrections, regularization and renormalization, dimensional regularization. elementary ideas of the systematics of renormalization ;
   - *Functional method techniques:*
     Scalar field theory quantization (with, if time permits, some discussion of critical phenomena in this approach) ;
     The last two lectures below while not relativistic QFT is included because i would be useful for HEP students too and hence is placed in the common section
   - *Non-interacting electrons:*
     Tight binding models, the many body ground state, quasi-particle and quasi-hole excitations. Partially filled bands and Fermi surface kinematics ;

2. *QFT 1 part II:* (For HEP students)

   - *LSZ formalism:*
     one loop diagrams in QED, Ward Takahashi identities, regularization in QED ;
   - *Path integral/Functional method*
     Quantization in spinor and vector (gauge) theories ;
   - *Systematics of renormalization:*
     Power counting, idea of counter terms, structure of one loop and beyond in scalar and QED. (no explicit 2 loop calculations etc.) ;

3. *QFT I part III:* (Many Body Theory for Condensed Matter/LEP students)

   - *Second quantization in operator formalism (non-relativistic):*
     Diagrammatic perturbation theory, Retarded Greens functions, Spectral function, quasi-particle lifetimes, Angle resolved photoemission spectroscopy (ARPES) ;
   - *Linear response theory and Kubo formulae ;*
   - *Interacting bosons:*
     Symmetry breaking, semi-classical spectrum. Applications to cold atoms and superfluids ;
   - *Mean field theory:*
     BCS hamiltonian and superconductivity ;
   - *Magnetism:*
     Heisenberg models. Spin waves. Coherent states and path integrals for spin systems. Non-linear sigma models ;

Part II and part III will run concurrently, however, to allow the more enterprising and interested students to attend both parts (if they so wish), lectures for these two parts are intended to be arranged at non-overlapping times.

Textbooks:

1. M. E. Peskin and D. V. Schroyder, *Quantum Field Theory*, Sarat Book House, 2005.
2. G. D. Mahan, *Many-Particle Physics*, Springer, 2010.

32) Mathematical Methods II (three hours classwork per week, **6 credits**)

- *Numerical interpolation techniques (including Lagrange method)*
- *Advanced Complex Analysis:*

  Analytic continuation, branch cuts, Multivalued functions, Riemann surfaces, Conformal Mapping, Method of steepest descent;
- *Group theory:*

  Discrete and continuous groups;
- *Numerical methods:*

  Numerical solution of integrals, Numerical solution of ODEs, Numerical solution of PDEs: finite di erence Monte Carlo method (especially solving integrals), Spectral techniques (including FFT) Numerical minimization techniques;
- *Probability and statistics:*

  Brief survey of probability theory and statistical distributions, Bayesian probability Data analysis;

Textbooks:

1. C. M. Bender and S. A. Orszag, *Advanced Mathematical Methods for Scientists and Engineers: Asymptotic Methods and Perturbation Theory* (vol. 1), Springer, 1999.
2. T. W. Gamelin, *Complex Analysis*, Springer, 2001.
3. E. T. Jaynes and G. L. Bretthorst, *Probability Theory: The Logic of Science* (vol. 1), Cambridge Univ. Press, 2003.
4. M. Tinkham, *Group Theory and Quantum Mechanics*, Dover, 2003.
5. R. Gilmore, *Lie Groups, Lie Algebras, and Some of Their Applications*, Dover, 2006.
6. J. H. Mathews and R. W. Howell, *Complex Analysis for Mathematics and Engineers*, Jones and Bartlett, 2006.
7. N. G. Van Kampen, *Stochastic Process in Physics and Chemistry*, 3rd Edition, North Holland, 2007.

33) Statistical Mechanics II (four-and-half hours classwork per week, **9 credits**)

- *Introduction to critical phenomena:*

  Survey of experimental results, scaling hypothesis and empirical scaling relations, self-similarity and fractals;

- *Interacting systems:*

  Critical phenomena and continuous phase transitions, symmetry and the order parameter, Landau theory, introduction to the Ising model, Curie-Weiss mean field theory, the absence of phase transitions in one dimension;

- *Criticality in spin systems:*

  The Ising model in one dimensions, solution using transfer matrices, the lack of phase transitions in one dimensions, the Landau-Peirls argument. The Ising model in two dimensions, Wannier's calculation of the critical temperature, mean field solutions of the Ising model, survey of principle results of Onsager's exact solution;

- *Criticality in classical field theories:*

  Landau-Ginzburg theory, the Landau-Ginzburg functional as an e ective Hamiltonian, calculation of correlation functions, exponents and thermodynamic quantities, mean field and RPA closures, the problem of divergences;

- *Introduction to the renormalisation group:*

  Historical survey, integration of short-wavelength degrees of freedom, classification of fixed points, flow equations, illustration with Kadano block spins in the 1d Ising model;

- *perturbative renormalisation in momentum space:*

  Philosophy of the perturbative RG scheme, significance of the upper critical dimension, diagrammatic expansion in momentum space, the expansion, exponents and thermodynamic quantities in powers of , comparison with mean field approximations;

- *Non-perturbative renormalisation in real space:*

  Kadano block spins, techniques of approximate non-perturbative renormalisation, numerical renormalisation in the Ising model;

- *Broken Symmetry:*

  Continuous symmetry groups and e ective Hamiltonians, the consequences of broken symmetry, Goldstone modes and fluctuations, elastic variables, topological defects, fluctuation destruction of long-range order, the Mermin-Wagner and Landau-Peirles arguments, the disclination and dislocation unbinding transitions;

- *Disorder:*

  Disorder in physical systems, quenched and annealed disorder, the Parisi solution for quenched disorder, illustrative examples;

- *Dynamics of fluctuations:*

  Linear response in physical systems, the regression of fluctuations and Onsager's hypothesis, symmetry of kinetic coefficients, the Fokker-Planck and Langevin descriptions of fluctuations, the fluctuation-dissipation theorem;

Textbooks:

1. L. D. Landau and E. M. Lifshitz, *Statistical Physics*, 3rd Edition, Butterworth-Heinmann, 1980.
2. H. E. Stanley, *Introduction to Phase Transitions and Critical Phenomena*, Oxford Univ. Press, 1987.
3. D. Chandler, *Introduction to Modern Statistical Mechanics*, Oxford Univ. Press, 1987.
4. M. Plischke and B. Bergersen, *Equilibrium Statistical Mechanics*, World Scientific, 1994.
5. R. K. Pathria, *Statistical Mechanics*, Butterworth-Heinmann, 1996.
6. S.-k. Ma, *Modern Theory of Critical Phenomena*, Westview Press, 2000.
7. P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics*, Cambridge Univ. Press, 2000.

34) Particle Physics I (three hours classwork per week, **6 credits**)

Standard Model, Part I:

- *Symmetries and Quarks*:

  Discrete symmetries, isospin-SU(2), G-parity, SU(3)-classification of mesons and baryons, mass formula, magnetic moments, motivation for colour as an internal symmetry;

- *Scattering Processes*:

  Relativistic kinematics, phase space, lifetimes and cross-sections, Golden rule; scattering of a spinless charged particle by electromagnetic field, scattering of electrons by electromagnetic field, e μ scattering, Moller scattering, electron-proton scattering and form factors, higher order corrections, vacuum polarization, charge renormalization, Lamb shift, g 2;

- *Parton Model and QCD*:

  Deep inelastic scattering (DIS) of electrons on nucleons, structure functions and scale invariance, parton model; quantum chromodynamics: Lagrangian, symmetries;

Standard Model, Part II:

- *Early Developments*:

  Beta-decay, μ-decay, parity violation, V A theory of weak interactions, conserved vector current (CVC) hypothesis;

- Strange particle decay, mixing of neutral K-mesons, Cabibbo theory, current-current interaction, PCAC and current algebra;

- *CP Problem*:

  C,P,T transformations, CP violation;

- *Electro-Weak Unified Theory*:

  Spontaneous symmetry breaking, Higgs mechanism, $SU(2) \times U(1)$ theory, electroweak unification, neutral current phenomena, W,Z bosons;

- *Current Phenomenology*:

  New flavours, KM-matrix and associated phenomenology, neutrinos, masses and mixing, neutrino oscillations.

Textbooks:

1. T. D. Lee, *Particle Physics and Field Theory*, Harwood, 1981.

2. F. Halzen, A.D. Martin, *Quarks and Leptons*, Wiley, 1984.

41) Quantum Field Theory II (four-and-half hours classwork per week, **9 credits**)

- *Functional Methods in Quantum Field Theory*:

  Quantization of the Klein-Gordon and Dirac fields and their interactions, derivation of the Feynman rules of covariant perturbation theory, quantization of the Maxwell field, issues of gauge fixing, BRST invariance and QED Ward identities;

- *Functional Integral Quantization of Non-abelian Gauge fields*:

  Faddeev-Popov method of gauge fixing, BRST invariance and Slavnov-Taylor identities, Gribov ambiguities, loop computations in non-abelian gauge theories and renormalizability;

- *Renormalization Group and its Applications*:

  The Gell-Mann, Low and Wilson approaches to the renormalization group, Callan-Symanzik equations and fixed points of the beta function, asymptotic freedom of non-abelian gauge theories, applications to perturbative QCD;

- *Anomalies in Abelian and Non-abelian Gauge Theories*:

  The axial vector anomaly in QED and its implications, non-abelian anomalies, anomaly freedom vs renormalizability and unitarity, Fujikawa's approach to anomalies;

- *Topological Solutions*:

  Soliton solutions and their implications, Polyakov-'t Hooft magnetic monopole and the BPS limit, instantons and tunneling in quantum field theory;

Textbooks:

1. S. Coleman, *Aspects of Symmetry*, Cambridge University Press, 1985.
2. R. Rajaraman, *Solitons and Instantons*, Elsevier, 1986.
3. M. Peskin and D. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley, New York, 1995.
4. S. Weinberg, *Quantum Theory of Fields*, Vols. I and II, Cambridge University Press, 1996.

42a) Cosmology and Gravitation (four-and-half hours classwork per week, **9 credits**)

- Principle of relativity, principle of equivalence, tensors, tensor calculus on Riemannian manifolds, symmetries of Riemannian manifolds, hypersurfaces, extrinsic curvatures, Gauss-Codazzi equations;
- *Einstein's field equations:*

  Newtonian limit, tests of general relativity, gravitational radiation;
- *Solutions of Einstein's equations :*

  Schwarzschild solution, Kerr solution, black holes;
- Tetrad formulation of gravity, generalizations to arbitrary dimensions;
- *Hamiltonian formulation :*

  For metric gravity, for tetrad formulation, canonical quantization and path integral quantization;
- Cosmology : Robertson-Walker model, early universe;
- Singularity theorems;

Textbooks:

1. S. Weinberg, *Gravitation and Cosmology*, Wiley, 1972.
2. R. Wald, *General Relativity*, Chicago, 1987.

42b) Particle Physics II (four-and-half hours classwork per week, **9 credits**)

- *Basic Ingredients of the Standard Model*:

  Yang-Mills fields, Higgs mechanism, asymptotic freedom;

- *Electroweak Sector*:

  Weinberg-Salam Model, phenomenological consequences, families and flavours, anomaly cancellations, radiative corrections and precession tests;

- *Quantum Chromodynamics (QCD)*:

  Lagrangian, perturbative QCD, Altarelli-Parisi equations, nonperturbative QCD and colour confinement models, strong CP problem, chiral perturbation theory, heavy quark e ective theory, Skyrme model;

- *Neutrino Physics*:

  Solar neutrinos, double beta decay, neutrino masses and mixing models;

- *CP Violation*:

  CP violation in $K \quad \bar{K}$ system, $B \quad \bar{B}$ system, models of CP violation;

- *Supersymmetry*:

  Hierarchy problem, construction of the supersymmetric standard model, search for SUSY signals;

- *Other Approaches beyond the Standard Model*:

  Grand unified theories;

Textbooks:

1. T Cheng and L. Li, *Gauge Theory of Elementary Particles*, Oxford University Press, 1984.

43) Advanced Condensed Matter Physics (four-and-half hours classwork per week, **9 credits**)

- *Correlated Electron Physics:* Second quantization review, Hubbard model, Heisenberg model;

  Materials phenomenology, magnetic phases, CDW states;

  Quantum magnetism, Stoner criterion, double exchange;

  Superconductivity, Cooper argument, BCS, gap equation, Bogoliubov-de Gennes equations, strong coupling theory, RVB and modern approaches to superconductivity in correlated systems;

  Quantum Hall e ect, integer and fractional, edge states, Laughlin and Jain wave functions, topological defects; Luttinger liquids, Bethe ansatz;

  Mesoscopic physics;

  Disordered electronic systems and metal insulator transitions;

- *Soft Condensed Matter Physics* Interactions in soft matter, entropic interactions, fluctuation-induced interactions, hard sphere statistical mechanics and crystallization;

  Self-assembly of amphiphiles, phases, theoretical approaches;

  Colloids, self-assembly, the freezing transition;

  Polymers, polymer structure, self-avoidance, Edwards model, osmotic pressure, Flory-Huggins theory, screening, semi-flexibility, persistence length;

  Membranes, biological membranes, lipid bilayers, physical properties, de Gennes-Taupin length, tethered membranes;

  Liquid crystals, nematic, cholesteric and smectic, order parameters, Frank free energy, Landau-de Gennes model defects, defect phases;

  Survey of hydrodynamics, hydrodynamic approaches to soft matter physics, dynamical properties of polymers, membranes, colloids;

  Soft matter away from equilibrium, shear-induced phases;

  Optional: Granular media and Glasses;

Textbooks: For Strongly Correlated Systems:-

1. M. P. Marder, *Condensed Matter Physics*, Wiley-Interscience, 2000.
2. A. Altland and B. Simons, *Condensed Matter Field Theory*, Cambridge University Press, 2006.
3. G. D. Mahan, *Many-Particle Physics*, Springer, 2010.

For Soft Condensed Matter:-

1. P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics*, 1st Edition, Cambridge University Press, 2000.

44a) Quantum Information and Computation (four-and-half hours classwork per week, **9 credits**)

- *Resume of Quantum Mechanics:*

  Composite quantum systems and tensor product Hilbert spaces, Subsystems and density operators, From Schrödinger to Liouville evolution; completely positive maps as quantum channels; From projective measurements to POVMs; State estimation;

- *Entanglement and its applications:*

  EPR argument and Bell inequalities; Separability vs. entanglement; Positive unphysical maps witnessing entanglement; Partial transpose criterion for checking separability; Other entanglement detection criteria; Multi-partite entanglement; Quantum teleportation, dense coding, entanglement swapping;

- *Connection with Shannon information theory:*

  Shannon's noiseless coding theorem and Schumacher's quantum counterpart; Accessible information and Holevo's bound; Shannon's noisy channel coding theorem and HSW theorem; Quantum channel capacities; Decoherence and quantum error correction;

- *Measures of entanglement:*

  Thermodynamic considerations of entanglement under LOCC; Entanglement concentration and dilution; Several measures of entanglement; Majorization;

- *Quantum Cryptography:*

  Basics of classical cryptography; RSA cryptosystem; Quantum key distribution; Security of quantum key distribution;

- *Entanglement in continuous variable systems:*

  Gaussian states; Role of Wingner description and symplectic transformations; Quantum information processing with continuous variable systems;

- *Quantum computation:*

  Classical and quantum computers; Circuit complexity; One- and two-qubit gates; Universality of gates; Deutsch-Jozsa algorithm; Grover's search algorithm; Quantum Fourier transform and Shor's factorization algorithm;

- *Implementations:*

  Quantum key distribution experiments; Unconditional quantum teleportation using continuous variable systems; Implementations of quantum computers using NMR, trapped ions, Josephson junctions, linear optical devices, etc.;

Recommended readings:

1. *Quantum Computation and Information*, Michael A. Nielsen and Issac L. Chuang (Cambridge University Press, 2000);
2. John Preskill's Lectures on Quantum Information and Computation, available at: http://theory.caltech.edu/people/preskill/ph229/♯lecture;
3. David Mermin's Lectures on Quantum Computation, available at: http://people.ccmr.cornell.edu/ mermin/qcomp/CS483.html;
4. *The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation*, Dik Bouwmeester, Artur Ekert, Anton Zeilinger (eds.) (Springer, 2000);
5. *Elements of Information Theory*, Thomas M. Cover and Joy A. Thomas (John Wiley & Sons, 1999);
6. Contemporary review articles available at:- http://xxx.imsc.res.in/archive/quant-ph

44b) Nonlinear Dynamics (four-and-half hours classwork per week, **9 credits**)

- *Hamiltonian formulation*:

  Iterative maps, fixed points, Lyapunov exponents, Integrable systems, Perturbed integrable systems, Poincaré-Birkho construction (illustration with driven pendulum);

- *Deterministic Nonlinear Dynamics*:

  Discrete dynamics and maps, di erentiable dynamics: dissipative systems, non-dissipative systems, Hamiltonian systems;

- *Integrability Aspects of Hamiltonian Dynamics*:

  Liouville-Arnold theorem, KAM theory;

- *Chaos*:

  In discrete dynamical systems, in Hamiltonian systems, in dissipative systems;

- *Semiclassical Analysis*:

  Berry-Tabor theory, Gutzwiller Theory;

- *Quantum Aspects.*

Textbook:

1. M. Tabor, *Chaos and Integrability in Nonlinear Dynamics*, Wiley, 1989.
2. M. C. Gutzwiller, *Chaos in Classical and QUantum Mechanics*, Springer, 1990.
3. I. Percival and D. Richards, *Introduction to Dynamics*, Cambridge, 1991.
4. L. Reichl, *A Modern Course in Statistical Physics*, Wiley, 1998.
5. S.H. Strogatz, *Nonlinear dynamics and Chaos: Applications to Physics, Biology, Chemistry and Engineering*, Cambridge, 2001.
6. M. Lakshmanan and S. Rajasekar, *Nonlinear Dynamics*, Springer, 2003.
7. L. Reichl, *The transition to Chaos*, Springer, 2004.

44c) Statistical Field Theory (four-and-half hours classwork per week, **9 credits**)

- Review of quantum statistical mechanics, functional integration representation of partition function, scalar field, charged scalars and Bose-Einstein condensation, Fermions, interactions and diagrammatic techniques, self-coupled scalar field theory, Yukawa theory, QED, renormalization and loop corrections to $\ln Z$.
- Spontaneous symmetry breaking and Higgs model QCD, deconfinement phase transitions.
- Salem-Weinberg model and symmetry restoration, early universe, nuclear matter and pion condensates, neutron stars.

Textbook:

1. P. Kapusta, *Finite Temperature Field Theory*, Cambridge University Press, 1989.

BACK TO MAIN

Courses of Study

INTEGRATED Ph.D. in PHYSICAL SCIENCES

(DUAL DEGREE)

(PROGRAM CODE: PHYS05)

SCHOOL OF PHYSICAL SCIENCES

National Institute of Science Education and Research Bhubaneswar

(An Off-Campus Center
Of
Homi Bhabha National Institute – a deemed to be University, Anushkati Nagar, Mumbai)

With effect from the Academic Year 2018

School of Physical Sciences Ph. D course structure (60 credits)

Core courses				
Sl. No	Course code	Course title/Description	Contact hours/week (Lectures + Tutorial + Lab)	Credits
Courses in odd semester				
1	P601	Classical Mechanics	3+1+0	6
2	P602	Mathematical Methods	3+1+0	6
3	P603	Electromagnetism	3+1+0	6
4	P698	Self Study/Mini project/credit seminar (One part of this will involve attending lectures of an elective course)		12
Courses in even semester				
5	P614	Statistical Mechanics	3+1+0	6
6	P615	Quantum Mechanics	3+1+0	6
7		Any elective course from list below	3+1+0	6
8	P699	Mini Project		12

Elective courses				
Sl. No	Course code	Course title/Description	Contact hours/week (Lectures + Tutorial + Lab)	Credits
1	P648	Nuclei and Particle Physics	3+1+0	6
2	P649	Atoms Molecules and Radiation	3+1+0	6
3	P650	Introduction to Condensed Matter Physics	3+1+0	6
4	P651	Advanced Solid State Physics	3+1+0	6
5	P652	Computational Physics	3+1+0	6
6	P653	Quantum Field Theory I	3+1+0	6
7	P654	Particle Physics	3+1+0	6

8	P655	Introduction to Phase transitions and Critical phenomena	3+1+0	6
9	P656	Nonlinear Optics and Lasers	3+1+0	6
10	P657	General Relativity and Cosmology	3+1+0	6
11	P658	Soft Condensed Matter	3+1+0	6
12	P659	Applied Nuclear Physics	3+1+0	6
13	P660	Many Particle Physics	3+1+0	6
14	P661	Physics of Mesoscopic Systems	3+1+0	6
15	P662	Introduction to Quantum Optics	3+1+0	6
16	P663	Astronomy and Astrophysics	3+1+0	6
17	P664	Plasma Physics and Magnetohydrodynamics	3+1+0	6
18	P665	Biophysics	3+1+0	6
19	P666	Quantum Nanoelectronics	3+1+0	6
20	P667	Nonlinear Physics, Chaos and Turbulence	3+1+0	6
21	P668	Magnetism and Superconductivity	3+1+0	6
22	P669	Density Functional Theory of Atoms, Molecules and Solids	3+1+0	6
23	P670	Quantum Field Theory II	3+1+0	6
24	P671	Quantum Information and Quantum computation	3+1+0	6
25	P672	Experimental High Energy Physics	3+1+0	6
26	P673	Experimental Techniques	3+1+0	6
27	P674	Introduction to Cosmology	3+1+0	6

Syllabus for Ph. D courses

1 Core courses

P601: Classical Mechanics

1. Generalized coordinates, velocities and momenta, Lagranges formulation
2. Principle of least action, formulation by Maupertuis, Euler, Hamilton. Liouville's theorem
3. Two-body central force problem (reduced mass), planet orbits, Virial theorem
4. Collisions and scattering, CM and Lab frames, scattering cross section
5. Motion in non-inertial frames, Coriolis force
6. Hamilton's equations, Poisson brackets
7. Canonical transformations, Hamilton-Jacobi equation, Generating functions, Symmetries and conservation laws
8. Small oscillations, Normal modes.
9. Rigid body dynamics, Euler angles, Euler equations, rotation of a top
10. Special topics : nonlinear oscillators, non-linear dynamics, Lyapunov exponents, Introduction to chaos.

References:

1. Classical Mechanics, H. Goldstein
2. Mecanics - Landau and Lifshitz
3. Classical Mechanics - John R Taylor
4. Classical dynamics of particles and systems - Marion and Thornton
5. Introduction to dynamics - Percival and Richards

P602: Mathematical Methods

1. Vectors and Tensors (index notation, vector analysis in curvilinear coordinates, Cartersian tensors and four vectors, General tensors)
2. Review of Linear Algebra with emphasis on applications to physical problems (linear transformations + Matrix representations, Eigenvalues, Eigenvectors, Inner product spaces
3. Review of complex analysis with applications (Cauchy-Riemann equations, Complex integration, Cauchy theorems, Contour integration, Branch points and branch cuts, Applications to integrals, series etc)
4. Hilbert space methods, special functions (Hilbert space, Orthonormal series expansions in Hilbert space especially Fourier series, Special functions)
5. Ordinary and Partial differential equations (Analysis of second order OFEs Sturm-Liouville system, Boundary value problems for Laplace, Diffusion(Heat) and wave equations)
6. Integral Transforms, its applications and Generalized functions (Laplace and Fourier transform, Dirac delta and other generalized functions, Greens functions of ODE and PDE)
7. Group theory (introduction using various groups occurring in physics, its algebra, Representation of groups, Characters)

References:

1. Mathematical Methods in the Physical Sciences, M. L. Boas
2. Mathematical Methods for Physicists, Arfken and Weber
3. Mathematical methods, C. Harper
4. Mathematical method for physicists, T. L. Chow
5. Mathematical methods in science and engineering (2books) - Seluk Bayin
6. Mathematical Methods in Physics and Engineering :Riley, Hobson
7. Mathematical Physics I and II: S.D. Joglekar
8. Mathematical Methods for Engineers and Physicists (3 books) -K. T. Tang
9. Graduate Mathematical Physics - James J. Kelly
10. Mathematical Methods In Classical And Quantum Physics : Tulsi Dass

P603: Electromagnetism

1. Electrostatics in vacuum, force, field, potentials and energy
2. Electrostatic boundary conditions and conductors
3. Solution of Laplace's equation in one, two and three dimensions, uniqueness theorem, methods of images, separation of variables, multipole expansion
4. Dielectrics
5. Current distributions, magnetic fields and magnetostatic boundary conditions
6. Motion of charges in electric and magnetic fields, energy and momentum of electromagnetic fields
7. Maxwell's equations, EM waves and their propagation in free space and in media
8. Potential formulation, Coulomb and Lorentz gauge, radiation from an accelerated charge, dipole radiation Special topics : Diffraction theory, polarization.

References:

1. Introduction to electrodynamics - David Griffiths
2. Foundations of electromagnetic theory - Reitz, Milford, Christy
3. Classical electrodynamics - J. D. Jackson
4. Electricity and Magnetism - M. H. Nayfeh, M. K. Brussel

P614: Statistical Mechanics

1. Review of thermodynamics, thermodynamic potentials, thermodynamic equilibrium and stability
2. Probability theory: Probability densities, cumulants and correlations, central limit theorem, laws of large numbers
3. Gibbs distribution : Ensembles, classical and quantum free particles, systems with continuous and discrete spectrum, degenerate Fermi systems, Bose condensation
4. Interacting systems: Cluster and Virial expansions, radial distribution function
5. Introduction to response, fluctuation and noise, Einstein formula
6. Phase transition : phenomenology of first order and continuous phase transitions, order parameters, 1D Ising model, universality and scaling, Ginzburg- Landau- Wilson theory, spontaneous symmetry breaking
7. Fundamentals of statistical mechanics: phase space, Liouville theorem, statistical distribution theorem
8. Brownian motion, Langevin equation, Markov processes and Fokker Planck equation

References:

1. Introduction to Statistical Mechanics - Kerson Huang
2. Statistical Physics - Reif
3. Statistical Physics of particles - M. Kardar
4. Introduction to Phase transitions and critical phenomena - H. E. Stanley

P615: Quantum Mechanics

1. Hilbert space (states, operators, evolution)
2. Review of one dimensional problems, delta and periodic potentials, Bound states vs scattering states, Simple harmonic oscillator
3. The central force problem, review of the hydrogen atom, hard and soft sphere
4. Angular momentum, rotation operators and the rotation group, spin, spherical harmmonics, addition of angular momentum.
5. Symmetries in quantum mechanics
6. Introduction to path integrals
7. Time independent perturbation theory, WKB approximation, variational method, Zeeman and Stark effects
8. Identical particles and exchange statistics
9. Time dependent perturbation theory, Heisenberg and interaction representations, Rabi Oscillations
10. Basic aspects of scattering theory : Born approximation and partial waves and phase shifts

    Special topics: Dirac equation/semi classical theory of radiation/geometric phase (a subset of these topics depending on available time)

References:

1. Principles of Quantum Mechanics - R. Shankar
2. Quantum Mechanics I and II - Cohen-Tannoudji, Diu and Laloe
3. Modern Quantum Mechanics - J. J. Sakurai
4. Introduction to Quantum Mechanics - David Griffiths
5. Quantum Physics - S. Gasiorowicz
6. Quantum Mechanics - E. Merzbacher
7. Quantum Mechanics - Bransden and Joachain
8. Introductory Quantum Mechanics - R. Liboff

2 Elective Courses

P648: Nuclei and Particle Physics

1. Nuclear systematics and stability (masses, sizes, spins, magnetic moments, quadrupole moments, energetics and stability against particle emission, beta decay).
2. Nucleon-Nucleon interaction, space-time symmetries, conservation laws, isospin symmetry, low energy (effective range, shape independence, meson exchange picture (qualitative).
3. Liquid drop model, compound nucleus and fission, nuclear vibrations and rotations.
4. Shell model, introduction to Hartree-Fock, spins and magnetic moments.
5. Direct nuclear reactions.
6. Mesons and baryons, resonances, SU(3) classification, isospin and strangeness, quark model, colour.
7. Weak interactions (nuclear and particle decays, neutrinos etc).

References:

1. Introduction to Nuclear Physics - Roy and Nigam
2. Nuclear Physics - Preston and Bhaduri
3. Introduction to particle physics - Griffith
4. Introduction to particle physics - Perkins

P649: Atoms, Molecules and Radiation

1. Hydrogen atom including l.s coupling and hyperfine interaction.
2. Helium atom introduction to exchange and correlation; variational calculation of ground and excited-states.
3. Introduction to the idea of effective potentials for electrons in many-electron atoms (Hartree theory and idea of self-consistency); use of Clementi-Roetti wave-functions.
4. One-electron atomic systems in an electromagnetic field; dipole approximation and associated selection rules; Stark and Zeeman effect (Note: Instructor will have to introduce the students to time-dependent perturbation theory here).
5. Einsteins A and B coefficients, population inversion, laser action, derivation of A and B coefficients from semi-classical treatment of light-atom interaction.
6. Molecular formation: Discussion of atom-atom interaction, van der Waals force, ionic interaction and covalent bond.
7. Molecular structure: Hydrogen molecule MO and VB pictures; Importance of correlations.
8. Molecular spectra (restricted to two atom molecules) electronic, rotational and vibrational.
9. Some lectures left for interesting current topics.

References:

1. Elementary Atomic Structure - G.K. Woodgate
2. Atomic Physics: C.J. Foot
3. Atoms, molecules and Photons: W. Demtroder
4. The Theory of Atomic Spectra: Condon and Shortley
5. Topics in Atomic Physics: C.E. Butkhardt and J.L. Leventhal
6. Physics of Atoms and Molecules - B.H. Bransden and C.J. Joachain

P650: Introduction to Condensed Matter Physics

1. General introduction, Drude and Sommerfeld model.
2. Crystal structure; x-ray diffraction.
3. Cohesive energy.
4. Blochs theorem; Band theory nearly free electrons; tight binding approximation; semi-classical dynamics of electrons in a band, definition of metals and insulators.
5. Basic properties of Semiconductors.
6. Thermal properties of insulators, phonons.
7. Landau levels - de Hass van Alphen effect and Integer quantum hall effect.
8. Introduction to Magnetism.
9. Introduction to Superconductivity.

References:

1. Introduction to Solid-state Physics, C. Kittel
2. Solid-state physics, N. Ashcroft and N.D. Mermin,
3. Solid-state physics, Rosenberg
4. Solid sate physics, Burn
5. Oxford Series in Condensed Matter [Oxford university press]

P651: Advanced Solid State Physics

1. Introduction to physics of metals and insulators. Electrical, thermal and optical properties of metals and insulators, and need to study excitation spectrum in detail.
2. Electrons, phonons and Magnons, Screening and Plasma Oscillations
3. Charge impurity in a metal: Friedel Oscillation, Magnetic impurity in a metal,
4. moment formation and suppression in metals.
5. Electron gas in Low dimension: impurity and interaction effects.
6. Quantum Hall Effect
7. Metal-Insulator transition
8. Electron - phonon interaction, Frohlich Hamiltonian and Superconductivity.

References:

1. Advanced Solid State Physics: Philip Phillips
2. Elementary Excitations in Solids: D. Pines
3. Solid State Physics: Marder
4. Concepts in Solids: P.W. Anderson
5. Basic Notions in Condensed Matter: P.W. Anderson

P652: Computational Physics

1. Monte Carlo: Markov chain, Metropolis algorithm, Ising Model, Quantum Monte Carlo
2. Molecular Dynamics: Integration methods, extended ensembles, molecular systems
3. Variational methods for SchrodingerdEquation: Hartree and Hartee-Fock methods, Post HF methods
4. Density Functional Theory: Fundamental theorem, XC-potentials
5. Quantum Molecular dynamics: Carr-Parinello approach, hybrid QM/MM method
6. Computational methods for lattice field theories

References:

1. Computational Physics, Joseph Marie Thijssen, Cambridge University Press
2. An Introduction to Computational Physics, Tao Pang, Cambridge University Press
3. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids, Clarendon Press
4. D. P. Landau and K. Binder, A Guide to Monte Carlo Simulations in Statistical Physics, Cambridge University Press
5. M. Suzuki, editor, Quantum Monte Carlo Methods, Springer-Verlag
6. I. Prigogine and Stuart A. Rice, New Methods in Computational Quantum Mechanics, Wiley.
7. D. Frankel and B. Smit, Understanding Molecular Simulation, second edition, Academic Press.
8. Computational Methods in Field Theory, H. Gausterer and C.B. Lang, Ed.s, Lecture Notes in Physics 409
9. R. G. Parr and W. Yang, Density Functional theory of atoms and molecules
10. F. Jensen, Introduction to Computational Chemistry
11. C. J. Crammer, Essentials of computational chemistry

P653: Quantum Field Theory I

1. Relativistic quantum mechanics - Klein-Gordon equation, Dirac equation, free-particle solutions
2. Lagrangian formulation of Klein-Gordon, Dirac and Maxwell eqns, Symmetries (Noethers theorem), Gauge field, Actions
3. Canonical quantization of scalar and Dirac fields
4. Interacting fields - Heisenberg picture, perturbation theory, Wicks theorem, Feynman diagram
5. Cross-section and S-matrix
6. Quantization of gauge field, gauge fixing
7. QED and QED processes
8. Radiative corrections - self-energy, vacuum polarization, vertex correction
9. LSZ and optical theorem
10. Introduction to renormalization

References:

1. An Introduction to Quantum Field Theory - Peskin and Schroeder
2. Quantum Field theory: K. Huang
3. Quantum Field Theory: Mandl and Shaw
4. Quantum Field Theory: Itzykson and Zuber

P654: Particle Physics

1. Elementary particles, discrete symmetries and conservation laws.
2. Symmetries and Quarks.
3. Klein-Gordon equation, concept of antiparticle.
4. Lorentz symmetry and scalar / vector / spinor fields.
5. Dirac equation
6. Scattering processes of spin-1/2 particles (Feynmans rules as thumb rule QFT course), propagators.
7. Current-current interactions, weak interaction, Fermi theory.
8. Gauge symmetries, spontaneous symmetry breaking, Higgs mechanism
9. Electroweak interaction, Glashow-Salam-Weinberg model.
10. Intoduction to QCD, structure of hadrons (form factors, structure functions), parton model, Deep inelastic sattering.

References:

1. Quarks and Leptons: An Introductory Course in Modern Particle Physics - Francis Halzen, Alan D. Martin
2. Introduction to Elementary Particles, David Griffiths
3. An Introduction to Quantum Field Theory - Peskin and Schroeder

P655: Introduction to Phase transitions and Critical phenomena

Experimental evidences of classical and quantum critical phenomena, thermodynamic potentials. heat capacity, magnetic susceptibility, phases, phenomenol-ogy of 1st order phase transitions, continuous transitions, order parameters and models: Ising, XY, Heisenberg, uni-versality and scaling, Ginzburg-Landau-Wilson theory, spontaneous symmetry breaking. Bose-Einstein condensation,expansion around upper critical dimension, domain walls and surface tension, 1D Ising model and instantons, critical behavior, critical exponents, relations between critical exponents, Kadanoff scaling, universality conjecture, calculation of critical exponents: real space RG methods, Phi- 4 theory, 4- epsilon expansion.?RG of Wilson and Fisher, contin-uous symmetry: Mermin-Wagner theorem. Goldstone modes, non-linear sigma-model, vortices, Kosterlitz-Thouless phase transition, topology and duality, surface roughening and Sine-Gordon models, quantum critical phenomena,dissipative quantum tunneling, quantum phase transitions, Bose-Hubbard model.

References:

1. Introduction to Phase Transitions and Critical Phenomena by H. Eugene Stanley
2. A Modern Approach to Critical Phenomena by Igor Herbut
3. Statistical Physics: Statics, Dynamics and Renormalization by Leo P. Kadanoff
4. The Theory of Critical Phenomena by J. J. Binney, A. J. Fisher, M. E. J. Newman
5. Modern Theory of Critical Phenomena by Shang-keng Ma
6. Statistical Mechanics of Phase Transitions by J. Yeomans
7. Field Theory, the Renormalisation Group and Critical Phenomena by Daniel J. Amit

P656: Nonlinear Optics and Lasers

Introduction to general lasers and their types, emission, absorption processes and rate equations, Population inver- sion, gain, optical cavities, three- and four- level lasers, CW and pulsed lasers, Q-switching and mode-locking, Physics of gas discharge, Atomic, Ionic, molecular, liquid, and excimer lasers, optical pumping, Holography, overview of non- linear Optics, nonlinear polarization, Nonlinear optical susceptibility, Symmetry considerations, Wave Propagation in nonlinear media, electro optical and magneto optical effects, higher harmonic generations, Phase matching and quasi phase matching, Sum and difference frequency generation, Optical parametric amplification and oscillation, Kerr ef- fect, Cross-Phase Modulation, Self phase modulation, Multiphoton Processes , Self focusing, Four-Wave Mixing, Laser Spectroscopy, wavefront conjugation Stimulated Raman Scattering, Stimulated Brillouin Scattering, Optical solitons and Optical Pulse Compression

References:

1. Lasers by P.W. Milonni and J.H. Eberly, John Wiley and Sons
2. Lasers by A. E. Siegman, University Science Books
3. Principles of Lasers by Orazio Svelto, Springer Verlag
4. The principles of nonlinear optics by Y. R. Shen, John Wiley and Sons
5. Nonlinear Optics by Robert W. Boyd, Academic Press
6. Nonlinear Optics: Basic Concepts by D.L. Mills, Springer Verlag
7. Optical waves in crystals by Amnon Yariv and Pochi Yeh, Wiley-Interscience
8. Laser Spectroscopy by Wolfgang Demtrder, Springer Verlag

P657: General Relativity and Cosmology

1. Review of Newtonian Mechanics. Special theory of relativity. Prelude to General relativity, historical developments
2. 4-Vectors and 4-tensors, examples from physics
3. Principle of Equivalence, Equations of motion, Gravitational force
4. Tensor Analysis in Riemannian space, Effects of Gravitation, Riemann-Christoffel curvature tensor, Ricci Tensor, Curvature Scalar
5. Einstein Field Equations, Experimental tests of GT
6. Scwartzchild Solution, Gravitational lensing
7. Gravitational waves: generation and detection
8. Energy, momentum and angular momentum in Gravitation
9. Cosmological principle, Robertson-Walker metric, Redshifts
10. Big-Bang Hypothesis, CMB.
11. Issues in Quantum Gravity

References:

1. A first course in General Relativity- B. Schutz
2. Gravity: HJ. Hartle
3. The Classical Theory of Fields: Landau and Lifshitz
4. Gravitation and Cosmology: S. Weinberg
5. Introducing Einstein's Relativity: D'Inverno

P658: Soft Condensed Matter

1. Prerequisite: Introduction to condensed Matter Physics, Statistical Physics
2. What is Soft Condensed Matter: forces, energies and time scales.
3. Phase transition in soft matter, Radial distribution function and description of liquids.
4. Colloids Polymers Gels Liquid Crystals
5. Soft matter in nature

References:

1. Chaikin Lubensky Condensed Matter Physics
2. D. Goldstein: States of Matter
3. Chandler: Statistical Physics (OUP 1987)
4. R A L Jones: Soft Condensed Matter (O U P 2002)
5. Soft Matter Physics: Daoud and Williams (Springer 1999)

P659: Applied Nuclear Physics

1. Basis of Nuclear Structure and reactions
2. Radioactivity and radioactive decays
3. Passage of charged particle through matter
4. Detectors and Accelerators
5. Applications: Effects of radiation on biological systems and nuclear medicine, Industrial applications
6. Power from fission and fusion: Characteristics of fission, Nuclear reactors, Thermonuclear fusion

References:

1. Nuclear Physics : Principles and Applications, John Lilley
2. The Atomic Nucleus, R. D. Evans
3. Fundamentals of Nuclear Reactor Physics, Elmer Lewis, Academic Press
4. An introduction to the passage of energetic particles through matter, N. J. Caron
5. Accelerator Physics, Shyh-Yuan Lee, World Scientific

P660: Many Particle Physics

1. Prerequisite: Statistical Physics, Quantum Mechanics, Introduction to Condensed Matter Physics
2. Second Quantization, One and two body operators
3. Observables and their relationship to one and two body Greens functions
4. Thermodynamic potential, Spectral functions, Analytic properties of Green's functions
5. Linear Response, correlation function, sum rules
6. Canonical Transformation: Bogoliubov Valetin, Schrieffer Wolf, etc.
7. Equation of motion,
8. Diagrammatic Perturbation theory for Green function and thethermodynamic potential, Luttinger Ward Identities.
9. Mean field theory
10. Functional Integration Methods

References:

1. Lifshitz Pitaeviski (Landau Lifshitz Stat Phys Part II)
2. Rickeyzen Greens function for condensed Matter
3. Doniach and Sondhaimer Greens function for condensed Matter
4. Fetter Walecka: Quantum Theory of Man body Particle systems:
5. Ben Simon: Many Particle Physics
6. Basic Notions in Condensed Matter: P.W. Anderson
7. Techniques and application of Path-integration Plan: S. Schulman

P661: Physics of Mesoscopic Systems

1. Prerequisite: Quantum Mechanics1; Statistical Mechanics; Introduction to Condensed Matter Physics
2. Effects of magnetic fields: The AharonovBohm effect; 2D electron gas; Landau levels; Transverse modes in 2D quantum wire; Shubnikovde Haas oscillations; Magnetic edge states; Integer Quantum Hall effect, Fractional Quantum Hall effect
3. Electron transport: Boltzmann semiclassical transport; Onsager reciprocity relations; Conventional Hall effect; Drude conductivity; Einstein relation; Electronic states in quantum confined systems; Conductance from transmission; Ballistic transport; Quantum of conductance; Landauer formula; Quantum point contact; T .matrices; Smatrix and Green functions; Current operator; LandauerButtiker formalism; Linear response and Kubo formula; Nonequilibrium Green's function approach to transport; Scattering: BreitWigner resonance and Fano resonance; Delay time for resonances; Friedel sum rule; Levinson.s theorem; Singleelectron tunneling: Coulomb blockade and Kondo effect
4. Quantum Information: Josephson Junctions and Cubits; Metastable states and escape dynamics
5. Disordered conductors: Weak localization; Mesoscopic fluctuations; Random Matrices; Anderson localization; Quantum Chaos; Dephasing; Decoherence

References:

1. Electronic Transport in Mesoscopic Systems, S. Datta, Cambridge University press.
2. Introduction to Mesoscopic Physics, Y. Imry, Oxford University Press.
3. Mesoscopic Electronics in Solid State Nanostructures, T. Heinzel, WileyVCH.
4. Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations, P. Mello and N. kumar, Oxford University Press.

P662: Introduction to Quantum Optics

1. Prerequisite: Quantum Mechanics I & 2; Electromagnetism I
2. Electro-magnetic field quantization: Quantum fluctuation and Quadrature operators of a single mode field, Thermal fields, Vacuum fluctuation and zero point energy, Quantum phase
3. Coherent and squeezed states of radiation field: Properties and phase space picture of coherent state, Generation of a coherent state, Squeezed state physics, Generation and Detection of squeezed light, Schrodinger cat states, Multi-mode squeezing, Broadband squeezed light, Squeezing via non-linear process
4. Atom-field interaction: Rabi model (Semi-classical model for atom-field interaction), Jaynes-Cummings model (fully quantum mechanical model for atom-field interaction), Dressed states, Density operator approach, Hanle effect, Coherent trapping, electromagnetically induced transparency, Four wave mixing
5. Quantum coherence function: Photon detection and quantum coherence functions, First order coherence and Young.s type double source experiment, Second order coherence, Physics of Hanbury-Brown-Twiss effect, Experiments with single photon, Quantum mechanics of beam splitter, Interferometry with single photon
6. Optical test of quantum mechanics: Photon sources: spontaneous parametric down-conversion, Hong-Ou-Mandel Interferometer, Superluminal tunneling of photons, EPR paradox and optical test of Bell.s theorem
7. Atom Optics: Mechanical effects of light, Laser cooling, Atom interferometry, Atoms in cavity, Experimental realization of Jaynes-Cummings model
8. Heisenberg-limited interferometry and quantum information: Entanglement and interferometric measurements, Quantum teleportation, Quantum cryptography, An optical realization of some quantum gates.

References:

1. Introductory Quantum Optics, C. C. Gerry and P. L. Knight, Cambridge University Press
2. Quantum Optics, M. O. Scully and M. S. Zubairy, Cambridge University Press
3. Quantum Optics, M. Fox, Oxford Master series in Atomic, Optical and Laser physics
4. Quantum Theory of Light, R. Loudon, Oxford science publication

P663: Astronomy and Astrophysics

1. Introduction and Tools :
   Tools - astronomical objects, scales, distance ladder, astrometry, magnitude scale
   Gravity - Keplers law, Virial theorem
   Radiation physics - radiative flux, transfer function, absorption, scattering and emission
2. Stars:
   Stars and stellar structures - stellar spectra, HR diagram
   Equilibrium in stars
   Star formation and Protostars
   Stellar evolution
   Supernovae
   black holes and gravitational waves
3. Interstellar medium
4. Galaxies
   The Milky way Galaxy - distribution of matter, differential rotation, formation of the spiral arms Elliptical and Spiral Galaxies
   Evidence for dark matter Active Galaxies - Active Galactic Nuclei, Seyfert Galaxies, Quasars, Blazers
5. Magnetic fields
   Astrophysical phenomena where magnetic fields are critical
   Galactic magnetic fields - dust and synchrotron polarization, Faraday rotation, Zeeman measurements
6. Gravitational Lensing (optional)
7. Clusters and Superclusters (optional)
8. Cosmology (optional)
   Cosmological Observations and the Cosmological Principle
   Newtonian Cosmology and Cosmological Models
   Cosmic Microwave Background

References/Textbooks: *References*:

1. Fundamental Astronomy - H. Karttunen, P. Krger, H. Oja, M. Poutanen, K. J. Donner
2. Introduction to Modern Astrophysics - B. W. Carroll and D. A. Ostlie
3. An invitation to Astrophysics - T. Padmanabhan

4. Astrophysical Concepts - Martin Harwit
5. Introductory Astronomy and Astrophysics - Zelike and Gregory
6. Universe - Roger Freedman
7. Physical Universe - F. Shu
8. Astrophysics Processes - Hale Bradt
9. Radiative processes in Astrophysics - Rybicki and Lightman
10. An introduction to Astronomy and Astrophysics - Pankaj Jain
11. Quasars and Active Galactic Nuclei - Kembhavi and Narlikar

P664: Plasma Physics and Magnetohydrodynamics

Introduction to plasmas, applications: in fusion, space and astrophysics, semiconductor etching, microwave generation: characterization of the plasma state, Debye shielding, plasma and cyclotron frequencies, collision rates and mean-free paths, atomic processes, adiabatic invariance, orbit theory, magnetic confinement of single-charged particles, two-fluid description, magneto hydrodynamic waves and instabilities, heat flow, diffusion, kinetic description, and Landau damping, ideal magnetohydrodynamic (MHD) equilibrium, MHD energy principle, ideal and resistive MHD stability, drift-kinetic equation, collisions, classical and neoclassical transport, drift waves and low-frequency instabilities, high-frequency micro instabilities, and quasilinear theory.

References:

1. Plasma Physics by Peter Andrew Sturrock
2. Principles of Magnetohydrodynamics by J. P. Hans Goedbloed , Stefaan Poedts
3. Hydrodynamic and Hydromagnetic Stability by S. Chandrasekhar
4. The Physics of Plasmas by T. J. M. Boyd, J. J. Sanderson
5. Fundamentals of Plasma Physics by Paul M. Bellan,
6. Introduction to Plasma Physics by R.J Goldston , P.H Rutherford
7. An Introduction to Magnetohydrodynamics by P. A. Davidson
8. An Introduction to Plasma Astrophysics and Magnetohydrodynamics by M. Goossens

P665: Biophysics

Under development.

P666: Quantum Nanoelectronics

Introduction and Review of Electronic Technology, From Electronics to Nanoelectronics: particles, waves and Schrodinger Equation, Quantum Description of atoms and molecules Quantum Description of metals, semiconductors, junction devices, Some newer building blocks for nanoelectronic devices, Fabrication and Characterization Methods for nanoelectronics, The field effect transistor FET: size limits and alternative forms, Devices based on electron tunneling, resonant tunnel diodes, Single electron transistors, molecular electronics, hybrid electronics, Devices based on electron spin and ferromagnetism, Qubits vs. binary bits in a Quantum Computer, Applications of nanoelectronic technology to energy issues, Summary and brief comment on the future of nanoelectronic techniques

References:

1. Quantum Nanoelectronics: An Introduction to Electronic Nanotechnology and Quantum Computing by Edward L. Wolf
2. Quantum Electronics - by Amnon Yariv
3. Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience - by Edward L. Wolf
4. Fundamentals of Nanoelectronics - by George Hanson
5. Introduction to Nanoelectronics: Science, Nanotechnology, Engineering and Applications - by Vladimir Mitin, Viatcheslav A. Kochelap, Michael A. Stroscio

P667: Nonlinear Physics, Chaos, Turbulence

1. General introduction and motivation : examples of linearity and nonlinearity in physics and the other sciences; modelling systems using iterated maps or differential equations, nonautonomous systems
2. General features of dynamical systems : Systems of differential equations with examples; control parameters; fixed points and their stability; phase space; linear stability analysis; numerical methods for nonlinear systems; properties of limit cycles; nonlinear oscillators and their applications; the impossibility of chaos in the phase plane; bifurcations: their classification and physical examples; spatial systems, pattern formation and the Turing mechanism; strange attractors and chaotic behaviour.
3. The logistic map: Linear and quadratic maps; graphical analysis of the logistic map; linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; chaotic behaviour and the determination of the Lyapunov exponent; universality and the Feigenbaum numbers; other examples of iterated maps.
4. Hamiltonian Sysytems: Phase space; Constants of motion and integrable Hamiltonians; Nonintegrable systems, the KAM theorem and period-doubling; applications.
5. Fractal geometry: dimension of an object, Mandelbrot set, Julia set, iterated function systems.
6. Spatio-temporal dynamics: Spatio-temporal chaos
7. Quantum Chaos: Quantum analogies to Chaotic behaviour, Correaltions in wave functions, chaos and semiclassical approaches to Quantum mechanics

References:

1. S. H. Strogatz, Nonlinear Dynamics and Chaos: With Applications in Physics, Biology, Chemistry and Engineering.
2. Robert C. Hilborn, Chaos and Nonlinear Dynamics.
3. Brian Davies, Exploring Chaos: Theory and Experiment.
4. K. T. Alligood, T. D. Sauer and J. A. Yorke, Chaos: An Introduction to Dynamical Systems.
5. Edward Ott, Chaos in Dynamical Systems.
6. 6. M.Tabor, Chaos and Integrability in Nonlinear Dynamics: An Introduction.

P668: Magnetism and Superconductivity

1. Prerequisite: Solid State Physics, Quantum Mechanics, Statistical Physics
2. Review of atomic/ionic magnetism.
3. Diamagnetism Paramagnetism Ferromagnetism characteristics, Occurrence.
4. Orbital magnetism, de Haas van Alfen effect.
5. Heisenberg Model: Ground state, Spin waves.
6. Hubbard Model and Itinerant exchange.
7. Magnetic domains and hysteresis.
8. The phenomenon of Superconductivity: historical perspective, characteristics, occurrence.
9. London Equations, Thermodynamics, Meissner Effect.
10. Ginzburg Landau Theory, Abrikosov Vortices.
11. Josephson Effect.
12. Cooper Instability, BCS wave function, Gap equation, thermodynamics and magnetic response.
13. Conventional and non-conventional superconductors.

References:

1. Solid State Physics, Neil W. Ashcroft and N. David Mermin
2. Interacting Electrons and Quantum Magnetism , A. Auerbach
3. Magnetism D.C. Mattis
4. Magnetism: R.M. White
5. Superconductivity - Schrieffer
6. Superconductivity - de Gennes
7. Superconductivity - Tinkham

P669: Density Functional Theory of Atoms, Molecules and Solids

Many-body problem: QM of electrons and nuclei, approximation methods for many electron systems, Born-Oppenheimer approximation, Hartree and HF theory, tight binding method, greens functions, electron correlation, CI & many-body and Moller-Plesset theory, complete active space methods, coupled cluster theory, density matrices, time-dependent approach to all the above formalism

Foundations of Density Functional Theory(DFT): Hohenberg-Kohn (HK) theorem, degenerate ground states, variational DFT, $N-$ and $v-$ representability problem, Levy-Lieb constrained search, fractional particle number & derivative discontinuity, spin polarized systems, Exited states part I: Effective Single Particle Picture: Kohn-Sham (KS) construction, non-interacting $v-$ representability, degenerate KS DFT, KS equations for spin polarized systems, interpretation of KS eigenvalues

Exchange-Correlation (XC) Energy Functional: exact exchange formalism within DFT, exact representations of the energy functional, LDA, GGA, meta-GGA, weighted density approximation, self interaction correction (SIC), virial theorems, exact exchange formalism (OPM, KLI, HS), where DFT goes wrong, strengths of DFT, strong correlation: DFT+U, RPA, GW, DFPT, DMFT, orbital free DFT, DFT-hybrid

Crossover to Excited-States: time-dependent DFT: Runge-Gross theorem, time-dependent KS equations, adiabatic LDA & TD XC potentials, linear response TDDFT, Excited states part II, spin polarized TDDFT, frequency dependent XC kernel, TDCDFT, TDOEP, relativistic DFT, molecular orbital theories

References:

1. Density Functional Theory of Atoms and Molecules by Robert G. Parr, Weitao Yang
2. Density functional Theory by R.M. Dreizler, E.K.U. Gross
3. Density Functional Theory by Eberhard Engel
4. Primer in Density Functional Theory by C. Fiolhais, F. Nogueira, Miguel A.L. Marques
5. Fundamentals of TDDFT by Miguel A.L. Marques et al.
6. Time-dependent Density Functional Theory by Miguel A.L. Marques et al.
7. Time-dependent Density Functional Theory by Carsten Ullrich
8. Quantal Density Functional Theory I & II by Viraht Shani

9. Recent Advances in Density Functional Methods (Part I, II & III) by Delano P Chong
10. Atomic and Electronic Structure of Solids - by Ethimios Kaxiras
11. Electronic Structure: basic theory and practical methods by Richard M. Martin
12. Many-Body Quantum Theory in Condensed Matter Physics by H. Bruus, K. Flensberg
13. Quantum Theory of the Electron Liquid by Gabriele Giuliani, Giovanni Vignale
14. Molecular Electronic Structure Theory by T.U. Helgaker, P. Jorgensen, and J. Olsen
15. Electronic Structure Calculations for Solids and Molecules by J. Kohanoff
16. Methods of Electronic Structure Calculations by M. Springborg
17. Self Consistent Fields in Atoms by Norman March
18. Computational Materials Science by J. G. Lee
19. Density Functional Theory in Quantum Chemistry by Takao Tsuneda
20. Material Modeling using DFT by Feliciano Giustino

P670: Quantum Field Theory II

1. Path-integral formulation of quantum mechanics
2. Path-integral for scalar fields, generating functional, connected Greens functions, Feynman rules, 1 loop diagrams
3. Grassmann variable, path-integral for Dirac field
4. Path-integral for Electromagnetic field, gauge fixing
5. QED, symmetries and Ward identity
6. Renormalization divergences and power counting, 4 theory, QED, spontaneous symmetry breaking, Renormalization Group basics (running of coupling).
7. Yang-Mills theory, gauge fixing and ghosts, BRST, asymptotic freedom

P671: Quantum Information and Quantum computation

1. Introduction to Classical information: Shannon entropy, Mutual Information
2. Quantum Information I: Hilbert space, density matrices, quantum entropy and Holevo bound
3. Quantum Information II: Entanglement, Teleportation, super dense coding and Bell inequalities
4. Quantum dynamics:Two level systems, decoherence and Rabi oscillations
5. Quantum computation: single qubit gates-phase, swap, Hadamard; two qubit gates-CNOT
6. Quantum algorithms: Deutsch, Grover, Introduction to Shor's algorithm
7. Quantum error correction
8. Applications: Quantum simulation and Adiabatic quantum computation
9. Solid state quantum information and computation: Introduction to entanglement in nanostructures, quantum computation with superconducting devices and topological quantum computation.

References:

1. V. Vedral, Introduction to Quantum Information Science (Oxford U. Press)
2. Nielsen and Chuang, Quantum Information and Computation (Cambridge U. Press)
3. Kaye, Laflamme, Mosca, An Introduction to quantum computing. (Oxford U. press)

P672: Experimental High Energy Physics

The interaction of high-energy particles with matter: specific applications related to EHEP.

1. Relativistic kinematics: Detailed derivation of kinematic variables and their transformations whenever needed. Decay kinematics. Rapidity, pseudo-rapidity, spacelike and time-like. Some examples where relativistic kinematics play important role for understanding of data.
2. Detectors in High Energy Physics: General concept of building a HEP experiment, coverage and options, Gas detectors; Semiconductor detector; Scintillator and Cerenkov detectors Specific to EHEP, Calorimeter and Preshower detectors: principle of electromagnetic and hadronic shower generation.
3. Detector Simulation: Need of simulation, various techniques, MC, some general Concepts.
4. Data Analysis in HEP: General approach of data cleanup, calibration, track reconstruction, reconstruction of events
5. Error analysis in EHEP.
6. Computing in EHEP: Basics of OO programming using C++, few applications in EHEPdata analysis.

References:

1. Relativistic Kinematics; A guide to the kinematic problems of High Energy Physics: R. Hagedorn
2. The Experimental Foundations of Particle Physics: R. N. Cahn, G. Goldhaber
3. Techniques for Nuclear and Particle Physics experiments: A How to Approach: W.R. Leo (Springer)
4. Experimental Techniques in Hugh Energy Nuclear and Particle physics: T. Ferbel (World Scientific)
5. Introduction to Experimental Particle Physics : R.C. Fernow
6. Data Reduction and Error analysis for the physical sciences: P. Bevington and D. K.Robinson
7. Data Analysis Techniques for High Energy Physics: R. Frunwirth, M. Regler, R. K. Bock and H. Grote

P673: Experimental Techniques

1. Mechanical drawing and designs: Basics tools: hand tools, machines for making holes, the lathe, milling machines, grinders, casting; Mechanical drawing, drawing tools, basic principles of mechanical drawing, dimensions, tolerances, from design to working drawings
2. Vacuum technology: gases, gas flow, pressure and flow measurement, vacuum pumps, pumping mechanisms, ultrahigh vacuum, leak detection
3. Optical systems: optical components, optical materials, optical sources Charge particle optics: electrostatic lenses, charged-particle sources, energy and mass analyzer
4. Detectors: optical detectors, photoemission detectors, particle and ionizing radiation detectors, signal to noise ration detection, surface barrier detector.
5. Particle detectors and radioactive Decay: Interactions of charged particles and photons with matter; gaseous ionization detectors, scintillation counter, solid state detectors
6. Electronics: electronic noise, survey of analog and digital I/Cs, signal processing, data acquisition and control systems, data analysis evaluation
7. Nano- and micro-fabrication: various lithography techniques such as photolithography, nanoimprint lithography, e-beam lithography, ion-ball milling
8. Some experiments: SEM, TEM, X-ray diffraction, SQUID Magnetometry, Magnetotransport, PL/CL time resolved spectroscopy, Rutherford Backscattering spectrometry (RBS), RBS-Channeling, UV-VIS-IR spectrometry.

References:

1. The art of Measurement, by Bernhard Kramer, VCH publication
2. Building Scientific apparatus by J. H. Moore et al.
3. Experiments in Modern Physics, Second Edition by Adrian C. Melissinos, Jim Napolitano
4. The art of experimental Physics by Daryl W. Preston,
5. Vacuum Technology, A. Roth North-Holland Publisher
6. Charge Particle Beams, by Stanley Humphries, John Wiley and Sons
7. Principles of charged Particles Acceleration, by Stanley Humphries, John Wiley and Sons
8. Radiation detection and Measurements, G. Knoll, 3rd Edition
9. Techniques for Nuclear and particles physics experiments, W. R. Leo, 2nd edition, Springer

P674: Introduction to Cosmology

1. The cosmic history and inventory.
2. A sketch of General Relativity.
3. The expanding Universe
4. Friedmann Equations and Cosmological Models
5. The Standard cosmological model.
6. The inflationary Universe.
7. Primordial nucleosynthesis and the thermal history of the Universe.
8. Perturbations in an expanding Universe.
9. Growth of perturbations
10. Dark Matter Halos.
11. Statistical description of gravitational clustering
12. Special Topics:
    Fluctuations in the CMB, Lensing, Cluster Cosmology, The Lyman-Alpha Forest, Reionization, Halo Model, Redshift Space Distortions.

References:

1. Introducing Einstein's General Relativity - Ray D'Inverno
2. The Early Universe - Kolb and Turner
3. Introduction to Cosmology - Barbara Ryden
4. Modern Cosmology - Scott Dodelson
5. Principles of Physical Cosmology - P.J.E. Peebles
6. Large Scale Structure of the Universe - P.J.E. Peebles
7. Structure Formation in the Universe - T. Padmanabhan

P675: Quark-Gluon-Plasma and Nucleus-Nucleus Collisions

1. Introduction to high energy heavy ion collisions and Quark-Gluon-Plasma, comparison of big bang and the little bang.
2. Thermodynamics:relativistic gas (hadrons, quarks and gluons) and its statistical and thermodynamical properties, MIT Bag model,Hagedorn gas, phase diagram of QCD.
3. Relativistic Kinematics: four vectors notation, rapidity variables, pseudorapidity varibales, light cone variables, relativistic invariants, Dalitz plot, cross sections .
4. Collision Dynamics: initial state of nuclear collisions, fluid dynamical evolution, kinetic transport model, freeze-out and particle production.
5. Experiments: a general overview of different experimental setup related to search for QGP and relevant observables.
6. Signatures of QGP: collective flow, J/Ψ suppression, strangeness enhancement, jet quenching, electromagnetic probes, Hanbury-Brown-Twiss measurement.
7. Recent progresses.

References:

1. Hadrons and QGP by Letterssier and Rafelski
2. Introduction to High Energy Heavy Ion Collissions by C. Y. Wong.
3. Phenomenology of Ultra Relativistic Heavy Ion Collissions by W Florkowski.
4. Ultrarelativistic heavy ion collisions by R. Vogt.
5. Introduction to relativistic heavy ion collisions, by L. P. Csernai.
6. A Short Course On Relativistic Heavy Ion Collission by A. K. Chaudhuri.
7. Extreme states of matter in strong interaction physics by Helmut Satz.
8. Relativistic Hydrodynamics by L. Rezzolla and O. Zanotti.
9. Finite Temperature Field Theory by J. I. Kapusta and C. Gale.
10. The Early Universe by Kolb and Turner.
11. Fantastic Realities by Frank Wilczek.

Syllabus for Diploma in Medical Radioisotope Techniques (DMRIT)

(PROGRAM CODE: HLTH07)

Scheme

Paper 1 - Basic Sciences for Nuclear Medicine – 100 marks

Paper II - Radiation Physics, Radiation Biology & Radiation Protection– 100 marks

Paper III - Diagnostic Radiopharmaceuticals & In-vitro Techniques – 100 marks

Paper IV- Instrumentation & Imaging Technology – 100 marks

Paper V - Clinical Nuclear Medicine Techniques – 100 marks

Basic Sciences for Nuclear Medicine - Paper 1

1. **Atomic structure & Periodic table** **2 Lectures**

Atom and sub atomic particles, Rutherford's atomic structure and its limitations, Bohr's atomic structure. Quantum numbers, Isotope, Isobar and Isotone, Periodic properties like atomic radius, ionic radius, Electro negativity, Ionisation potential, Electron affinity.

2. Introduction Human Anatomy and Physiology **10 Lectures**

Human Anatomy, Brief introductory anatomical features of: Cardiovascular system, Respiratory system, Alimentary system, Renal system, Central nervous system, Endocrine systems, Reproductive system, Musculoskeletal system. Haematology. Human Physiology and Pathophysiology.

3. General Cell Biology & Cellular Physiology **2 Lectures**

The basic structure of eukaryotic and prokaryotic cell and their internal environment. Cell wall, cell membranes. Functions of endoplasmic reticulum, mitochondria, Golgi complex, lysosomes. Transmembrane potential of mitochondria and its implications in transport and intramitochodrial localization of isonitrile compounds. Transport across cell membranes, Functional systems in the cells. Cell reproduction; Concept of Cell doubling time and its implication in Oncology.

4. Basic Electronics **8 Lectures**

Fundamentals of electricity and electronics, Coulombs law, Ohms law, Ohmic & non ohmic devices, Kirchhoff's law, regulated power supply, Semiconductor physics, PN junction diode, LED, Rectifiers, Transistors (PNP & NPN), Feedbacks, Operational amplifiers, Oscillators, Binary, Octal, Hexadecimal number system, Logic circuits, CRO , ADC and DAC. Defibrillator circuit and uses.

5. Basic Mathematics **12 Lectures**

Numbering system, Accuracy and Precision, Significant figures, Matrices, Mathematical Constants. Linear and Polynomial Equations, Linear and Quadratic Equations and Identities, Slope, Roots, Relation between Roots and Coefficients. **Logarithms;** Definition, Laws of Logarithms, Rule for Change of Base, Common and Natural Logarithms, **Permutations and Combinations,** Probability, Factorials. **Calculus;** Relations and functions, Limits, Definition of Derivative, Physical Significance, Differentiation of Simple Functions, Differential Equations, integration and Summation, Definition of Trigonometric Functions, Identities.
Introduction to Mathematical Transformation: Fourier Transform, Laplace transform.

6. Chemistry relevant for radiopharmaceuticals **10 Lectures**

Concept of Bohr model, Hybridization with example of Methane, Ethylene and acetylene etc, Solvent strength, Acid base , pH, buffers, Titrations, Organic Chemistry, Resonance effect, Steric effect, Dielectric constant, various type of organic solvents, Mesomeric effect, determination of organic acid base strength and other organic phenomena utilizing the basic principle, various type of organic reactions, Nucleophilic Substitution reactions in details, Aromatic substitution reactions, ^{99m}Tc-chemistry, Core structures of various common ^{99m}Tc-radiopharmaceuticals, labelling techniques, importance of ^{99m}Tc-kit components, peptide chemistry with respect to ^{68}Ga/^{177}Lu-DOTATOC, DOTA-TATE etc. Principle of radionuclide choice for imaging and therapy with example of ^{68}Ga, ^{177}Lu, ^{90}Y, ^{18}F, ^{99m}Tc etc. Principle of TLC, HPLC with respect to radiochemical purity (RCP).

7. Introduction to Immunology: **4 Lectures**

Structure and function of immune system, Immune response – humoral and cell-mediated immune response – primary and secondary responses. Antigens, Antibodies, Structure of Antibodie's, Classification of antibodies, Antigen-antibody interaction, and Monoclonal antibodies. New generation antibodies. Implications in molecular imaging & therapy.

8. Basic Biochemistry and Molecular biology **10 Lectures**

Introduction to carbohydrates, Proteins, Nucleic acids, Enzymes, Lipids. Protein structure and protein 3-dimensional shape, Structure-function relationship, Proteins purification, Nature of enzyme catalyzed reactions, their regulation, inhibition and mechanisms. Structure and function of carbohydrates and their importance in central metabolism. Structures and nature of fatty acids and lipids found in biological membranes. Lipid Metabolism. Nucleic Acids and Biological Information Flow. Related Biochemical and molecular biology techniques. Aptamers with radiolabelled apatamers for Nuclear imaging and therapy.

9. Biostatistics **12 Lectures**

Basic Concepts: Probability, a Priori and posteriori Probabilities. Statistical significance of probabilities Sample and Population, Variables, Classification of Variables, Nominal, Ordinal, interval and Ratio, Fixed and Random, Population Distributions: Binomial distributions and Poisson distributions – their properties, parameters and applications. Normal and't' distributions – Population and Sample Parameters. Measures of central tendency, measures of dispersion, Variance, degrees of freedom, confidence limits and intervals. Probability of occurrence – use of Z and t tables. Sampling, Estimates and Hypothesis testing: Sampling methods, Random sampling and estimates of population parameters from samples. Sample statistics, Hypothesis testing. Drawing inferences and confidence limits. P values. Student's t test for comparing means. General and paired t tests. Special cases where Variances are unequal. Central Limit Theorem. Analysis of Variance- F- Distribution, Test for Homogeneity of Variance One Way ANOVA, Comparison of Means of Multiple Groups By Partitioning of the total Sum of Squares as within and between Sum of Squares, Assumptions in ANOVA, Missing Values, Two Way ANOVA; Design of Experiments. Correlation and Regression: Pearsons' Product Moment Correlation Coefficient, comparison of Correlation Coefficients, Partial and Multiple Correlation, Linear Regression Analysis. Interpretation of Regression Coefficients. Application of Correlation and Regression in Method Comparison and Evaluation. Nonparametric Statistics: Spearman's Coefficient of Rank Correlation, Chi Square Test. Nonparametric Methods for Hypothesis Testing Based on Ranks. Mann Whitney U Test, Wilcoxon Signed Rank test, T Test.

Clinical Statistics: Cohort Studies, Case Control Studies, Sample Size calculations, Clinical Trials, Meta analysis. Demonstration of application Software's in Statistics.

10. Introduction to Biology of cancer **2 Lectures**

Neoplastic processes. Inflammatory & Degenerative processes. Classification and nomenclature of neoplasms. Concept of Cell doubling time and its implication in Oncology; Warburg effect and its implications in metabolic imaging, Apoptotic pathway and role of Annexin V.

11. Basic Medical Terminology **2 Lectures**

Descriptive – describing shape, color, size, function, etc, and eponyms. Word root for eg. Myocarditis (prefix) (root) (suffix). Prefix change, Suffix change. -itis, -osis, -ectomy, -otomy, -ostomy, a/an -, micro -, macro -, mega -/ -megaly, -scopy/ -scopic with examples. Pathological Nomenclatures Specially For Tumours.

12. Introduction Common hospital practices **2 Lectures**

Pathogens, Disinfection methods, Sterilisation, Communicable diseases, Nosocomial infections, Hepatitis, HIV, Biohazards, Principles of asepsis - handling of contaminated swabs, used syringes and needles, Bio-waste management. Policies for management of Niddle stick injury/Exposure to blood or body fluids.

Radiation Physics, Radiation Biology & Radiation Protection - Paper -II

1. Origin & Types of Radiation **4 Lectures**

Fundamental constituents (quarks, leptons) and interactions of matter according to the "Standard Model", Properties of Nuclear Forces, Phenomenological Nucleon-Nucleon Potentials, Stability of nuclides - binding energy forces and nuclear forces, Spin, electric and magnetic moments, Experimental Nuclear Moments, Size, Parity and Isospin of Nuclei, Laws of radioactivity, Units of radioactivity. Decay modes, Stability of atom, Mass defect, Binding energy, The basis of radioactivity (N/Z ratio).Types of radioactivity depending on N/Z ratio Types of radiation (α[one body theory of alpha decay, microscopic theories of alpha decay], β[theory of beta decay; types of weak interaction; selection rules in beta decay; parity non conservation in beta decay], γ, X-ray, n). Theory of gamma decay, Experimental gamma ray transition rates: isomeric states; Vibrational motion (theory of Nuclear vibrations); Rotational motion (theory of Nuclear rotation); Interacting Boson models; Clustering (especially in context of alpha particles); Recent developments (qantum chromodynamics, perturbation theory, meson field theory and chiral perturbation theory), radionuclide chart, Laws of successive transformations, Theories of alpha, beta and positron emission; beta particle spectrum; K shell electron capture; Cerenkov radiation, characteristic radiation, Auger effect, Bremsstrahlung radiations, Metastable state and isomeric transition, internal conversion. Nuclear reactions, Nuclear reaction cross section, neutron activation with thermal neutrons, Nuclear isomerism, nuclear fission, fission products, nuclear reactors.

2. Interaction of radiation with matter **5 Lectures**

Gamma ray interactions - Excitation, ionization, photoelectric effect, Compton effect, pair production, annihilation radiations, specific ionization and linear energy transfer; Charged Particle interactions: range of charged particles, Interaction of neutrons with matter, Elastic scattering. Importance of these interactions in radiology and nuclear medicine.

3. Radiation Quantities and units **3 Lectures**

Exposure, Absorbed dose, Radiation weighting factor, Concept of radiation weighting factor W_R, Sievert, Equivalent dose, Concept of tissue weighting factor W_T, Effective dose, Committed equivalent dose, Committed effective dose, ICRP and AERB dose limits. Use of dose constraints for staff and comforter. Annual Limit of Intake and derived air concentration. Reference levels: Recording levels, Investigation levels and Action levels.

4. Gas filled detector **3 Lectures**

Theory of ionization chamber, design consideration in an ionization chamber, operating voltage, theory and construction of condenser type of chambers and thimble chambers; gas multiplication, pulse mode detector for single ionizing events, Proportional Counters - design and characteristics, Geiger-Mueller Counters - design consideration, dead time and recovery time, characteristics of organic and inorganic quenchers, operation.

5. Scintillation detectors – (Organic and inorganic) **3 Lectures**

Atomic basis of scintillation. Scintillation process. Dopants. Inorganic and Organic Scintillators, Comparison of properties by comparison of characteristics like stability, light output, decay time, intrinsic efficiency, dead time, considerations on fabrication and cost.

6. Gamma Ray Spectrometry **5 Lectures**

Construction of a Gamma Ray Spectrometer. Components of GRS. Detection principle – light collection, light guide, and Photomultiplier tubes. Coincidence & anti coincidence circuits. Single channel analyzer, multi channel analyzer. Study of gamma ray spectrum: photopeaks, Compton valley, edge and plateau, characteristic X-ray peak, backscatter peak, Iodine escape peak, annihilation peak, coincidence peak. Gamma ray spectrometer : calibration, energy resolution, integral & differential counting, linearity, counting efficiency.

7. Statistics of counting: **3 Lectures**

Poisson distribution, Poisson approximation to radioactive decay, measures of counting error. Accuracy and precision, standard error, counting in low background and high background scenarios, net count rates and standard deviation of count rates. Gaussian distribution and propagation of errors. Distribution of counting times to minimize errors.

8. Semiconductor detectors: **2 Lectures**

Semiconductors junction and surface barrier detectors, Diode detectors, Ge(Li) detectors, High Purity Germanium detectors, their response and characteristics, energy calibration and detector efficiencies, Cadmium-zinc-telluride detector. Room temperature semiconductor diodes. Advantages and disadvantages of semiconductor detectors.

9. Liquid Scintillation Counters **2 Lectures**

Composition of liquid scintillator, scintillation cocktail: primary solute, secondary solute and organic solvent (toluene, 1, 4 dioxane, anthracene) and solublizing agents for tissues, PM tubes, Coincidence circuits and count display systems. Quenching, Quench corrections methods: Internal standard method, external standard method and channel ratio. Discrimination of alpha, beta by liquid scintillations.

10. Radiation Biology **10 Lectures**

Radiolysis of water, interactions of free radicals, Direct versus indirect effects. Influence of LET, oxygen and various compounds on free radical forming reactions Target Theory, Multitarget theory, Target size, Multi hit theory, Multitarget multi hit theory.

Radiation effects on macromolecules, cell membrane, chromosomes. Chromosomal type aberrations. Radiation effects on cell division. Radiation effects on microorganisms and independent cell systems.

Differential cell sensitivity. Criteria of sensitivity, Factors affecting sensitivity. Anti-oxidative enzymes: Super Oxide dismutase, Catalase, Glutathione reductase, Glutathione -S-transferase, Monoamine oxygenase, Glutathione peroxidase.

Radiation effects on major organ systems: hematopoietic system, digestive system, reproductive system, nervous system. Effects of Ionizing Radiation on the Embryo and Fetus. Teratogenic and delayed effects.

Linear Energy Transfer, Relative biological effectiveness, Dose rate effect, chronic irradiation, factors influencing radiation response - oxygen concentration, Temperature etc.

Acute radiation effects: Lethality, Stochastic and Nonstochastic effects of radiation: Late effects in normal tissue systems and organs, Radiation carcinogenesis, genetic effect of radiation, radiation induced mutations, dose effect relationship, pre-natal effects of radiation, types of genetic disorders, risk estimation, direct method, doubling dose method, uncertainties. Basis for ICRP dose limits for occupational exposure, embryo / fetus, members of the public, risks associated with recommended limits, Biodosimetry, Bioassays, Extremity dosimetry. Low Dose Exposure to Ionizing Radiation: Medical, Natural background, Radon. Radiation Hormesis; BERT.

11. Personnel monitoring devices **4 Lectures**

Film badges, Ring badges, Thermoluminescent dosimeters (TLD's), Pocket dosimeters. Characteristics of TLD phosphors, Glow curves, dose and energy response, sensitivity and application in dosimetry and personnel monitoring devices. Other types of dosimeters - radiation calorimetry, photographic dosimetery, chemical dosimetry.

12. Radiation Protection: **6 Lectures**

Types of exposure: internal and external exposure, Routes of internal exposure Principles of radiation protection, time, distance, shielding. Exposure rate & shielding calculations by defining types of materials, and thickness needed using attenuation coefficients. Concept of Half value layer and tenth value layer. Work place monitoring: Radiation field, contamination and airborne radioactivity monitoring. AERB directive for derived working levels for radioactive contamination, airborne radioactivity and Radiation field. Radiation protection in diagnostic nuclear medicine, therapeutic nuclear medicine (with AERB directives for discharge of patients) and Medical cyclotron.

13. Radiation dosimetry **7 Lectures**

Metabolic pathways of radioisotope deposition, beta particle dosimetry; Equilibrium Dose rate equation. Gamma dose calculation, Specific gamma ray constant (Γ) and average geometrical factor. MIRD method of internal dose calculation, Absorbed Fraction and calculation of absorbed dose.

14. Transport of radioactive material **2 Lectures**

Classification of radioactive materials, general packing requirements, transport documents, Type of package, Transport Index, Category of package, approval requirements, TREMCARD.

15. Radiological emergency and preparedness **1 Lecture**

Major spillage, loss of radioactive source, Misadministration, Medical emergencies involving radioactive patients and Death of therapy in-patient. AERB directives to handle the cadaver. Radioactive decontamination.

16. Radioactive waste management **2 Lectures**

Philosophy of radioactive waste management, Management of solid waste, liquid waste and gaseous waste, Segregation, Collection and Safe disposal, Delay tank facility. Radioactive & Biohazardous Waste Disposal Methods - Decay in Storage, Separation by Half Life, Incineration, Sewer or Atmosphere. Airborne Radiation Exposure Measurements, Effluent Concentration (^{131}Iodine, ^{177}Lutetium, etc). AERB directives for safe disposal of radioactive waste. Concept of Exclusion, exemption and clearance of radionuclide in solid materials.

Diagnostic Radiopharmaceuticals & In-vitro Techniques - Paper III

1. **Radionuclides in Nuclear Medicine** **3 Lectures**

Radioactive decay, Physical Half-Life, Activity, Decay Constant, Mode of radioactive decay, Alpha particle decay, Beta particle decay, Gamma ray, Requirements for Radiotracers, Radionuclides used in Nuclear Medicine, Radionuclide Considerations, Type and Energy of Emissions, Specific Activity, Radionuclidic Purity, Chemical Properties, Economics, Production of radionuclides, Radiopharmaceuticals, Ideal radiopharmaceuticals, Important characteristics of a radionuclide to be used in imaging.

2. **Production of reactor & accelerator produced radionuclides** **5 Lectures**

Successive decay and radioactivity equilibrium, Equation for radionuclide production Reactors and charged particle accelerators. Nuclear reactors: neutron energy and neutron flux, neutron cross section, targets and specific activities, mathematical principles, general radiochemistry. Charged particle accelerators: physics of linear accelerator, Cyclotron, Synchro-cyclotron, Isochronous cyclotron. Medical cyclotron: threshold energy, nuclear cross section, q value, RF frequency, magnets, beam focusing and extraction, target design. Types and makes. Cyclotron produced radionuclides, cyclotron based generator.Chemical processing of reactor and accelerator targets; Separation techniques using precipitation, solvent extraction, distillation, gas evolution, ion exchangers; Structure of cation and anion exchangers; relative affinity of ions in exchangers; Use of exchangers in ion exchange columns; other column separation techniques.

3. **Compartmental Analysis** **4 Lectures**

Compartmental analysis and its applications in Nuclear Medicine, Assumptions in Compartmental model, Single compartment model, The Continuously stirred tank reactor (CSTR); Single Compartment model: The Charged Capacitor; Single Compartment model:

Discrete time analogues for two compartment systems; Occupancy theorem. Application of Differential equations, Open and closed models, Single compartment, two compartment and multicompartment models, reversible and irreversible exchanges, Mammary and Caternary models, Problems on radioactive generators, biological elimination processes of radiopharmaceuticals. Distributed Models.

4. **Generator produced Radionuclides** **5 Lectures**

Need for Generator, Advantages of generator system, Definition, Properties of Ideal Generator, Basic Principle, Principles of generator system, Parent Daughter Growth –Decay Relationship, Parent Daughter Equilibrium, Transient Equilibrium, Secular equilibrium. Various generator systems.

a) Gamma emitting radionuclidic generators: ^{99}Mo - ^{99m}Tc, ^{113}Sn – ^{113m}In, Special emphasis on ^{99}Mo - ^{99m}Tc generator: Production of parent, Decay Scheme, Characteristics of Daughter Radionuclide, Types of generators – column generator, solvent extraction generator, gel generator, sublimation generator, various generator suppliers, Applications of Daughter Radionuclide.

b) Beta emitting radionuclidic generators: ^{188}W -^{188}Re, ^{90}Sr - ^{90}Y, ^{194}Os - ^{194}Ir, ^{132}Te - ^{132}I. Production of parent, decay Scheme, characteristics of daughter radionuclides, generator suppliers, applications of daughter radionuclide.

c) Positron emitting radionuclidic generators: ^{68}Ge – ^{68}Ga, ^{82}Sr - ^{82}Rb : Production of parent, Decay Scheme, Characteristics of Daughter Radionuclide, Various generator suppliers, Applications of Daughter Radionuclide.

d) Alpha emitting radionuclidic generators and Complex Systems: ^{225}Ac - ^{213}Bi, $^{224}Ra/^{212}Pb/^{212}Bi$.

5. **Radiopharmaceutical Chemistry** **4 Lectures**

General physicochemical properties of radioactive compounds: distinction between radionuclide, radiochemical and radiopharmaceuticals, carrier concept (carrier-free, carrier added, no carrier added). Chemistry of tracer radionuclide metals: hydrolysis, reduction-oxidation, concentration methods, radiolytic decomposition.

Study of Phosphorous (P), Chromium (Cr), Cobalt (Co), Iron (Fe), Indium (In), Thallium (Tl), Technetium-99m (Tc), Iodine (I), Yttrium (Y), Strontium (Sr), Rhenium (Re), Samarium (Sm), Lutetium-177 (Lu), radioactive gases (i.e. Xenon ^{133}Xe, ^{127}Xe, ^{81m}Kr-) & positron emitting nuclides like Fluorine (F), Oxygen (O), Carbon (C), Nitrogen (N), Copper (Cu), Rubidium (Rb), Gallium (Ga).

6. **Development of radiopharmaceuticals** **2 Lecture**

Empirical and Rational approaches to design, charge and size of the molecule, protein binding solubility, stability and bio-distribution. Structure- activity relationship. Biological properties of radiopharmaceuticals, pharmacokinetics, distribution, metabolism, excretion.

7. **Modes of localisation:** **2 Lectures**

localisation in organ of interest for diagnostic and therapeutic purposes. Various Mechanism of localisation with respect to each radiopharmaceutical. Ideal characteristic of RP for modes of localisation: Active and passive modes of localisation. Substrate specific radiopharmaceutical localization, Receptor mediated biochemical, metabolic trapping, enzyme substrate, antibodies to tumor associated antigens. Filtration, Phagocytosis, Cell Sequestration, Capillary blockade, ion Exchange, Chemisorption, Cellular migration.

8. **Methods of radiolabeling:** **4 Lectures**

Definition of a Radiopharmaceutical, ideal Radiopharmaceutical, availability, short effective half-Life, particle emission, decay by electron capture or isomeric transition. High target-to-nontarget activity ratio. Design of new Radiopharmaceuticals. General considerations. Factors influencing the design of new radiopharmaceuticals. Methods of radiolabeling. Isotope exchange reactions. Introduction of a foreign label. Labeling with bifunctional chelating agents. Biosynthesis. Important factors in labelling. Efficiency of the labeling process. Chemical stability of the product. Denaturation or alteration. Isotope Effect. Carrier-free or No-carrier-added state. Storage conditions. Purification analysis, shelf life.

9. **Specific methods of labelling: Radioiodinated radiopharmaceuticals:** **2 lectures**

Introduction, isotopes of iodine, production of isotopes with physical properties, principle of radioiodination, methods of radioiodination, iodination of organic compounds – Chemistry of Iodine, chemical properties, oxidation, methods to minimize oxidation. Various radioiodinated radiopharmaceuticals –1)^{131}I-NaI, 2)^{131}I-OIH, 3) ^{131}I-Rose Bengal, 4)^{131}I-IMP (n-isopropyl, p-iodo amphetamine), 5)^{131}I-HIPDM (NNN'-trimethyl,N'(2-hydroxy,,3-methyl,5-iodobenzyl)1,3propane diamine), 6) ^{131}I-mIBG, 7)^{131}I-Fibrinogen, 8)^{131}I- lipiodol, 9)^{131}I-19-Iodocholesterol, radioiodination of peptides, proteins, antibodies/monoclonal antibodies, Methods of labelling, Applications, Advantages, Disadvantages, Dose Administration etc.

10. Specific methods of labeling – Technetium labeling **4 Lecture**

Chemistry of Technetium with respect to oxidation states, reduction methods, technetium tin-ligand reactions in aqueous solution, hydrolysis, re-oxidation, complexation, carrier effects, radiolytic decomposition.

Kit formulation of radiopharmaceuticals and their classification. Additives, stabilisers and preservatives.

Labelling with ^{99m}Tc: formation of ^{99m}Tc- complexes by ligand exchange, structure of ^{99m}Tc-complexes, oxidation states of ^{99m}Tc in radiopharmaceuticals and kits for ^{99m}Tc-labeling-: DTPA, GHA, DMSA, MIBI, MAG_3, MDP, Phytates, ECD, EC, IDA compounds and Sulfur Colloid. Dextran colloid and labeled particles. Metal chelate and congugates, ^{99m}Tc-tricarbonyl core, ^{99m}Tc-nitrido compounds, ^{99m}Tc-Hynic-TOC.

11. Radiolabeling of Cells: **2 Lectures**

Methods of labelling for blood pool studies & detection of gastrointestinal bleeding , ^{99m} Tc-RBC (i.e. In-vitro, In-vivo and modified In-vivo), ^{99m} Tc- RBC's (denatured) for splenic imaging, ^{99m} Tc- / ^{111}In- - Leucocytes (i.e. Methods of radiolabeling for inflammation / abscess localization), ^{51}Cr- red blood cells (i.e. Methods of radiolabeling for blood volume measurement & Splenic Sequestration studies), ^{111}In-platelets (i.e. Methods for radiolabeling).

12. Altered biodistribution related to improper preparation of Radiopharmaceuticals. 1 Lecture

Radiopharmaceutical formulation problems, problems caused by radiopharmaceutical administration technique and procedure, changes in biochemical and phathophysiology, previous medical procedure such as surgery, radiation therapy and dialysis, drug interactions.

13. PET radiopharmaceuticals: 6 Lectures

Positron emitters & radiochemistry to produce, ^{18}F-Sodium Fluoride, ^{18}F-Fluorodeoxyglucose (FDG) , ^{18}F-Fluorodopa , ^{18}F-Fluorothymidine (FLT), ^{18}F-MISO, ^{18}F-FAZA, ^{18}F-FET, ^{18}F-FBA, ^{11}C-Sodium Acetate, $^{13}NH_3$ and $H_2{}^{15}O$._FDG synthesis and QC Details of automated steps involved during synthesis, QC done before supply for patient's use.

14. Molecular Imaging probes: Target specific radiopharmaceuticals 1 Lecture

Basics of molecular imaging, methodology of molecular imaging, Classification of radiopharmaceuticals, blood flow/membrane transport radiopharmaceutical, metabolism based radiopharmaceutical. Receptor & transport mediated radiopharmaceutical. Receptors, receptor binding, design of radiopharmaceutical, bifunctional approach, chelating agents, radiolabeling, Ideal radiopharmaceutical, Various receptor imaging agents SSTR, Bombesin, Vasoactive intestinal peptides, α-Melanocyte-Stimulating Hormone, Neurotensin, Substance P (SP), Cholecystokinin (CCK), Neuropeptide Y (NPY) reporter genes for imaging.

15. Quality control of Radiopharmaceuticals 4 Lectures

General Schemes, Physicochemical tests: physical characteristics, pH and ionic strength, radionuclide purity, radiochemical purity, chemical purity, radio assay.

QC of kits – radiochemical purity, sterility check, membrane filtration, chromatography, pyrogen test, bio-distribution studies, Molybdenum break through test. Breakthrough of methyl ethyl ketone, alumina. QA of PET radiopharmaceuticals by TLC scanner, HPLC and gas chromatography (GC). QC in hospital radiopharmacy practices - includes aseptic practices & pharmaceutical safety aspects. Good manufacturing practice (GMP), ISO and ISI standards in radiopharmaceuticals. Adverse reactions to and altered biodistribution of radiopharmaceuticals, iatrogenic alterations in the biodistribution of radiopharmaceuticals Regulations, ethics and registration of radiopharmaceuticals.

16. Therapeutic applications of radionuclides 2 Lecture

Radionuclide therapy (RNT), definition, Problems for development of therapeutic RP, Uptake mechanisms of therapeutic radiopharmaceuticals, types of preparation, Properties of ideal therapeutic radiopharmaceuticals, selection of appropriate radionuclides includes particle emission, half-life, Specific Activity, decay characteristics, characteristics of the ideal therapeutic radiopharmaceutical.

Ranges of emitted particle radiation in the tissue: Beta particle emitting radionuclides: Response of beta particle radiation on tumor, classification of b- particles, Alpha particle emitting Radionuclides, Auger-electrons emitting radionuclides, properties of Auger-electron-emitting radionuclides. Dosimetry in therapy by Radiopharmaceuticals: Absorbed radiation dose, Patient Specific Dosimetry.

17. Radioisotopes: Beta particle emitting radioisotopes **3 Lectures**

Phosphorus-32, Samarium-153, Holmium-166, Thalium-170, Rhenium-186, 188. Rhenium Chemistry, Rhenium-188, Production and Physical Characteristics, Issues with Column Generator Production, Uptake and Biokinetic Properties, Rhenium radiopharmaceuticals.

Lutetium-177: Production and physical characteristics influence of production mode for ^{177} Lu, ^{176}Lu-route versus ^{176}Yb-route, Uptake and biokinetic properties, Peptide receptor radionuclide therapy, Dosimetry.

Yttrium-90: Production and physical characteristics, ^{90}Sr/^{90}Y generators, uptake and biokinetic properties, uses of ^{90}Y Radiopharmaceuticals: microspheres, MAA, antibodies, dosimetry.

18. Alpha emitting Radioisotopes for therapy **1 Lecture**

^{223}Radium-: Alpharadin, (Generator prod. RP ^{227}Ac - ^{223}Ra), ^{212}Bismuth, (^{212}Bi is produced by chemistry generator from ^{224}Ra), ^{213}Bismuth (^{213}Bi is produced by chemistry generator from ^{225}Ac), ^{211}Astatium: (cyclotron produced RP. ^{209}Bi (α, 2n) ^{211}At), ^{225}Actinium: Cyclotron produced RP. ^{226}Ra (p, 2n) ^{225}Ac. Production and physical characteristics, uptake and biokinetic properties.

Auger-electrons emitting Radioisotopes: ^{111}Indium (^{111}In): Production and physical characteristics, uptake and biokinetic properties, dosimetry. Application of therapeutic radiopharmaceuticals: Bone pain palliatiation, Radiosynovectomy, Radioimmunotherapy.

19. Nanotechnology **2 Lectures**

Concepts and its biomedical applications, liposomes, aerosols, nanoparticles, immuno-liposomes, drug delivery systems. Introduction to Nanotechnology and their application in nuclear medicine for diagnostic and therapeutic purposes. Different types of drug delivery nanocarriers for diagnostic and therapeutic purposes (Liposomes, micelles, phytosomes, Chitosan Nanoparticles etc) and their advantages over present drug delivery systems. Methods of preparation of Nanocarriers and quality control procedures. Mechanism of localisation of nanodrug delivery systems. Future applications in Nuclear Medicine.

20. Design of Radiopharmacy laboratory: **2 Lectures**

Regulatory requirements, pharmaceutical aspects, radiation protection aspects, local constraints, design of hospital pharmacy, stocking of consumables and labels, disposable materials. Laminar airflow (LAF) hood, its testing and maintenance.

Centralized Nuclear Pharmacy, considerations & layouts. Automated Modules.

Licenses and procurement of radiopharmaceuticals. Trace of delayed shipments, surveys, wipe tests, packaging, disposal, storage requirements, and record keeping logs.

21. Diagnostic In-vitro Techniques: **12 Lectures**

Principle of RIA, Immunoradiometric assay (IRMA), Enzyme linked immunosorbent assay (ELISA), Fluorescent immunoassay (FIA), Chemiluminescent Immunoassay (CLIA), Methods of receptor assays. In-vitro Uptake studies, In-vitro radiorespirometry, Quality Control Parameters and methods and Applications for hormones & drugs, example of assays for T_3, T_4, TSH, free hormones, thyroid antibodies and thyroglobulin, other hormones and drugs.

Instrumentation & Imaging Technology - Paper - IV

1. QC of Radiation Protection Instruments **2 Lectures**

QC of - Ionization chamber Type, Geiger-Muller Counter, pocket dosimeter, Dose calibrator, Scintillation type Gamma ray spectrometer, Zone monitors.

2. Instrumentation aspects of Medical Cyclotron **4 Lectures**

Reactors and charged particle accelerators. Physics of linear accelerator, cyclotron, synchro-cyclotron, isochronous cyclotron. Medical cyclotron: threshold energy, nuclear cross section, q value, RF frequency, magnets, beam focusing and extraction, target design. Types and makes their advantages and limitations. Safety Concerns. Cyclotron produced radionuclides, Cyclotron based generators.

3. Collimator Systems **4 Lectures**

Counting Geometry & Need for Collimator, Types of Collimator- Parallel Hole, Slant Hole, Rotating Hole, Focusing, Convering Hole and Diverging Hole Collimators, Material design with regards to Cost, Geometric Efficiency and Resolution. Pinhole Collimator and its Adaptation in Gamma Camera. Fanbeam collimator, Slit collimator, Slit slat collimator, Collimator in 2D PET.

4. Probe systems **2 Lectures**

Thyroid uptake probe, basic components, system set-up and calibration, flat field collimator, iso-response curve and working distance. All quality control parameter including iso-response curve, and working distance. Significance or application in non imaging procedures.

5. Rectilinear scanner **2 Lectures**

Block diagram, principle of working, effect of scanning speed, dot factor, time constant, line spacing, film density, information density, photo recording display, contrast enhancement and clinical applications. Focal plane and depth of focus.

6. Gamma Camera and quality control **5 Lectures**

Scintillation camera, Basic principles of gamma camera, collimators, NaI (T) detector, position determining circuits, Display. Gamma camera-computer interface- ADC/DAC. Correction Circuits. Criteria of Selection & installation of Gamma camera, Frontiers of Gamma Camera Technology, LSF, MTF, Avalanche photodiodes, CZT detectors.

7. Application of Computers in Nuclear Medicine **3 Lectures**

Image Acquisition Matrix, Byte Mode and Word Mode, Frame Mode Acquisition, List mode, Static, Dynamic and Gated Acquisition, Image Display methods, Image Perception and Analysis, Image Manipulations and Presentations, Background Correction Methods, Image Interpolation, Region of Interest Analysis, Time Activity Curves and General Filters and Normalization methods, Automated ROI's and Computational methods.

8. Single Photon Emission Computerized Tomography & QC **5 Lectures**

Principles of Tomography, longitudinal and transverse or axial tomography, Theoretical aspects of image acquisition & reconstruction techniques, filters, artifacts in SPECT, effect of scatter & scatter correction, noise, role of collimators, rotating gamma camera, single or multiple detector devices, data collection, SPECT acquisition – step & shoot/continuous.

Whole body SPECT. SPECT v/s Planar camera, SPECT v/s other modalities (CT, MRI, Ultrasonography).

9. Positron Emission Tomography Equipment: 5 Lectures
Gamma camera for PET imaging. Dedicated and hybrid PET systems. Principles of PET imaging, detectors assembly, various corrections in PET, 2-D and 3-D acquisitions, performance of PET imagers, sensitivity, spatial resolution. PET Detectors, Attenuation correction, TOF concept, instrumentation, data collection, data correction, data storage, reconstruction, quality control, Performance characteristics, NECR, NEMA specifications, PET v/s SPECT, PET Protocols.

10. Multicrystal Gamma Camera and Intraoperative probes 2 Lectures
Emerging designs and considerations of Multicrystal Gamma Camera and Intraoperative probes, its relevances in nuclear medicine, Discussions on Standards and Quality Control. Small animal imaging systems.

11. Overview of Whole body counting system: 1 Lecture
Whole body counting: principles of whole body counting, design of whole body counting system, stationary systems, single and multiple crystal systems, shadow shield geometry, moving systems, calibration of whole body system, clinical and other applications of whole body counters.

12. Medical Informatics 2 Lectures
Image Formats, Concept of DICOM (Digital image communication in medicine) and DICOM-RT and etc, DICOM and interfile conversion software, Interfacing; TCP/IP protocols, PACS (Picture Archiving and Communication System); Telemedicine.

13. Biomedical Ultrasound 2 Lectures
Ultrasound generators, properties of ultrasound waves and its propagation in biological tissues, Pulse echo techniques, Scan types. Doppler principle.

14. Magnetic Resonance Imaging (MRI) 2 Lectures
Basic Magnetism, Physics of magnetic resonance, MRI equipment its advantage over CT / Ultrasound, – Image artifacts – MRI safety. Principal of FMRI (functional magnetic resonance imaging), MR spectroscopy, MRI contrast, Limitations and uses of MRI. Configuration of machines available, PET/MRI fusion problems and solutions.

15. Radiological Instrumentation - CT scanner 4 Lectures
Discovery - Production - Properties of X-rays, basic requirements for diagnostic tubes, Classification of tubes, Filters, Measurement of kV and mAs, CT detectors, CT acquisition, CT reconstruction, CT attenuation correction, CT dose index, dose length product, Radiation dose, CT-PET fusion, Quality Control of CT, Scanner design, Spiral Computed Tomography, Difference between conventional single slice, multislice, spiral and electron beam CT. Comparison of patient radiation doses and effects of slice thickness.

16. **Advanced Molecular Imaging 1 Lecture**
Optical, Molecular, Positron Emmision Mammography: (Basic principles, Instrumentation)

Clinical Nuclear Medicine Techniques - Paper V

1. Non-imaging applications of radionuclides **4 Lectures**

^{51}Cr labeled RBC's for blood volume, red cell volume measurement, spleen uptake, red cell survival studies. Schilling's test using ^{58}Co/^{57}Co for vitamin B12 absorption, applications of ^{14}C radiorespirometry for H.Pylori ulcers, Ferrokinetic studies using radioisotopes of Iron.

Important: ***Common in all In-Vivo Techniques is a discussion on choice of radiopharmaceuticals and its dose, choice of equipment, imaging considerations, patient preparation & instruction, selection of imaging parameters, interventional approaches, quantitative data analysis, display, filming or its report generation.***

Clinical Nuclear Medicine Techniques in two parts

i) One by the technologists emphasizing the **technical part** and (ii) the other by the Clinical Staff.

2. Thyroid studies **3 +3 Lectures**

Thyroid imaging and uptakes (^{99m}Tc and ^{131}I), Perchlorate discharge test, T_3/T_4 suppression test, TSH stimulation test. ^{131}I whole-body imaging. Post Therapy Scans.

3. Lung imaging studies **4+4 Lectures**

Ventilation lung imaging studies using gases (^{133}Xe, ^{81m}Kr), Inhalation imaging using aerosols, aerosols generators, mucociliary clearance, COPD, Pulmonary permeability using DTPA, perfusion imaging using MAA, Microsphere, and pulmonary embolism.

4. Liver-spleen imaging **2+2 Lectures**

Liver imaging for Diffuse and Focal liver diseases, Dynamic Liver studies, Quantitative methods for Hepatic Perfusion Index, Blood pool liver studies. portosystemic shunt evaluation by Per-rectal Scintigraphy.

5. Hepatobiliary imaging **3 +3 Lectures**

Hepatobiliary imaging protocols, Neonatal hepatitis versus Biliary atresia, Gall bladder dynamic studies using IDA compounds. Deconvolution analysis, Hepatic Extraction Fraction, Interventional methods. Bile leak studies.

6. Gastrointestinal studies **5+5 Lectures**

Conventional imaging modalities used for GI studies. Advantages and disadvantages of these modalities over scintigraphy. Oesophageal transit time studies, Gastric oesophageal reflux, gastric emptying time, Duodeno-gastric reflux, Meckel's diverticulum imaging, GI bleeding with ^{99m}Tc-RBC, ^{99m}Tc-S.Collide. Advantages and disadvantages of each method

7. Cardiac studies **5+5 Lectures**

ECG, First pass study (shunt detection), Importance of Electrocardiogram (ECG), gated blood pool study, MUGA, Ejection fraction, Wall motion analysis, Infarct avid imaging, Rest / Stress myocardial imaging, Gated SPECT, Pharmacological stress, Bulls Eye analysis, Severity scores. Use of ^{201}Tl, ^{18}FDG and $^{13}NH_3$ for cardiac studies.

8. Bone imaging **3 +3 Lectures**

Routine bone (whole body and spot) imaging, bone flow study, quantitative bone scan-sacroiliac index, 3-phase bone scans, Bone SPECT. Bone imaging in Metabolic Disorders. MDP retention studies, ^{18}F-Fluoride Bone Scans.

9. Renal imaging studies **5+5 Lectures**

Standard Renogram, Diuretic renogram, Captopril renogram, Renal Perfusion analysis, Differential function, GFR estimation by Gates Method, Renal transplant studies, Background subtraction methods, Rutland Patlak-Plot, Plasma Sampling methods, Advantages and Disadvantages of various GFR estimation methods, Uretic reflux study, Interventional methods, Direct and indirect radionuclide cystourethrography, Cortical Renal Scans using ^{99m}Tc-GHA &^{99m}Tc-DMSA, Differential function by Geometric Mean.

10. Brain imaging **3+ 3 Lectures**

Cerebral blood flow dynamic studies, Blood Brain Barrier imaging, Perfusion Imaging, Brain SPECT, Interventional methods, Cisternography, CSF leak,PET brain imaging.

11. Tumour Imaging: **2 Lectures**

^{18}F-FDG PET Scans for Oncologic Staging and Evaluation of Post therapy status. Imaging for Medullary Carcinoma of Thyroid, Neural Crest Tumours, Apoptotic Imaging. Post Therapy Scans. Organ specific (cold spot, hot spot), nonspecific (^{67}Ga- Citrate, ^{201} Tl, ^{131}I MIBI, ^{99m}Tc Tetrofosmine, ^{18}F-FDG), Tumor type specific (^{131} I for papillary and follicular carcinoma,^{131}I mIBG (adrenal cortex), NP59 for adrenal medulla, ^{99m}Tc Mebrofenin for hepatocelluar ca, Antibody (^{111}In Oncoscint, ^{99m}Tc CEA,^{111}In Prostascint, ^{99m}Tc-Verluma, peptide (^{111}In Somatostatin,^{68}Ga DOTATATE).

12. Lymphoscintigraphy & Sentinel Node Scintigraphy **2 Lectures**

13. Infection and inflammation **2+2 Lectures**

Use of Labelled Leukocyte, ^{99m}Tc-Ciprofloxacin, ^{68}Gallium for detection of Infectious foci. Discussion of imaging preferences.

14. Salivary gland imaging **1 Lecture**

Imaging for parenchymal and obstructive diseases of salivary glands. Post Radiation Xerostomia evaluation.

15. Parathyroid Imaging **1 Lecture**

Dual isotope technique and Subtraction scans. ^{99m}Tc-MIBI wash out studies.

16. Bone marrow imaging **1 Lecture**

Imaging techniques for visualisation of Bone marrow infiltration

17. Lymphoscintigraphy & Sentinel Node Scitigraphy **2 Lectures**

Infrequently performed studies in Nuclear Medicine

18. Scrotal Imaging **1 Lecture**

19. Dacryoscintigraphy **1 Lecture**

20. Scintimammography **1 Lecture**

Early and Delayed Imaging. Special Positions and Restraining means.

21. Hysterosalphingography **1 Lecture**

22. Contrast Agents **2 Lectures**

Contrast media agents: Oral, IV – ionic/nonionic, Rectal, Intrathecal, Catheters, Types/indication/chemical makeup etc. Iodinated contrast materials, Characteristics of iodinated contrast materials, Water solubility and hydrophilicity, Osmolality, High osmolar contrast media (HOCM), Low osmolar contrast media (LOCM), Advantages of LOCM, Disadvantages of LOCM, Viscosity, Calcium binding, Iodine concentration, Adverse reactions. Substitution of barium based contrast instead of iodinated oral contrast, Indications for steroid premedication, Contraindications for steroid premedication.

23. Radiation protection in NM - Regulatory Aspects **8 Lectures**

Guidance level for diagnostic administration, misadministration and preventive measures, reporting of misadministration.

Layout of Nuclear Medicine Laboratory, Design of radiation labs, types of labs, Security of Sources and radioactive cautions signs and labels. The Atomic Energy Act, Rules issued under the Act, Surveillance procedures issued under the Rules, Notifications issued under RPR, 2004, AERB Safety Directive, Safety code for NM facility, Duties of RSO, Regulatory clearance-Approval of NM Lab, Physician & RSO, Regulatory consent, authorisation- for disposal of radioactive waste and safe transport of Radioactive materials. Radiation Safety Program, Radiation Safety Officer and duties of Radiation Safety Officer, Radiation Safety Committee, Responsibilities for Implementation of Basic Safety Standards Requirements, AERB Regulation Related to Medical Cyclotron and PET.

Practicals

A. Practicals – Physics

1. To measure Half Value Layer of β and γ emitters and to measure the absorption coefficients of different materials with gamma rays and beta particles.
2. To study back scatter.
3. To determine the half life of a radioactive material.
4. To study the change in activity of a sample consisting of two independently decaying radioisotopes (or a mixture of isotopes)
5. To determine the plateau of GM tube and find out the dead time/ resolving time of GM counter.
6. To determine the efficiency of GM counter and find out the activity of the given unknown radioactive source.
7. Gamma ray spectrometry of ^{137}Cs with a single channel analyzer.
8. To find out the spectrum of energies emitted by a radioisotope by using gamma ray spectrometer. (e.g. ^{131}I)
9. To study the statistics of radioisotopic measurements and observe the effect of background on the counting statistics.
10. To determine the energy resolution of spectrometer
11. To study the energy linearity of given spectrometer
12. To observe gamma ray spectrum of the given two radionuclide sources (A and B) and identify composition of a tube containing mixture of these two radionuclide sources by evaluating scatter fraction.
13. To identify unknown radionuclide on the basis of its principal energy by using scintillation counter.
14. To study iso- response curve of Flat Field Collimator. To perform QC and calibration of uptake probe
15. To study the line spread function of a parallel hole collimator at various depths.
16. To perform Quality Control of Planar Gamma Camera and assess (intrinsic/extrinsic) uniformity, resolution by 4 quadrant bar phantom and assessment of linearity.
17. To study the counting errors originating from sample geometry and determine Critical Volume for counting in a well counter.
18. To estimate pipetting error and Estimation of Unknown Volume by Dilution principle
19. To perform Tomography with Jaszczak Phantom and evaluate the results.
20. Gamma Spectrometry with HPGe detector : Energy calibration, Efficiency and Identification of Unknown radionuclides

Practicals - Radiopharmaceutical & *In-vitro* Techniques

1. Perform Radioimmunoassay & IRMA.
2. To perform quality control of Dose Calibrator
3. Radiopharmacy procedure: Elution of generators and Determination of Impurities (a) Radionuclidic (^{99}Mo breakthrough in ^{99m}Tc), (b) Chemical (Alumina Breakthrough) and (c) Radiochemical (TcO4 paper chromatography)
4. Q.C. of radiopharmaceuticals by paper chromatography & to determine the Rf of ^{99m}Tc and the given labeled compounds by using ascending chromatography including Rapid determination of radiochemical purity of radiopharmaceuticals.
5. QC of ^{68}Ga and ^{177}Lu labeled radiopharmaceuticals by ITLC and paper chromatography
6. Q.C. of PET radiopharmaceuticals by TLC scanner and HPLC
7. Rapid determination of radiochemical purity of radiopharmaceuticals..
8. Biodistribution study of radiopharmaceuticals.

(Demonstration)....

1. Quality Controls of SPECT/CT system (once SPECT/CT is procured)
2. Quality Controls of PET/CT system (Uniformity, Attenuation correction, Partial volume effect, Co-registration evaluation of SPECT/CT & PET/CT, SUV measurements, CT QC)
3. Biological Quality control (a) ST (b) BET,
4. CPCR (Cardio-pulmonary & cerebral resuscitation
5. Visit to BARC (Reactor, whole body counter,TLD reader, biodosimetry),
6. Visit to BRIT.
7. Visit to NM centres to see special studies and instruments.

Apprentice Program:

420 hours (roughly eight months of Apprentice in various areas of Nuclear Medicine @3hrs per day)

BACK TO MAIN

HRI

Masters Program in Physics

(PROGRAM CODE: PHYS08)

Course Structure

The Masters program consists of four semesters of pedagogical lectures

No	COURSE CODE	Semester I	No	COURSE CODE	Semester II	No	COURSE CODE	Semester III	No	COURSE CODE	Semester IV
1	08PHYS08-001-	Classical Mechanics	6	08PHYS08-006-	Numerical Methods	11	08PHYS08-011-	Condensed Matter I	16	08PHYS08-016-C	Particle Physics
2	08PHYS08-002-	Quantum Mechanics I	7	08PHYS08-007-	Quantum Mechanics II	12	08PHYS08-012-	Quantum Mechanics III	17	08PHYS08-017-C	Elective II
3	08PHYS08-003-	Electrodynamics	8	08PHYS08-008-	Statistical Mechanics	13	08PHYS08-013-C	Quantum Field Theory I	18	08PHYS08-018-C	Elective III
4	08PHYS08-004-	Mathematical Methods I	9	08PHYS08-009-	Electronics	14	08PHYS08-014-C	Mathematical Methods II	19	08PHYS08-019-C	Project
5	08PHYS08-005-	Laboratory I	10	08PHYS08-010-	Laboratory II	15	08PHYS08-015-C	Elective I	20	08PHYS08-020-C	Laboratory III

Elective I : Choose one from — Advanced Statistical Mechanics, Fluid Mechanics, General Relativity, Non-linear Dynamics, Quantum Information and Computation I.

Elective II and III : Choose two from — Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure, Quantum Field Theory II, Quantum Information and Computation II, Quantum Optics, Soft Matter, Ultra Cold Atoms.

Semester I

(1) Classical Mechanics

- A rapid review/summary of Newtonian mechanics
- Calculus of variations: Concept of variation - Euler equation - Applications - Variation subject to constraints and Lagrange multipliers.
- The Lagrangian formulation: Generalised coordinates and velocities - The principle of least action and the Lagrange equations of motion - Extension to constrained systems.
- Conservation laws: Symmetries and Noether's theorem.
- Integration of the Lagrange equations of motion: Motion in one dimension - The two body problem, reduced mass and the equivalent one-dimensional problem - Motion in a central field - Kepler's problem - Scattering.
- Small oscillations: Free, damped and forced oscillations in one dimension - Resonance - Damped and forced oscillations - Parametric resonance.
- Rigid body motion: Angular velocity - The inertia tensor and angular momentum of a rigid body - The equations of motion- Eulerian angles - Motion of tops - Motion in a rotating frame - Coriolis force.
- The Hamiltonian formulation: Hamiltonian and Hamilton equations - Poisson brackets - Dynamics in the phase space - Hamilton-Jacobi equation - Separation of variables and solutions - Action-angle variables - Adiabatic invariants.
- Elements of non-linear dynamics: Differential equations as dynamical systems - Lyapunov exponents.

Textbooks:

1. Mathematical Methods of Classical Mechanics, V I Arnold,
2. Classical Mechanics, T W B Kibble and F H Berkshire,
3. Classical Mechanics, H Goldstein,
4. Classical Mechanics, L D Landau and L M Lifshitz,
5. Introduction to Dynamics, I. Percival and D. Richards.

(2) Quantum Mechanics I

- Basic notions: states, operators, time evolution
- One-dimensional problems: harmonic oscillator, periodic potential, Kronig-Penny model;
- Three-dimensional problems: central force potential, the hydrogen atom
- Charged particle in an electromagnetic field: gauge invariance, Landau levels
- Symmetries and conservation laws in QM: Degeneracies, Discrete symmetries
- Angular momentum in quantum mechanics: raising and lowering operators, angular momentum addition, Clebsch-Gordon coefficients; Tensor operators and Wigner-Eckart theorem
- Time-independent perturbation theory: non-degenerate and degenerate cases, Stark and Zeeman effects
- Semiclassical (WKB) approximation and variational methods

Textbooks:

1. Introduction to Quantum Mechanics, D. J. Griffiths,
2. Quantum Mechanics, B. H. Bransden and C. H. Joachain,
3. Principles of Quantum Mechanics, P.A.M. Dirac,
4. Modern Quantum Mechanics, J. J. Sakurai,
5. Quantum Mechanics, E. Merzbacher,
6. Quantum Mechanics, L. I. Schiff,
7. Quantum Mechanics (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz.

(3) Classical Electrodynamics

- Special theory of relativity and electrodynamics: Lorentz transformation of electromagnetic fields, Lorentz covariant formulation of electrodynamics; gauge invariance, Maxwell equations from action principle.
- The electrostatic limit of Maxwell equations, multipole expansion, uniqueness, boundary value problems, solution of Poisson equation.
- The magnetostatic limit of Maxwell equations, applications.
- Electrodynamics: motion of charges in external fields; electromagnetic waves in vacua and propagation through continuous media; energy-momentum of electromagnetic field and Poynting theorem.
- Advanced and retarded Green functions; Lienard-Wiechert potentials; dipole radiation and Larmor's formula; spectral resolution and angular distribution of radiation from a relativistic point charge; synchrotron radiation; Rayleigh and Thomson scattering; collision problems; Bremsstrahlung and Cerenkov radiation.
- Scattering of electromagnetic waves: Rayleigh and Thomson scattering, radiation damping.

Textbooks:

1. Introduction to Electrodynamics, D.J. Griffith,
2. Classical Electrodynamics, J.D. Jackson,
3. Electrodynamics of Continuous Media, Vol. 6 of Course of Theoretical Physics, L.D. Landau and E.M. Lifshitz.

(4) Mathematical Methods I

- Vector Analysis: operations with vectors, scalar and vector fields, gradient, curl and divergence. Line, surface, and volume integrals, Curvilinear coordinate systems, Elements of tensors.
- Vector Spaces, linear transformations, scalar product and dual space, bases, linear operators, eigenvalues and eigenfunctions, unitary and hermitian operators
- Complex Analysis: functions of a complex variable, analytic functions, integral calculus, contour integrals, Taylor and Laurent series, singularities, residues, principal values, Riemann surfaces, conformal mapping, analytic continuation

- Ordinary differential equations: linear ODEs, Green functions, second order differential equations: classification of singularities and local solutions, special functions
- Elements of statistics: probability, random walk. Probability distributions.

Textbooks:

1. Mathematical Methods in Physics, J. Mathews, R. L. Walker,
2. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag,
3. Mathematical Methods for Physicists, G. B. Arfken, H. J. Weber, F. E. Harris,
4. Fundamentals of Mathematical Physics, E. A. Kraut,
5. Complex Variables, M. J. Ablowitz and A. S. Fokas.

(5) Laboratory I

- Forced Oscillations-Pohl's Pendulum:
- Coupled Pendula and Chaotic oscillator:
- Photoelectric effect:
- Normal and Anomalous Zeeman Effect:
- Michelson Interferometer:
- Mach-Zehnder Interferometer:
- Faraday Effect:
- Millikan Oil-drop Experiment:
- Electron Diffraction:
- Fine Structure:

Semester II

(6) Quantum Mechanics II

- Scattering theory and applications
- Schrodinger and Heisenberg pictures; postulates of quantisation
- Time dependent perturbation theory, Interaction picture, Fermi golden rule
- Path integrals: propagators, amplitudes as path integrals, Semiclassical methods revisited
- Quantum mechanics of many particles, identical particles and symmetries of the wave-function, scattering of identical particles
- Relativistic quantum mechanics, Klein-Gordon and Dirac equations and their solutions, gyromagnetic ratio of the electron, relativistic corrections to the Schrodinger equation
- Entangled states and Bell inequalities

Textbooks:

1. Principles of Quantum Mechanics, P.A.M. Dirac,
2. Quantum Mechanics and Path Integrals, R. P. Feynman and A. R. Hibbs,
3. Modern Quantum Mechanics, J. J. Sakurai,
4. Quantum Mechanics, E. Merzbacher,
5. Quantum Mechanics, L. I. Schiff,
6. Quantum Mechanics (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz

(7) Research Methodology and Numerical Methods

- Research Methodology including quantitative methods, communication skills, seminar presentation and review of research papers
- Introduction to programming languages: F77, F90 or C
- Errors in numerical calculations.
- Numerical linear algebra, eigenvalue and eigenvectors.
- Interpolation techniques.
- Generation and use of random numbers.
- Sorting and searching.
- Differentiation and Integration (including Monte Carlo techniques)
- Root finding algorithms
- Optimisation, extrema of many variable functions.
- ODEs and PDEs: including FFT and finite difference methods, integral equations.

Textbooks:

1. Research Methodology: Methods and Techniques, C.R. Kothari,
2. Numerical Mathematical Analysis by J. B. Scarborough,
3. Computer oriented numerical methods, V. Rajaraman,
4. Data reduction and error analysis for the physical sciences, P. R. Bevington and D. K. Robinson,
5. An Introduction to Error Analysis, J.R. Taylor.

(8) Statistical Mechanics

- Basics: phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
- Non interacting classical systems: few level systems, ideal gases, oscillators.
- Non interacting quantum systems: method of second quantisation, electrons in metals, relativistic electron systems, electrons in a strong magnetic field, lattice vibrations and phonon physics, photons, blackbody radiation, Bose condensation.

- Interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
- Phase transitions: symmetry breaking and long range order, mean field approach, Landau theory, 2nd and 1st order transitions, Landau-Ginzburg functional, illustrative examples, estimate of fluctuations.

Textbooks:

1. Statistical Mechanics, K. Huang,
2. Statistical Mechanics, R. K Pathria,
3. Fundamentals of statistical and thermal physics, F. Reif.

(9) Electronics

- Circuit theory: lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive networks, node and loop analysis, Thevenin and Norton's theorem, time domain response of RL, RC and RLC circuits, frequency domain response, impedance, filters and transfer function.
- Analog electronics: discrete devices, characteristics and operation - diode, Zener diode, LED, photodiode. Simple diode circuits. Bipolar junction transistor (BJT): biasing, h parameters, small and large signal response, amplifiers. Field effect transistors.
- Operational amplifiers: device properties, integrator, differentiator, RC active filter, negative and positive feedback, oscillators.
- Digital electronics: logic gates, truth table, multiplexer, combinatorial circuits, flip-flop, counters, programmable logic devices, microprocessors.

Textbooks:

1. Electronic Principles, A. P. Malvino and D. J. Bates,
2. Digital Electronics, A. P. Malvino and A. P. Leach,
3. Integrated Electronics, J. Millman and C. C. Halkias.

(10) Laboratory II

- Coupled Oscillator Circuits:
- Thermal Equation of State and Critical point:
- Lock-in Amplifier and Signal Processing:
- OpAmps I: Amplifiers & Negative Feedback:
- OpAmps II: Limitations & Applications:
- Diodes: Clamps, Rectifiers, Power supplies
- Transistors I: Switch, Common Emitter Amplifier, Push-pull Follower
- Transistors II: Characteristics, Comparators, MoSFET, CMoS Inverter
- Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
- Flip-flops: as Memory element, Shift Register, Counters

- Microcontroller I: Programming to MCU, using the port for input
- Microcontroller II: Some Applications, Seven Segment Display

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Semester III

(11) Condensed Matter Physics I

- The building blocks - atoms to solids: atomic physics, Coulomb effects, crystal fields in solids, local moments and band electrons, lattice vibrations, electron-lattice coupling, electron-electron interactions.
- Structure: characterizing structures - crystalline/amorphous/liquids, classification of periodic structures, reciprocal space, x-ray and neutron diffraction.
- Electronic structure: free electrons - spectrum, density of states, thermodynamics, band electrons - nearly free electron and tight binding limits, consequences for thermodynamics and transport.
- Physics of metals: specific heat, susceptibility, impurity scattering, basic transport theory. Response to magnetic fields: Landau quantization, quantum Hall effect.
- Phonons: Debye and Einstein model, spectrum of a real lattice, thermodynamics of phonons, anharmonic effects, Debye-Waller factor.
- Magnetism: spin paramagnetism, itinerant-vs-localised electrons, Stoner and Heisenberg models, mean-field theory, spin waves.
- Superconductivity: phenomenology, pairing interaction, BCS theory, Ginzburg-Landau theory and type II superconductors.

Textbooks:

1. Condensed matter physics - N. W. Ashcroft and N. D. Mermin,
2. Solid State Physics - C. Nayak,
3. Solid State Basics - S. Simon,
4. Introduction to many body physics - T. Giamarchi, A. Lucci and C. Berthod,
5. Lessons from nano-electronics - a new perspective on transport - S. Datta.

(12) Quantum Mechanics III

- Atomic physics: One electron atoms - spin-orbit interaction, fine structure, Lamb shift, Zeeman effect, Stark effect.

- Two electron atoms: spin wave functions, approximate handling of electron-electron repulsion. Coupling of angular momenta, multiplet structure, gyromagnetic effects. Hyperfine and nuclear quadrupole interactions.
- Many electron atoms: central field approximation, Thomas-Fermi and Hartree-Fock methods.
- Molecular physics: Born-Oppenheimer approximation, molecular structure, rotation and vibration of diatomic molecules, hydrogen molecular ion, vibrational-rotational coupling, effect of vibration and rotation on molecular spectra. Electronic structure- molecular orbital and valence bond theories.
- Atoms and light: transition rates, dipole approximation, Einstein coefficients, radiative damping, optical absorption, ac Stark effect.
- Cold atoms: Doppler cooling, magneto-optical trap, ion traps, dipole force, evaporative cooling, optical lattice.
- Collective effects: Feshbach tuning of interactions, Bose condensation of alkali atoms, BCS-BEC crossover, the unitary Fermi gas. Imaging cold atoms.
- Computing with atoms: qubits and their properties, entanglement, quantum logic gates, decoherence and error correction.

Textbooks:

1. Theoretical Atomic Physics, H. Friedrich,
2. Atomic Physics, C. Foot,
3. Physics of Atoms and Molecules, B. H. Bransden and C. H. Joachain,
4. Molecular Quantum Mechanics, P. Atkins and R. Friedman.

(13) Quantum Field Theory I

- Non-relativistic quantum field theory: quantum mechanics of many particle systems; second quantisation; Schrodinger equation as a classical field equation and its quantisation; inclusion of inter-particle interactions in the first and second quantised formalism
- Irreducible representations of the Lorentz group, connection to quantum fields
- Symmetries and conservation laws: examples in non-relativistic and relativistic field theories; translation, rotation, Lorentz boost/Galilean transformation and internal symmetry transformations; associated conserved charges
- Free Klein-Gordon equation: classical action and its quantisation; spectrum; Feynman rules for computing n-point Green functions of elementary and composite operators.
- Interacting Klein-Gordon field: Feynman rules for computing Green functions; physical mass of the particle from the analysis of two point Green functions; S-matrix and its computation from n-point Green functions; relating S-matrix to cross-section.
- Quantisation of free Dirac fields: spectrum; Feynman rules
- Quantisation of free electromagnetic field: role of gauge invariance; gauge fixing; physical state condition; spectrum; Feynman rules

- Quantum electrodynamics: coupling Dirac field to electromagnetic field; gauge invariance; quantisation; Feynman rules for computing Green functions; Spectrum and S-matrix from the Green functions.

Textbooks:

1. An introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder,
2. Quantum Field Theory, C. Itzykson and J-B Zuber,
3. Relativistic Quantum Fields, J. D. Bjorken and S. Drell.

(14) Mathematical Methods II

- Integral transforms, Fourier transforms, inversion and convolution, Laplace transforms
- Advanced topics in ODE, Partial differential equations: classification of second order PDEs, Laplace and Poisson equations, applications to electrostatics, Heat equation, Wave equation
- Group theory, definitions and examples of groups. Homomorphism, isomorphism and automorphism, Permutation groups
- Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group. Symmetries in physical systems, Young Tableau.

Textbooks:

1. Mathematics for Physicists, P. Dennery and A. Krzywicki,
2. Introduction to Topology, Differential geometry, and group theory to physicists, S. Mukhi and N. Mukunda,
3. Classical Groups for physicists, B. G. Wybourne,
4. Group Theory, P. Ramond.

(15) Elective I

Choose any one of the following topics, Advanced Statistical Mechanics, Fluid Dynamics, General Theory of Relativity, Techniques in Nonlinear Dynamics, Quantum Information and Computation I.

• Advanced Statistical Mechanics

- Critical phenomena : Liquid-gas transition and Van der Waals equation of state, Classical spin systems, Transfer matrix for one dimensional systems, Order parameters, Mean field approach, Landau theory, Universality, Critical exponents, Scaling hypothesis, Estimating fluctuations
- Renormalisation : Hubbard-Stratanovich transformation and the Ginzburg-Landau-Wilson functional,Self-consistent approximation, Basic ideas of renormalisation

group, Real space RG in one and two dimensions, Spherical limit, Wilsonian RG and ε-expansion, Field theoretic RG, Two dimensions and BKT transition
- Equilibrium dynamics : Conserved and broken symmetry variables, Hydrodynamic approach, Dynamical critical phenomena
- (Extra module : one of the following two) :
- Non-equilibrium phenomena : Fluctuation-dissipation, Linear response, Kubo formula, Langevin and Fokker-Planck descriptions
- Stochastic thermodynamics : Non-equilibrium work theorems (Jarzynski, Crooks, …), Non-equilibrium steady-states, Stochastic heat engines, Examples from colloidal systems and molecular motors

Textbooks:

1. Field Theory and Renormalisation Group, D. J. Amit,
2. Modern Theory of Critical Phenomena, S. K. Ma,
3. Lectures on Phase Transition and The Renormalisation Group, N. Goldenfeld,
4. Quantum Field Theory and Critical Phenomena, J. Zinn-Justin.

• Fluid Mechanics

- Ideal Fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity
- Viscous Fluids: Viscosity, Navier-Stokes equation, Reynolds number, laminar flow, exact solution to the eq. of motion.
- Turbulence: Stability of flows, instabilities, quasi-periodic flows, Strange attractors, turbulent flows, jets, free shear layers, wakes, boundary layers
- Thermal Conduction in fluids: eq. of heat transfer, conduction in incompressible fluid, law of heat transfer, convection, convective instability in static fluid
- Compressible flows
- Relativistic Fluid dynamics: eq. of motion, energy-momentum tensor, eq. for flow with viscosity and thermal conduction.

Textbooks:

1. Fluid Mechanics, L. D. Landau and E. M. Lifshitz,
2. An Introduction to Fluid Dynamics, G. K. Batchelor,
3. Relativistic Fluid Dynamics, A. Anile and Y. Choquet-Bruhat.

• General Theory of Relativity

- Review of Lorentz transformations and special theory of relativity.
- Tensors and their transformation laws; Christoffel symbol and Riemann tensor; geodesics; parallel transport along open lines and closed curves; general properties of the Riemann tensor.

- Equivalence principle and its applications: gravity as a curvature of space-time; geodesics as trajectories under the influence of gravitational field; generalisation to massless particles; gravitational red-shift; motion of a charged particle in curved space-time in the presence of an electric field; Maxwells equation in curved space-time.
- Einsteins equation, Lagrangian formulation, Einstein-Hilbert action.
- Schwarzschild solution: construction of the metric and its symmetries; motion of a particle in the Schwarzschild metric; Schwarzschild black hole; white holes and Kruskal extension of the Schwarzschild solution: construction of the metric and its symmetries; Motion of a particle in the Schwarzschild metric; precession of the perihelion; bending of light; horizon, its properties and significance.
- Precession of the perihelion; bending of light; radar echo delay.
- Initial value problem; extrinsic curvature; Gauss-Codacci equations;
- Linearised theory, gravitational waves, field far from a source, energy in gravitational waves, quadrupole formula
- Elementary cosmology: principles of homogeneity and isotropy; Friedman-Robertson-Walker metric; open, closed and flat universes; Friedman equation and stress tensor conservation, equation of state, big bang hypothesis and its successes.

Textbooks:

1. General Relativity, S. Weinberg,
2. Lecture Notes on General Relativity, S. Carroll,
3. Introducing Einstein's Relativity, R. D'Inverno,
4. General Relativity, R. M. Wald.

• Nonlinear Dynamics

- Long time behaviour of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.
- Periodic orbit for conservative systems, periodic orbits for dissipative systems (limit cycles) and their stability, Bifurcations and centre manifolds.
- Different kinds of perturbation theory for calculating periodic orbits, Renormalisation group aided perturbation theory, Poincare Bendixon theorem, chaos and strange attractors.
- Maps, fixed points, cycles and stability, bifurcations , period doubling, intermittency and quasi periodicity, universal behavior at the onset of chaos , renormalization group and scaling behaviour.
- Partial differential equations, patterns, Galerkin truncations and reduction to dynamical systems.

Textbooks:

1. Chaos in Dynamical Systems, E. Ott,

2. Arithmetical Chaos, E. B. Bogomolny, B. Georgeot, M.-J. Giannoni, C. Schmit,
3. Nonlinear Dynamics and Chaos, S. H. Strogatz.
4. Deterministic Chaos, H. G. Schuster.

• Quantum Information and Computation I

- Quantum formalism: states, evolution, measurements.
- Multipartite quantum systems: description and manipulation of bipartite systems and beyond.
- Entanglement: quantification and detection in bipartite and multipartite systems.
- Quantum communication: no-cloning theorem, quantum teleportation, quantum dense coding, multipartite communication protocols.
- Quantum cryptography: essential classical cryptography, BB84, B92, Ekert, and secret sharing protocols.
- Quantum computation: quantum algorithms, universal gates.
- Interface of quantum information with other sciences.
- Experimental realisations.

Textbooks:

1. Quantum Computation and Quantum Information, M. Nielsen and I. Chuang,
2. Lecture Notes of J. Preskill, available at http://www.theory.caltech.edu/~preskill/ph229/
3. Quantum information, G. Alber et al (Editors),
4. Lectures on Quantum Information, D. Bruss and G. Leuchs,
5. Quantum Theory: Concepts and Methods, A. Peres,
6. The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation, D. Bouwmeester, A. Ekert, and A. Zeilinger.

Semester IV

(16) Particle Physics

- Experimental methods: fixed target and collider experiments, particle detectors.
- Role of symmetries: charge conjugation, parity, time reversal, isospin and SU(2), quark model and SU(3).
- Introduction to relativistic kinematics: Mandelstam variables, phase space, calculation of cross-sections and decay widths.

- Basics of quantum electrodynamics: electron-positron annihilation, electron-muon scattering, Bhabha scattering, Compton scattering.
- Deep inelastic scattering: Bjorken scaling, parton model, scaling violation, introduction to quantum chromodynamics and tree level processes.
- Introduction to weak interactions: parity violation, V-A theory, pion and muon decay, neutrino scattering.
- Standard Model: Glashow-Salam-Weinberg model, neutral current, physics of W, Z and Higgs, CKM mixing and CP violation.
- Neutrino physics, neutrino oscillation

Textbooks:

1. Quarks and Leptons: F. Halzen and A. Martin,
2. An Introductory Course of Particle Physics: P. B. Pal,
3. Dynamics of the Standard Model: J. F. Donoghue, E. Golowich and B. R. Holstein,
4. Field Theory and Particle Physics: B. De Witt and J. Smith.

(17) Elective II and (18) Elective III

Choose any two of the following topics,

Astrophysics, Condensed Matter Physics II, Cosmology, Introduction to Electronic Structure Calculations, Quantum Field Theory II, Quantum Optics, Soft Matter, Ultra cold Atoms.

• Astrophysics

- Introduction to celestial objects, coordinates and the concept of time. Radiation transfer. Equations of radiation transfer, Black-body/thermal radiation, Opacity and optical depth, solutions of the radiation transfer equations in limiting cases, Rosseland mean opacity.
- Thermal Bremsstrahlung emission, synchrotron emission. Self-absorption and the emergent spectrum. Thomson scattering. Compton and Inverse-Compton scattering. Scattering in a region with magnetic field, Faraday rotation Introduction to fluid dynamics. Convection instability and transfer of energy from cores of stars. Supersonic motion, shocks.
- Introduction to Magneto-hydro dynamics, flux freezing, Generation and amplification of magnetic fields in astrophysical situations.
- Stellar structure. Mass-radius relation for main sequence stars, Minimum and maximum mass for nucleosynthesis, Hertzsprung-Russell diagram, Evolution of a star on the HR diagram. Novae and Supernovae, End points of stellar evolution. Inter-stellar medium. Phases of interstellar medium. Thermal, photoionisation, chemical and pressure equilibrium, Star formation, feedback and the evolution of ISM.

- Orbits around massive bodies, Tidal disruption, restricted 3 body problem, Roche limit. Orbits in external potentials, potential-density pairs. An overview of models for galaxies. Accretion of matter on to a point mass, spherical accretion, Eddington limit.
- Introduction to Cosmology, Friedmann models, equations. Hubble's law. A brief overview of the thermal history of the universe.

Textbooks:

1. Theoretical Astrophysics-I, T. Padmanabhan,
2. Theoretical Astrophysics-II, T. Padmanabhan,
3. An Introduction to Modern Astrophysics, B. W. Carroll and D. A. Ostlie,
4. Astrophysics for Physicists, A. Roy Choudhuri.

• Condensed Matter Physics II

The course will consist of any two of A-D:

Part A: Mesoscopics and spintronics:

- Foundation: low dimensional systems: quantum Wells, wires and quantum dots, 1D and 2D heterostructures, coupled wells and superlattices.
- Charge Transport: transmission and its relation to conductance, Landauer theory, transmission function, S matrix and Green functions. Non-equilibrium Green functions and Landauer-Buttiker theory. Noise in Charge transport, scattering theory of shot noise.
- Spintronics: introduction to spintronics.(Datta-Das spin transistor) equilibrium and non-equilibrium spin currents, spin Hall effect, coupled charge and spin transport, TMR, spin shot noise, entanglement generation and its detection.

Part B: Electronic structure:

- Physics in low dimensions: surface states, reconstructions, adsorption, atomic wires and clusters.
- Electron-electron interactions: Hartree-Fock approximation, electron gas, density functional theory.
- Anharmonic effects in crystals: thermal expansion, lattice thermal conductivity, umklapp processes.
- Phonons in metals: Kohn anomaly, dielectric constant, temperature dependence of electrical resistivity.
- Dielectric properties of insulators. Plasmons, magnons etc.

Part C: Mesoscopics and interacting systems:

- Quantum Hall effect
- Quantum dots and quantum wires, Kondo effect
- Fermi liquid theory and non-Fermi liquids
- Bosonization and Luttinger liquids.
- Quantum spin systems

Part D: Correlated electrons:

- Mott physics: electron localization, magnetic order, doped phase, physics in the cuprates.
- Kondo systems: physics of the single impurity, dense systems Kondo and Anderson lattice, heavy fermions, quantum criticality.
- Metallic magnets: ferromagnetism in strongly repulsive systems, the transition metals, spin-fermion systems, the double exchange model, the classical Kondo lattice.
- Electron-phonon coupling: the classical theory, polaron formation, many electron systems, polaron ordering, physics in the manganites.
- Superconductivity: the BCS-BEC crossover, superconductivity in repulsive systems, competition with magnetism, effect of disorder.

Textbooks:

1. Condensed matter field theory - A. Altland and B. Simons,
2. Field theories of condensed matter physics - E. Fradkin,
3. Electronic transport in mesoscopic systems - S. Datta,
4. Composite fermions - J. K. Jain,
5. Topological insulators and topological superconductors - B. Bernevig and T. Hughes.
6. Aromaticity and Metal Clusters, Ed. P. Chattaraj
7. Introduction to Cluster Dynamics, P.-G. Reinhard and E. Suraud
8. Surface Science, an Introduction by Oura et al.
9. Principles of Surface Physics, F. Bechstedt
10. Physics at Surfaces, A. Zangwill

• Cosmology

- Friedman-Robertson-Walker metric, Friedman equation and stress tensor conservation, equation of state: matter, radiation, cosmological constant, experimental evidence for dark matter and dark energy.
- Age of the universe, cosmological horizon, expansion rate.
- Thermal history of the universe, formation of hydrogen and origin of CMBR, decoupling of neutrinos, nucleosynthesis, recombination.
- The horizon problem, possible resolution via inflation, slow roll condition and slow roll parameters, reheating, inflationary origin of density perturbation.
- Early history, electroweak baryogenesis via leptogenesis, dark matter.

- Theory of cosmological perturbations: gauge invariant scalar and tensor perturbations, spectral index, ratio of tensor to scalar fluctuation and Lyth bound, transition from quantum to classical perturbation: horizon exit and reentry, from density fluctuation to CMB fluctuations via Boltzmann transport equation, origin of the acoustic peak, and origin of CMB polarisation, E and B modes.

Textbooks:

1. Cosmology, S. Weinberg,
2. Physical Foundations of Cosmology, V. Mukhanov,
3. Particle Physics and Inflationary Cosmology, A. Linde.

• Introduction to Electronic Structure

- Review of QM: variational method, identical particles, many fermion wave functions.
- First-principles Hamiltonian and Born-Oppenheimer approximation.
- Treating electron-electron interactions: Hartree-Fock approximation, exchange energy, correlation energy.
- Density functional theory: Thomas-Fermi method, Hohenberg-Kohn theorems, Levy constrained search formulation, Kohn-Sham formulation, exchange-correlation energy, LDA and GGA functionals, spin density functional theory.
- Solution of the Kohn-Sham equations, basis sets - LCAO: STO-NG, 4-31G, 6-31G etc, quality of basis sets, polarisation functions, spin-restricted calculations, Roothan equations.
- Spin unrestricted calculations. Plane wave basis set.
- Pseudopotentials and PAW in conjunction with plane waves.
- Structure optimisation, Hellman-Feynman theorem.
- Simple practical applications: band structure of standard solids, metals and semiconductors, optimisation of lattice constants, cohesive energies and other simple properties.
- Possible advanced topics: hybrid functionals, van der Waals interactions, density functional perturbation theory, phonon band structure, electron-phonon coupling. CI, CCSD methods, QMC.

Textbooks:

1. Density Functional Theory of Atoms and Solids, R. G. Parr and W. Yang,
2. Modern Quantum Chemistry, A. Szabo and N. S. Ostlund,
3. Electronic Structure of Materials, R. Prasad,
4. Electronic Structure, R. Martin.

• Quantum Field Theory II

- Path integrals for scalar and fermionic fields: generating functional, Feynman rules, loop diagrams.
- Renormalisation of scalar and Yukawa theories: power counting, regularisation, renormalisable and non-renormalisable theories, Green functions at 1 loop of some prototypical theories, basics of renormalisation group (running coupling), 1PI effective actions.
- Spontaneous symmetry breaking and Goldstone's theorem.
- Path integrals for the Maxwell field, gauge fixing.
- Renormalisation of QED: 1 loop diagrams, Landau pole.
- Non-abelian Gauge Theories: Classical theory of non-abelian gauge theories, Quantization of non-abelian gauge theories by path integral methods, Non-abelian gauge theories at one loop and asymptotic freedom, Spontaneous symmetry breaking in non-abelian gauge theories.

Textbooks:

1. An introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder,
2. Quantum Field Theory, C. Itzykson and J-B Zuber,
3. Quantum Field Theory: A Modern Primer, P. Ramond.

• Quantum Information and Computation II

- General evolution and Decoherence theory.
- Master equations (Markovian and Non-Markovian, Various measure of nonmarkovianity).
- Advanced entanglement theory (GM, GGM, newly proposed measures etc).
- Quantum Correlation beyond Entanglement (Quantum Discord, Geometric discord, Work-Deficit etc).
- Resource theory in QI (Entanglement, Quantum Coherence, Reference Frame, Asymmetry etc).
- Quantum Thermodynamics.
- Advanced topics in quantum channels.
- Quantum information and condensed matter systems.

Textbooks:

1. Lecture Notes on the Theory of Open Quantum Systems by D. A. Lidar,
2. The Theory of Open Quantum Systems by H.-P. Breuer, F. Petruccione,
3. Classical and Quantum Computation, A. Yu. Kitaev, A. H. Shen, and M. N. Vyalyi.

• Quantum Optics

- Introduction: Quantization of the electromagnetic field, Fock states, coherent states, squeezed states, basic atom-photon interaction, density-matrix formalism.
- Theory of coherence; Semiclassical theory of atom-photon interaction.
- Quantum theory of atom-photon interaction.
- Quantum theory of dissipation.
- Quantum information in continuous variable systems; Quantum state engineering.
- Quantum operations based on beam splitters, mirrors, squeezing and homodyne and heterodyne measurements and nonlinear operations such as parametric down converters.
- Photon addition and subtraction operations; Elements of cavity QED.

Textbooks:

1. Quantum Optics, M. O. Scully and S. Zubairy,
2. Introductory Quantum Optics, C. C. Gerry and P. L. Knight,
3. Quantum Optics, D. F. Walls and G. J. Milburn,
4. Quantum Information with Continuous Variables of Atoms and Light, N. J. Cerf, G. Leuchs and E. S. Polzik (eds.),
5. Quantum information with continuous variables, S. L. Braunstein and P. van Loock.

• Soft Matter

- Forces, energies and timescales in soft matter, van der Waals force, hydrophobic and hydrophilic interactions. Basic phenomenology of liquid crystals, polymers, membranes, colloidal systems. Phase behaviour, diffusion and flow, viscoelasticity.
- Order parameter, phase transitions: mean-field theory and phase diagrams, elasticity, stability, metastability, interfaces.
- Colloidal systems: Poisson-Boltzmann theory, DLVO theory, sheared colloids, stability of colloidal systems, measurement of interaction.
- Polymers: model systems, chain statistics, polymers in solutions and in melts, flexibility and semi-flexibility, distribution functions, self-avoidance, rubber elasticity, viscoelasticity, reptation ideas.
- Membranes: fluid vs. solid membranes, energy and elasticity, surface tension, curvature, de Gennes-Taupin length, brief introduction to shape transitions.
- Experimental tools and numerical approaches: Stokes limit, Rouse and Zimm Model for polymers, membranes, relaxation, computational studies, multiscale modelling.
- The intent is to train students in the applications of classical statistical mechanics in areas like fluids, colloids, membranes polymers. This includes training in the mathematical tools as well as the phenomenology.

Textbooks:

1. Soft Matter Physics, M. Kleman and O. D. Lavrentovich,
2. Soft Condensed Matter, R. L. Jones,
3. Principles of Condensed Matter Physics, P. Chaikin and T. C. Lubensky (Cambridge),
4. Statistical Mechanics of Surfaces, Interfaces and Membranes, S. A. Safran,
5. Soft Matter Physics, Ed, M. Daoud and C. E. Williams,
6. The Structure and Rheology of Complex Fluids, R. Larson,
7. Intermolecular and Surface Forces, J. Israelachvili.

• Ultra-Cold Atoms

- Spatial, time, and energy scales in cold atom physics.
- Experimental background: trapping and cooling, Feshbach resonance, optical lattices, cold atom spectroscopies.
- Basic theory: many particle physics, mean field theory, phase transitions, perturbation theory.
- Continuum bosons: bosons in free space, weak interactions, Bogoliubov theory, BEC in trapped systems, Gross-Pitaevski equation.
- Continuum fermions: fermions in free space, trapped fermions, Fermi liquid theory, weak attraction - BCS instability, strong attraction - BEC of pairs, the unitary Fermi gas, Stoner instability.
- Optical lattices: Hubbard model - Bose/Fermi cases, superfluid-Mott transition for repulsive bosons, BCS-BEC crossover for attractive fermions, Mott transition in repulsive fermions.
- Spin systems: quantum, S = 1/2, magnetism on unfrustrated and frustrated lattices. Entanglement in many body systems: pure states, mixed states, area laws, tensor network states.
- Special topics: population imbalance, Anderson localisation, gauge fields, quench dynamics.
- The course combines elements of atomic physics with many body theory to model collective phenomena in cold atomic gases. The students would learn of the application of quantum statistical mechanics and many body theory in the context of interacting Bose and Fermi gases.

Textbooks:

1. Many Body Physics with Ultracold Gases, Les Houches Lectures, Ed, C. Salomon, G. Shlyapnikov and L. F. Cugliandolo,
2. Ultracold Quantum Fields, H. T. C. Stoof, K. B. Gubbels and D. B. M. Dickerscheid,

3. Ultracold Bosonic and Fermionic Gases, K. Levin, A. L. Fetter and D. M. Stamper-Kurn,
4. Bose-Einstein Condensation in Dilute Gases, C. J. Pethick and H. Smith,
5. Bose-Einstein Condensation, L. P. Pitaevskii and S. Stringari,
6. Theory of Ultracold Fermi Gases, S. Giorgini, L. P. Pitaevskii and S. Stringari,
7. Ultracold Atoms in Optical Lattices: M. Lewenstein et al.
8. Cold Atoms and Molecules: Weidenmuller, Zimmerman.

(19)Project

In this semester, every student is supposed to do a project on a theoretical physics topic under the supervision of HRI faculty. Main fields in theoretical physics represented at HRI at the moment are, Astrophysics, Condensed Matter Physics, Particle Physics Phenomenology, Quantum Information and Computation, and String Theory.

(20) Laboratory III

- Ferro to Para Electric Phase Transition (or its Magnetic analogue)
- Raman Spectroscopy
- ESR
- Earth's field NMR gradient
- Bragg Diffraction by Microwaves
- Hall Effect
- G-M counter, Counting Statistics, Gamma ray absorption cross section
- Gamma ray Spectroscopy
- STM with Graphene, HOPG, Gold, Semiconductors and CDW
- Measurement of Speed of Light

Other Electives

• Advanced Particle Physics

- The discovery of the Higgs boson; the Higgs and vacuum stability.
- Issues in collider physics, motivations and outcome of the LHC, motivations for future collider experiments.
- CP-violation, the unitarity triangle, outcomes of B-factory measurements.
- The evolution of parton distribution functions, Altarelli-Parisi equation, applications to LHC physics.
- The motivations for physics beyond the Standard Model current constraints from accelerator and astroparticle/cosmological data, the dark matter issue; supersymmetry, grand unification.

Textbooks:

1. Gauge Theory of Elementary particle physics, T.-P. Cheng and L.-F. Li,
2. Foundations of Quantum Chromodynamics, T. Muta,
3. Collider Physics, V. D. Barger and R. J. N. Phillips,
4. Beyond Standard Collider Phenomenology of Higgs Physics and Supersymmetry, M. C. Thomas.

• Spectroscopic Methods

- Probes for matter on different energy and spatial scales.
- Interaction of electromagnetic radiation with matter, correlation functions in classical and quantum matter, point group symmetries and selection rules.
- Electron spectroscopy in atoms and molecules: single and many electron atoms, simple molecules, vibronic transitions.
- Vibration and rotational spectroscopy: infrared, Raman and microwave methods. Computing the spectrum of simple atomic and molecular systems.
- Probing spin states: electron spin resonance and nuclear magnetic resonance. Mossbauer spectroscopy. Spectra of magnetic ions. Solid state effects on the spectrum.
- Probe of collective effects: X-ray and neutron scattering from condensed matter. Static structure and dynamical correlations. Effect of phonons on lattice dynamical structure factor. Dynamical magnetic structure factor from ferro and antiferromagnetic spin waves. Diffuse magnetic scattering. Dynamics of classical liquids.
- Extended electronic states: angle resolved photoemission spectroscopy, computing the spectrum for weakly correlated electron systems.
- Ultrafast dynamics: control and probe of chemical reactions via femtosecond spectroscopy.

Textbooks:

1. Modern Spectroscopy, J. M. Hollas,
2. Symmetry and Spectroscopy, Harris and Bertolucci,
3. Introductory Raman Spectroscopy, J. R. Ferraro, K. Nakamoto and C. W. Brown,
4. Understanding NMR Spectroscopy, J. Keeler,
5. Theory of Neutron Scattering from Condensed Matter, S. W. Lovesey,
6. Dynamic Light Scattering, Berne and Pecora,
7. Photoemission in High Tc Superconductors, Campuzano, Norman and Randeria, in Bennemann and Ketterson, Superconductivity Vol. 2,
8. Chemical Reactions and their Control on the Femtosecond Time Scale, P. Gaspard and I. Burghardt Femtosecond Laser Spectroscopy, Ed, P. Hannaford.

- # Quantum Many Body Theory

- Basics: second quantisation, the many body Hilbert space, few particle problems. Green functions: formal definition, Lehmann representation, calculation for quadratic problems, expression of observables in terms of Green functions. Finite temperature: the imaginary time formulation, analytic continuation.
- Perturbation theory: the interaction representation, Wicks theorem, low order expansion and diagrammatic representation, Dyson equation and self-energy, vertex functions and Bethe-Salpeter equation, explicit calculations in the Anderson impurity model.
- Resummations: random phase approximation in the electron gas, ladder summation in dilute hardcore systems, Hartree-Fock and higher order conserving approximations.
- Long range order: self-consistent calculations for broken symmetry phases, static mean field and dynamical calculations, Nambu formulation and Eliashberg theory. Goldstone modes in the ordered phase - metallic antiferromagnets and superconductivity,
- Functional integral methods: representing the partition function, bosons and fermions, quadratic integrals, Hubbard-Stratonovich decomposition of interactions, saddle point, gaussian fluctuations, beyond the gaussian theory, Ginzburg-Landau expansions.

Textbooks:

1. Introduction to Many-Body Physics, P. Coleman,
2. Fundamentals of Many-Body Physics: Principles and Methods, W. Nolting,
3. Quantum Theory of Many-Particle Systems, A. L. Fetter and J. D. Walecka,’
4. Many-Body Physics, G. D. Mahan.

BACK TO MAIN

TMC

M.D. PATHOLOGY
(PROGRAM CODE: HLTH09A01)

HOMI BHABHA NATIONAL INSTITUTE (HBNI)

CURRICULUM FOR MD PATHOLOGY

YEAR 2009 - VERSION 1

PRODUCED BY – Department of Pathology

DATE ACTIVE – Sept 2009

DATE OF REVIEW -

INDEX

1. INTRODUCTION

The MD Pathology course under the HBNI comprises of histopathology, autopsy pathology cytopathology, clinical pathology, and hematology and transfusion medicine

The course complies with Medical Council of India Guidelines and ensures the following

- MD Pathology Post Graduate (PG) program is of three years duration after MBBS
- Postgraduate curriculum is competency based
- Learning in Postgraduate program is essentially autonomous and self directed
- A combination of both formative and summative assessment is vital for the successfu completion of the PG program
- The training of PG students involves learning experience 'derived from' and 'targeted to' the needs of the community

2.SELECTION GUIDELINES

1. Students for the postgraduate medical course shall be selected strictly on the basis of their academic merit
2. The basis of merit will be determined by the competitive test conducted by the State Government of Maharashtra or by the competent authority appointed by the State Government of Maharashtra to determine merit (such as MHCET)
3. Any other inputs may be obtained from Dean's Office

3. DURATION OF TRAINING

The period of training will stretch over three years

It is recommended that the course of Doctor of Medicine (Pathology) or MD (Pathology) be of THREE YEARS duration in the form of a residency program that is FULL TIME

The course curriculum is divided into three stages covering these three years as

Junior registrar I, Junior registrar II, Junior registrar III

The major components of the postgraduate curriculum are as as under

- Theoretical Knowledge
- Practical and Clinical skills
- Thesis skills
- Attitudes including communication skills
- Training in research methodology

4. PURPOSE OF THE CURRICULUM

The educational programme is aimed at providing:

- ✓ Experience of the diagnostic techniques required to become technically competent in Practical Laboratory Diagnostic Work

- ✓ Broad practical and theoretical knowledge of all aspects of routine surgical pathology and also specialist areas such as cytopathology, hematology, oncopathology and histopathology of specific systems in order to be able to provide specialist advice

- ✓ Experience of the practice of evidence based clinical medicine through attendance in joint clinics or multi disciplinary teams.

- ✓ Inculcating a habit of literature searches, attendance at scientific meetings, and the presentation of scientific work

- ✓ Competency to impart training to students at various levels including postgraduate level in the subject and carry out research

- ✓ Competency for planning, organizing and establishing pathology services / department in all types of medical establishments

5. BROAD OBJECTIVES

Cognitive Domain

- Diagnose routine and complex clinical problems on the basis of Histopathology (Surgica Pathology) and Cytopathology specimens, Blood and Bone Marrow examination and various tests under the domain of Laboratory Medicine (Clinical Pathology, Clinica Biochemistry/Chemical Pathology) as well as Blood Banking (Transfusion Medicine).
- Interpret clinical and laboratory data with reasonable accuracy.
- Correlate and advice further on pathology data so that various clinical aspects of disease can be correlated and explained.
- Should be able to teach pathology to undergraduates, postgraduates, nurses and paramedica staff including laboratory personnel.
- Able to supervise work of subordinate laboratory staff and colleagues.
- Able to initiate research questions and systematically write or present a paper and publish in a journal.
- Aware of quality control and biosafety and waste disposal issues in a laboratory.
- Subject himself/herself to continuing education and constantly update his/her knowledge o recent advances in Pathology and allied subjects.

Psychomotor Domain

- Able to perform most of the routine tests in a Pathology Laboratory including grossing o specimens, processing, cutting of paraffin sections making smears, making frozen sections anc staining.
- Able to collect specimens by routinely performed non-invasive out-patient procedures such as venepuncture, finger-prick, fine needle aspiration biopsy of superficial lumps and bone-marrow aspirates.
- Perform an autopsy, dissect various organ complexes and display the gross findings.
- Should be familiar with the function, handling and routine care of equipment in the laboratory.

Affective Domain

- Should be able to function as a part of a team that is essential for the diagnosis anc management of a patient and interact with the patient, the clinician and all other colleagues tc provide the best possible diagnosis or opinion.
- Always adopt ethical principles and maintain proper etiquette in his/her dealings with patients relatives and colleagues.
- Develop communication skills to word reports and interact with patient's relatives, peers anc paramedical staff.

6. TRAINING SCHEDULE

Scope of training –

As pathology is a bridge between basic medicine and all other clinical branches it covers a wide range of subjects and subspecialities.It involves both clinical skills and laboratory technological methods which are both traditional and novel. It is difficult to expect full proficiency in all branches of pathology within the limited span of three years. Keeping the aims of this course in mind the following are the levels of competence that are expected to be achieved.

A) High Degree of Professional Competence: In the subjects of Anatomic Pathology (Surgical Pathology and Cytopathology) and Haematology

B) Reasonable working knowledge: In the subjects of Laboratory Medicine (Clinical Chemistry/Clinical Pathology/ Microscopy) and Transfusion Medicine (Blood–Banking)

C) General /Theoretical Acquaintance in the following subjects

- **Immunopathology / Immunofluoroscence**
- **Immunohistochemistry**
- **Molecular Pathology/ Cytogenetics/ Tissue Culture**
- **Medical Statistics / Ethics**
- **Library / Information retrieval / Web search engines in medicine.**

7. ROTATION SCHEDULE

There will be two years of training in Tata Memorial Hospital and one year training in a General Teaching Hospital (either Government or Municipal).

Section /Subject	Duration in months
(i)Orientation Rotation	2
(ii) Government / Municipal Medical College /Hospital*	6
(iii) Surgical Pathology and Fine Needle Aspiration Cytopathology	14
(iv) Hematology	2
(v) Exfoliative Cytology	1
(vi) Transfusion Medicine/Blood Bank	2
(vii) Basic sciences including Molecular Biology, Cytogenetics, Research techniques	1
(viii)Government / Municipal Medical College /Hospital **	6
(ix) Elective / Reorientation)	2
TOTAL	36 Months

*The peripheral posting in the first year in Government / Municipal Medical College / Hospital will specifically include Autopsy, non oncology related aspects of Pathology, Clinical Pathology, Hematology, Systemic Pathology, Blood Bank and Immunohematology.

** The peripheral posting in the third year in Government / Municipal Medical College /Hospital will include Surgical Pathology specialized postings such as Neuropathology, Dermatopathology, Cardiac Pathology and Renal Pathology

8. YEARLY ASSESSMENT

Purpose of assessment

This assessment seeks at evaluating students in the areas they were trained within the period. A standardized scheme is necessary to train candidates in any teaching program

Method of assessment

Log book (Work Diary) : Record of Three Years

The postgraduate students should record all their activities in a log book includes duration of posting, the period of absence if any, skills performed, and remarks if any by teacher/ faculty member

The log book should also record journal clubs, seminars attended / part taken as well as undergraduate and paramedical teaching activities the candidate has participated

Annual assessment based on the work diary shall be done by the P G teacher and Head of the Department

First year assesment (External & Internal) : Total Marks 500

i)Multiple choice question / MCQ paper (Hematology & Surgical Pathology) = 220 marks
ii) Brief answer question paper comprising 10 questionsX 10 marks = 100 marks
iii) Microscopy test (10 slides X 5 marks) = 50 marks
iv) Thesis status discussion by external assessor = 30 marks
v) General Viva= 100 marks

Final year examination : Total marks 800

a)Essay paper – 400 marks
There shall be four theory papers of 100 marks each

Paper I - General pathology including general neoplasia, immunopathology and cytopathology
Paper II - Systemic Pathology including Systemic Neoplasia
Paper III – Hematology, Transfusion Medicine, Immunohematology, including recent advances
Paper IV – Clinical Pathology, Chemical Pathology, Pathology of Infectious Diseases, Recent Advances

b)Practical examination- 400 marks
Details of exercises and marks

1. Histopathology Slides (25slides X 5 marks each)- 125 marks
2. Clinical case – 75 marks
   - Urine Examination
   - Biochemical Test
   - Hemogram

- Special Hematology test
- Case Discussion

3. Hematology and Cytology Slides (15 slides X 5 marks each) - 75 marks
4. Gross/ Morbid Anatomy – 35 marks
   - Seven spots of Gross specimens (7 X 5 marks each)and no viva for the same
5. Autopsy/Reconstructed Autopsy – 20 marks

   Student have to do internal or external examination of dead body in post mortem room
6. Histopathology Techniques – 15 marks
   - To perform H & E staining
   - Block cutting on microtome
   - To perform special stains
   - Viva for the same
7. Serology technique – 15 marks
   - Blood grouping
   - Cross matching
   - DCT/ ICT titre
   - Viva for the same

c) Viva Voce Examination - 40 marks

Includes thesis discussion

d) **Dissertation**

Date of submission: Six months before the Final Examination

Aims:
To encourage the spirit of enquiry, inventiveness and inculcate aptitude for research.

Objectives:
1.Discern and recognize areas where research is informative and useful to improve medica practice

2.Assimilate/ analyze data and compare results from similar studies in past or in latest world literature

General guidelines:
1. Dissertation based on research work is aimed at encouraging a spirit of enquiry, aptitude foı research, critical analysis of methods and results in the light of the latest developments in medicine.

2. All students registered for the course will have to submit dissertation/thesis work during the course The research work done independently by the candidate under the guidance of his guide should be the basis of the dissertation.
3. Prior sanction – IRB review

If the research work involves coordination or collaboration with another department, a suitable co-guide from that department from among the PG teachers may be designated by the Head of the Institution.

If the PG guide becomes unavailable, on account of transfer, retirement etc in the last two terms o training, the student may be allowed to continue under the same guide and sign the required certificate with specific approval from the University. If the guide becomes unavailable earlier than the 5th term, a new guide has to be assigned to the student. The new guide cannot be assigned for another PG student for the next term or next two terms as the case may be.

The age limit for PG teachers for guiding students shall be 65 years

Once the dissertation is accepted, the candidate can appear for the final examination for up to 4 years Any candidate failing to appear in the final examination within 4 years, will be required to undergo training again for a period of 4 terms before appearing for degree examination.

Grading of students

Criteria for passing : Minimum 50% of total marks in each paper and practicals separately

9. LEARNING MODULES

The following teaching/learning methods will be used to identify how individual objectives will be achieved.

a) Routine work: the most important learning experience will be day-to-day work.
b) Textbooks: A departmental library is available for quick reference for students
c) Histology, cytology and hematology slide meetings.
d) Gross meetings
e) Journal club
f) Symposia
g) Intradepartmental student debate
h) Interhospital CPC meeting
i) Attend monthly teaching pathologist meeting
j) Attend specialist lectures, training courses and CME's conducted in house and elsewhere
k) Scientific meetings: Residents will be encouraged to attend and participate in the Maharashtra Chapter and National meeting of the Indian association of Pathologist and microbiologist (IAPM).
l) Clinical meetings: - Comprising weekly multi faculty hospital joint meeting and interdepartmental multidisciplinary joint meeting.
m) E-learning and internet literature search
n) Log book
o) Basic statistics training program
p) Good clinical practice training

10. DETAILED SYLLABUS

09HLTH09A01-001-C

SURGICAL PATHOLOGY

AIM – Training to include

1. Grossing of all surgical specimens in keeping with protocol or guidelines for handling various specimens
2. Identify, and systematically and accurately describe the chief gross and microscopic alterations in the surgically removed specimens
3. Correctly diagnose majority of the lesions received on an average day from the surgical service of a general hospital.
4. Knowledge and incorporation of internationally approved terminology for classification of diseases e.g. WHO and TNM staging for tumors.

Title	Gross	Skill	Knowledge
General Surgical Pathology	Correct specimen orientation Protocols for obtaining fresh tissues for ancillary methods Grossing of all common specimens and understanding attention to detail during specimen description and section taking	Setting up a microscope Normal histology of various organs Be able to start a tissue processor, process tissues make a paraffin block and cut sections of good quality on a rotary microtome. Stain paraffin sections Haematoxylin & eosin, PAS stain, mucin, Masson Fontana, AFB.	Normal histology and pathologic conditions, types of fixatives, tissue processing, special stains Frozen section competency, Ancillary methods in histopathologic diagnosis like Immunofluorescence, ultra structure, cytogenetics, understand integration of ancillary methods and clinical information
Breast	Grossing mastectomies, breast conservative surgical resection specimens including lymphnode dissection.	Diagnosis of invasive breast carcinoma and subtypes, Histopathology reporting and essentials to be included in a report on breast carcinoma.	Prognostic and predictive factors in breast cancer, Identifying DCIS, firboadenoma, phyllodes tumor, spectrum of proliferative breast disease, special tumors like adenomyoepithelioma, Paget's disease, Diagnostic methods, disease of male breast,
Gastrointestinal tract	Grossing of Radical excisions such as APR, anterior resections etc	Classification of gastritis, identifying Barrets esophagus, identifying H pylori, diagnosis and classification of inflammatory bowel	Congenital and mechanical disorders, Molecular and etiopathogenetic mechanisms in adenocarcinoma, premalignant disease, Prognostic and predictive

		disease, different histology's in polyps, Adenomas, Infections and parasites affecting the GIT Diagnosis and histopathology reporting of carcinomas and other tumors such as Gastrointestinal stromal tumors,	factors in carcinomas of GIT, unique lymphomas involving the GIT, neuroendocrine tumors of GIT, Polyposis syndromes, malabsorption syndromes, Celiac disease and tropical sprue, vascular disorders, diverticulosis, intussusceptions,
Hepatobiliary system	Hepatectomy specimens Cholecystectomy specimen Whipple's surgery	Histopathology reporting in hepatectomy, Cholecystectomy and Whipple's resection. Liver biopsy – diagnosis of cirrhosis and malignancies , classification or grading of hepatitis	Types of cirrhosis, Drug induced hepatitis, metastatic carcinoma, Hepatocellular carcinoma(HCC) variants like fibrolamellar HCC, hepatoblastoma, Metabolic liver disease, Liver in inherited disorders of metabolism e.g. Wilsons disease, glycogen storage disorder Pancreatic disease e.g. diabetes mellitus, islet cell tumors
Head and Neck	Grossing of major resections in head and neck e.g. composite resection, hemimandibulectomy, maxillectomy, salivary gland excisions etc	Diagnosis of squamous carcinoma Evaluating dysplastic changes in squamous epithelium Identify chief types of salivary gland tumors- Pleomorphic adenoma, adenoid cystic carcinoma, Warthin's tumor, ductal carcinoma	Nasal polyps, common tumors in children, Myoepithelial salivary gland tumors, neck cysts
Neuropathology	Neurosurgical resections	Common brain tumors, Metastatic carcinomas, tumors of peripheral nerves, WHO classification of CNS tumors	Dementia, Demyelinating diseases of brain, muscle/ nerve biopsy

Gynecology	Examination of hysterectomy and salphingo-oophorectomy for benign and malignant diseases. Cervix cone biopsy processing Grossing of placenta	Endometrial pathology, leiomyoma, endometriosis, adenomyosis, common ovarian tumors, Cervical pathology including intraepithelial neoplasia, Reporting of Wertheim's hysterectomy	Normal ovarian and endometrial histology, Polycystic ovarian disease, endometrial biopsy interpretation in infertility or dysfunctional bleeding, Endometrial stromal sarcom, malignant mixed mullerian tumor, placental pathologic abnormalities, ectopic pregnancy, Gestational trophoblastic disease
Male genital system	Radical prostatectomy, Orchidectomy and penectomy specimen evaluation	Evaluating prostatic biopsies for cancers Diagnosis of testicular germ cell tumors Histopathology reporting of orchidectomy	Gleason's grading system, Non germ cell tumors of testes. carcinoma of penis and scrotum, Testicular biopsy and investigations in male infertility
Urology and Nephropathology	Renal and bladder tumor excisions	Renal biopsy interpretation with emphasis on glomerular disease, bladder biopsy evaluation for urothelial tumors and inflammations, Histopathologic reporting of nephrectomy specimens	Immunofluorescence and ultrastructural findings in glomerular diseases, Urinary outflow obstruction causes and pathology.
Dermatopathology	orientation of skin biopsy	Inflammatory skin biopsy :- descriptions and observations, Diagnose basic skin carcinomas Diagnosis of nevi and melanoma	Histologic findings in bullous skin lesions, pemphigus, psoriasis, dermatitis herpetiformis, seborrheic keratosis, actinic keratosis, hemangiomas, skin cysts, granulomatous lesions of skin, infections, common ski adnexal tumors,
Lymph Node pathology	Recording abnormal gross appearances	Identifying metastatic carcinoma, granulomatous lesions, Distinguish reactive Vs malignant lymphoid proliferation, Hodgkin's from Non	Recognition of viral / bacteri lymphadenitides and lymphadenopathies, Immunohistochemical distinction between different primary carcinomas Immunohistochemistry in lymphoid disorders and lymphomas

		Hodgkin's lymphoma, Identify broad categories of Non Hodgkin's lymphoma	
Respiratory tract	Lung resections lobectomy and pneumonectomies	Reporting on lung cancer resections, Lung biopsy interpretation for cancer , granulomas.	Histologic subtypes of lung carcinomas, Lung biopsy interpretation in interstitial lung disease Distinguishing primary from metastatic lung carcinomas, common pleural tumors :- mesothelioma
Mediastinum	Wide excsions of tumors	Core biopsy in mediastinal tumors, Thymic tumors-classification and diagnosis	Diagnosis and approach to common tumors and cysts within the mediastinum
Endocrine System	Thyroidectomy and parathyroid, adrenal excisions	Diagnose goitre, papillary thyroid carcinoma, follicular carcinoma, adenoma in thyroid. Distinguish parathyroid hyperplasia from adenoma or carcinoma Distinguish adrenal adenoma from a carcinoma. Diagnose a Pituitary adenoma.	Approach to evaluation of solitary thyroid nodule, Hurthle cell tumors, Types of thyroiditis, Graves disease, Functional disorders of thyroid, Metabolic disorder associated with parathyroid hormone secretion. Clinical presentation and Investigations in secreting tumors of pituitary and adrenal gland, Multiple endocrine neoplasia
Musculoskeletal system	Soft tissue tumor resections, Bone tumor and amputation grossing	Common bone and soft tissue tumors	Paget's disease of bone, osteomyelitis, Degenerative and dystrophic muscle disease, synovial diseases, Cytogenetic and immunohistochemistry in bone and soft tissue tumors, tumor like lesions, joint diseases and arthritis, metabolic bone disease and bone biopsy interpretation, synovial biopsy indications and evaluation
Pediatric pathology	Pediatric embroyonal tumor excision grossing	Inflammatory and neoplastic lesions in children Hirshsprung's disease evaluaution.	Myofibroblastic tumors in children, common developmental pediatric tumors e.g neuroblastoma, retinoblastoma, hepatoblastoma, Wilms tumors and rhabdomyosarcoma.

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AUTOPSY PATHOLOGY

AIM – Resident should be able

1. To perform autopsies safely, eviscerate and dissect organs
2. To liase with clinician and identify issues to be addressed by autopsy exmination
3. Correctly identify all major lesions which have caused, or contributed to, the patient's death on macroscopic examination.

Systems	Technique	Knowledge expected
Cardiovascular	Demonstration of heart chambers, major vessels and coronaries. Demonstration of pulmonary embolism identification of abnormalities like infarcts and congenital anomalies	Normal age related changes, All major pathologic processes involving valves and vessels, causes of cardiac failure, infarction, rheumatic heart disease, infective and non infective endocarditis, cardiomyopathy, myocarditis, pericarditis and effusion, causes of sudden cardiac death, congenital heart disease, dissectior of aorta, classification of vasculitis, aneurysms, tumors of vessels and heart
Respiratory	Dissection of bronchi and lung lobes Demonstration of pneumonia, air embolism, pneumothorax	Gross appearance of lung tumors, infarct, interstitial lung disease, pneumoconiosis, sarcoidosis, infections like tuberculosis, fungal infections etc , adult respiratory distress syndrome, drug, toxin and radiation induced injury, obstructive pulmonary disease, bronchial asthma, bronchiectasis, chronic bronchitis, emphysema , atelectasis, pulmonary hypertension, pleural effusion causes
Gastrointestinal tract (GIT)	Dissection of entire system in continuity, Identification of ampulla of Vatr Normal mucosal surface in entire GIT	Appearances of esophageal varices, distinguishing the various ulcerative lesions within the GIT, Diverticulitis, gangrenous changes etc
Hepatobiliary	Removal of liver and dissecting the gall bladder and entire bilary tract , hepatic vein and portal vein	Evaluation of different abnormal changes in liver in cirrhosis etc. Causes and spectrum of acute and chronic liver failure chronic and acute hepatitis, autoimmune hepatitis, alcoholic liver injury and alcoholic liver disease, Biliary obstruction, veno occlusive disorder, Budd Chiari syndrome, Portal hypertension effects anc causes, cholecystitis, Acute and chronic pancreatitis

		Identification of tumors in the system
Male genital	Dissection of entire urinary system with kidneys and urinary bladder in continuity with vas deferens, prostrate and testes	Evaluation of abnormalities of kidney and pelvicalyceal system Diseases affecting the male genitals
Endocrine	Removal of pituitary, parathyroid, adrenal and thyroid	Normal weights and gross abnormalities ir these organs
Nervous	Brain removal and slicing to demonstrate important brain nuclei, internal capsule, hypothalamus and other structures Demonstration of circle of Willis	Abnormal appearances of vessels, infarcts, atrophic changes and tumors, Ateriovenuos malformations, cerebrovascular disease, increased intracranial pressure causes and effects,
Lymphoreticular	Examination of draining nodes in different systems Spleen removal and examination Collecting marrow	Knowledge on common blood diseases and causes of nodal or spleen enlargement
Musculoskeletal	Identify fractures and collecting muscle biopsy	Pathological conditions affecting bone anc soft tissue

CYTOPATHOLOGY

Subject	Skill	Knowledge
Gynecologic cytology	Technique for spreading and fixing a smear, specimen adequacy , how to screen a smear, knowledge of infections in cervical smears, picking up abnormal cells, understanding the Bethesda system of reporting cervical smears, understand reasons for cytology-histology discrepancy	Smear taking techniques, Basic knowledge of colposcopy and treatment implications of abnormal cytology report, awareness of pitfalls and limitations of cervical smear screening.
Nongynecologic exfoliative cytology	Preparation and fixing of smears Diagnose malignancy in commonly investigated sites like pleural fluid, ascitic fluid and urine, distinguish from reactive mesothelial cells	Knowledge of staining techniques, understand structuring of reports and histological correlation, understand pitfalls and artifacts in processing
Fine needle aspiration cytology	Breast :- Diagnose malignancy and fibroadenoma Thyroid:- Diagnose papillary carcinoma, approach to diagnosis of follicular lesions, medullary carcinoma and lymphoma Lymph nodes:- Recognize specific and nonspecific reactive lymphadenitis,	Understand role of FNAC in diagnosis of lesions of thyroid, breast, node and salivary glanc Recognize when definitive diagnosis requires histology, Familiarity with processing of guided FNAC, Awareness of situations requiring

	diagnose metastatic carcinoma and lymphoma Salivary gland :- Diagnose pleomorphic adenoma, Warthin's tumor, adenoid cystic carcinoma Diagnose cancer in Lung, Liver, Mediastinal and Abdominal FNAC	multidisciplinary discussions
Miscellaneous	Knowledge of likely outcome of all diagnosis., of malignancy or infections in unusual specimens e.g. bile duct brushings etc	Quality assurance in cytology, Audit of cervical screening programs etc, role of ancillary methods like immunocytochemistry, flow cytometry in common cancers

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CLINICAL PATHOLOGY and ROUTINE HEMATOLOGY

Aim :-

(1)Establish and direct a hematopathology laboratory that includes clinical hematology, urine analysis, clinical microscopy, flow cytometry and diagnostic hematopathology

(2) to provide consultation to clinicians on patient problems related to hematopathology.

Training period: four month rotation in the service, weekly didactic teaching and slide sessions

Subject	Skill	Knowledge
Blood collection	Learn safe practices for patient blood collection, use of different anticoagulants for blood collection. Blood collection procedures for venous, capillary and from central lines	Understand physiological variations in samples
Blood cell counters / Automated Hematology	Interpret results of automated and manual cell counts and scattergrams. Review abnormal results, correlate results with peripheral blood smear findings and clinical history	Knowledge of the principles of automated cell counting including RBC indices and their derivation and the principles by which each instrument type arrives at a 5 part differential. Know the effect of nucleated RBC on WBC counting, and appropriate WBC correction, Know the importance of absolute versus relative counts and the absolute neutrophil count (ANC) and its clinical utility, principles of automated Reticulocyte enumeration, pathophysiology and laboratory findings of the major disorders causing anemia

Peripheral smear analysis	Learn proper preparation and handling of peripheral blood smear Learn normal RBC, WBC and platelet morphology Estimate WBC and platelet counts, Recognize abnormal RBC, WBC, platelet morphology, and interpretation in a clinical context Detection of parasites in peripheral blood	Knowledge of methods of staining peripheral thick and thin smear and trouble shooting Knowledge of WBC, RBC and platelet disorders Implications for an abnormal peripheral smear finding Knowledge of special types of smears and timing for collecting blood for detection of parasites like microfilaria etc
Blood indices , ESR, Reticulocyte counting	Methods to estimate hematocrit / blood indices and ESR Perform manual hematocrit and ESR testing	Principle of estimation and abnormalities in erythrocyte sedimentation rate Understand the principle and utility of supravital stains, reticulocyte stain, Heinz body demonstration etc
Body fluid analysis **(Pleural, ascitic fluid, CSF, synovial fluid)**	Learn manual hemocytometer cell counting, Understand cytocentrifuge preparation and slide staining Identify blood and body fluid cell morphology Recognize malignant cells and recommend appropriate confirmatory tests. Identify organisms: bacteria, fungi, parasites	Neubauer's chamber use and counting principle, Stains used to count cells in fluid, Knowledge of fluid composition in normal and pathologic states, ability to diagnose based on findings documented and Correlate with clinical history and other laboratory results. Principles and use of dark field or fluorescent and polarized microscopy in fluid examination Abnormalities seen and reporting of a semen sample in infertility Special stain on fluids, India Ink preparation on CSF, Gram stain, Z N stain
Urine analysis	Interpret routine urinalysis(Cellular and chemical) and identify abnormal cells and organisms, Know to perform chemical tests in urine sample for pH, occult blood, protein, sugar chyluria, bile salts/ pigments, etc	Understand the principles of methods involved in urine chemistry and urine cytology by wet preparation examination Understand indications for urinalysis Understand the principles of

		automated urine cytology analyzers
Stool examination	Wet mount of stool for examination Identify abnormal cells, parasites. Learn to detect occult blood in stools	Knowledge of parasites in stool , their stages of development, Implications of detection of abnormalities

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HEMATOPATHOLOGY

Subject like lymph node pathology and bone marrow trephine biopsy will be reported in the surgical pathology section while marrow aspirates and fluid hematology will be covered in 7th floor hematology laboratory and residents will rotate through Gvernment/ Municipal hospital for non neoplastic and immunohematopathology training

Subject	Skill	Knowledge
Bone marrow aspirates	Work up a aspirate right from obtaining the peripheral blood smear, aspirate smear, relevant lab results /history to seeing cells Learn normal aspirate cellular findings, approach to diagnose abnormal findings and integrate aspirate with trephine biopsy findings Recognize normal WBC, RBC and platelet maturation, as well as cellular dysplasia Diagnosis of all common hematological conditions. Stain and Interpret cytochemical stains like Pearl/Iron stain, Myeloperoxidase, Non Specific Esterase	Abnormalities detected in a marrow aspirate including abnormal cells, abnormal maturation, viral inclusions, marrow in storage disorders, diagnose iron overload, Marrow findings in refractory anemia's, leukemia's and lymphomas Understand the principle and clinical utility of cytochemical stains, their interpretation, and applications
Bone marrow trephine biopsy	Learn technical aspects of performing and analyzing bone marrow aspiration and biopsy Learn handling, preparation and interpretation of bone marrow biopsy specimen including special stains (e.g.Wright's, LAP(Neutrophil	Know causes of cytopenias or aplastic marrow, Integrate morphology, cytochemistry, immunophenotype and molecular and cytogenetics and render a preliminary diagnosis. Knowledge of all subtypes of

	Alkaline Phosphatase), Iron, Myeloperoxidase, Non Specific Esterase,Tatrate Resistant Acid Phosphatase, Alkaline Phosphatase, Prussian blue) Correctly assess bone marrow cellularity, storage iron and fibrosis. Recognize reactive bone marrow and abnormal infiltrates, effects of chemotherapy and growth factor stimulation on blood and bone marrow Diagnose and classify leukemia , hematolymphoid malignancies	acute and chronic leukemias, myeloproliferative disease, patterns of involvement by lymphoma.
Flow Cytometry	Observe lymphoma/leukemia panel performed on blood and/or bone marrow. Clinical presentation, morphology, evaluate and interpret results of flow cytometry in conjunction with cytochemistry Clinical Presentation, Morphology and immunohistochemistry studies	Understand the physical components and operating principles of a flow cytometer and quality control procedures, Know the principles of routine flow cytometry evaluation of leukocytes, including both surface and intracellular markers, and recognize clonal abnormalities, principle of tests designed to evaluate the DNA content (ploidy) and cell cycle. Understand the diagnostic, prognostic information provided by flow cytometry and lymphocyte subset analysis: know the commonly used antigens to define T helper, T suppressor, natural killer and B cell, Understanc the characteristic clinical, morphologic, immunophenotypic, cytochemical and

		cytogenetic/molecular features of leukemia's, lymphomas and Plasma cell dyscrasias, Paroxysmal Nocturnal Hemoglobinuria
Coagulation profile	Be able to perform coagulation tests like Prothrombin Time, Activated Partial Thromboplastin Time Interpret results of laboratory tests utilized in the management of bleeding and thrombotic disorders, Interpret results of coagulation tests in the setting of fibrinolytic therapy Recognize platelet function abnormalities associated with acquired and congenital thrombocytopathies (thrombasthenia, Bernard Soulier Syndrome, Storage Pool Disease), Interpret platelet function studies including platelet aggregation and secretion studies, and screening studies and "in vitro" screening tests of platelet function Interpret studies performed for the evaluation of vWD	Develop basic understanding of haemostatic and thrombotic disorders Knowledge of the effect of hematocrit and blood drawing technique on anticoagulation of blood sample for coagulation testing principles of routine coagulation analysis (PT, APTT, fibrinogen, Thrombin Time), INR derivation and its clinical significance, principle of tests involved in monitoring heparins, laboratory evaluation of DIC, qualitative and quantitative testing. pathophysiology of the coagulation factor deficiencies tests involved in the identification of lupus anticoagulant and antiphospholipid antibody syndromes Interpret results of tests measuring components of the fibrinolytic system Interpret results of test for thrombotic risk factor identification: Protein C, S, ATIII, and Activated Protein C Resistance Discuss risk factors leading to arterial and venous thromboembolic disease. Understand the mechanism of action of platelet directed inhibitors and fibrinolytic agents, and their effects on laboratory testing
Hemoglobinopathies	Be able to perform Sickling test and osmotic fragility test, Interpret an Hb electrophoretic pattern and diagnose major hemoglobinopathies (Sickle cell anemia, alpha/beta thalassemia, Hgb E disease	Understand the role of Fe in RBC production/hemoglobin synthesis Describe Fe metabolism and laboratory tests for Fe (Serum ferritin Serum iron and total iron binding capacity) Understand Hemoglobin synthesis

	and Hgb C disease)	and degradation and genetic mechanisms in hemoglobinopathies. Knowledge of principles of hemoglobin screening by HPLC and electrophoresis, osmotic fragility test, sickle solubility screening, Kleihauer Betke, Ancillary tests for the RBC disorders related to enzyme defects (G6PD deficiency, methemoglobinemia) / Hereditary spherocytosis/ Paroxysmal nocturnal hemoglobinuria / Hemolytic Anemia / Congenital dyserythropoietic anemias Prenatal diagnosis of Thalassemias
Platelet disorders	Perform manual estimation of platelets	Knowledge of causes of Thrombocytopenia and thormocytosis, Understand the principles of platelet discrimination and counting by automated hematology analyzers, Knowledge of platelet function tests and their uses.

09HLTH09A01-005-C

IMMUNOLOGY

Subject	Skill	Knowledge
Cells of immune system	Interpret lymphocyte immunophenotyping on flow cytometry data used to characterize leukocyte populations	Understand the growth and development of cells that comprise the immune system and the principles of structural and functional evaluation of B-cells, T-cells, NK-cells, and phagocytic cells. Knowledge of the T-cell receptor and Ig rearrangement, HLA class I and class II molecules, pathways for acquired immune response, acquired immunodeficiency disorders. Understand principles of neutrophil and phagocyte function assays, and methods to evaluate Understand the molecular changes in lymphoid neoplasms and be able to correlate with clinical behavior of disease and current and potential therapy.

Immunoglobulin - Quantitative and Qualitative Disorders	Interpret the protein electrophoresis patterns observed in normal serum, normal plasma, normal urine, and in large monoclonal gammopathies such as multiple myeloma and Waldenstrom's macroglobulinemia	Knowledge of the basic biology of immunoglobulins structure, classes of immunoglobulins, the types of immunoglobulin fragment and the principles of protein electrophoresis & immunofixation
Proteins of Innate Immunity and Inflammation	Knowledge of the role of the complement system or proteins in health and disease, complement protein measurements to assess inherited and acquired deficiency states, Understand the acute phase response and acute phase proteins, such as C-reactive protein, to assess inflammatory conditions. Understand cytokines as mediators and markers of immune and inflammatory responses.	
Transplant associated pathology	Bone marrow and solid organ transplant – principles, GVHD types and diagnosis, chimerism	

09HLTH09A01-006-C

TRANSFUSION MEDICINE

The objective is to produce a specialist who possesses the competencies and skills to cope with the problems presented by everyday in-hospital and outpatient Transfusion Medicine practice.

Subject	Skill	Knowledge
Donor selection and bleeding	Good practices for collection of blood and bleeding donors, phlebotomy techniques.	Donor selection criteria , Donor counseling , donor notification associated with positive infectious disease testing results, blood bags and coagulants used in a blood bank, adverse reactions associated with blood donation/phlebotomy (whole blood and aphaeresis donations) Knowledge of handling massive transfusion protocols , Multiple transfusions, evaluating patients refractory to platelet transfusions,
Routine blood grouping and cross matching	Procedure for correct identification of blood samples Able to do ABO and Rh Grouping (cell and reverse),	Knowledge of abnormal blood groups like Bombay O group, Lewis Blood Group Substance Secretors, Non secretors and ABO groups in saliva,

	cross match procedure	Identify ABO and Rh Discrepancies , weak antibodies , auto antibodies etc Demonstrate familiarity with the requirements of all applicable regulatory and accrediting agencies
Antibody	Perform Direct Coombs(DCT)and Indirect Coombs Test (IAT)	Antibody Identification Procedure, Causes for warm and cold antibodies and handling transfusions in patients with these antibodies
Special techniques in blood bank		Viral inactivation, autologus transfusion, therapeutic apheresis, plasma fractionation, Cryopreservation, leucodepletion and use of irradiated blood
Transfusion reactions	Recognize the symptoms and signs of hemolytic and non-hemolytic transfusion reactions,	Pathophysiology, treatment, outcomes and prevention of noninfectious and infectious transfusion transmitted diseases. Knowledge of protocol for investigating a transfusion reaction and typing the exact nature
Blood components	Be able to review requests for blood components and discuss with the requesting physician, Collect blood for component preparation and know how to store blood components	Steps in blood component and blood derivative preparation, Composition and Clinical use of common blood components :- Packed cells, platelets, granulocytes etc Artificial blood substitutes
Transplantation	----	Knowledge of HLA cross matching problems, Principles of hematopoietic stem cell transplantation including collection, processing, and storage of these stem cell products, and the indications for use (e.g., bone marrow peripheral blood, and cord blood

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BIOCHEMISTRY / LABORATORY MEDICINE

Aims:

Plan and organize the work flow in a routine clinical pathology laboratory in keeping with gooc laboratory practices

Be able to correctly interpret the laboratory data of such studies, and discuss their significance with ε view to arrive at a diagnosis

Subject	Skill	Knowledge
Laboratory instrumentation	Handling and use of automated biochemical analyzers	Principle of Instrumentation, use and application of (i)Photoelectric colorimeter (ii) Spectrophotometer (iii) pH meter (iv) Centrifuge (v) Analytical balance (vi)Electrophoresis apparatus (vii)Electrolyte Analyzer (viii)Osmometer Prepare standard solutions anc reagents relevant to the above tests, including the preparation ol normal solution, molar solution anc Buffers.
Routine biochemical investigations	Independently perform the Quantitative Estimations by Manual / Automated Techniques : Blood urea, Blood sugar, Albumin, Serum Proteins(total & fractional) Serum Cholesterol, Serum Creatinine Knowledge of manual evaluation of the tests listed above is desirable	Normal values and units for each ol the investigations, significance anc interpretation of an abnormal result Demonstrate familiarity with the following Quantitative Estimations by Automated Techniques. Cholesterol, Proteins, Billirubir (Total & Direct) Uric acid, Serum Transaminases (ALT and AST/SGOT and SGPT) Serum Alkaline Phosphatase Creatinine Biochemical principles involved ir the estimation of Renal functior test, Liver function test, Gastric anc Pancreatic function, Endocrine function test and Tests foi malabsorption
Arterial, Capillary, & Venous blood gas analysis	Familiarity with use of machines used for the blood gas analysis Interpret results generated and ability to diagnose conditions based on same.	Knowledge of causes of electrolyte imbalances - Serum Electrolyte (Na+ and K+), Serum calcium anc phosphorous, etc
Tumor Markers	Interpretation of Electrophoresis In Multiple Myeloma / Abnormal proteins	Automated procedures foi Estimation of protein Electrophoresis, Immunofixation, Quantitation o immunoglobulins, Bence Jones Proteins Significance and reference values Background of Tumoui markers, New Tumour Markers

		Principle of Enzyme Immunc Assay, Radio Immuno Assay
Quality control and Automation in a laboratory	Know the principles, advantages and disadvantages scope anc limitation of Automation in laboratory, Types of chart or methods usec to monitor quality in a routine laboratory, use of standards for routine biochemical testing, Levy Jennings chart etc Accreditation in Biochemistry, Proficiency Testing (EQAS), and peei evaluation	

09HLTH09A01-008-C

Molecular Pathology

Subject	Knowledge
	Basic structure of DNA / RNA, Various techniques used in molecular pathology, principles, scope and limitations
Reverse Transcriptase Polymerase Chain Reaction (RT –PCR)	Principle, steps in technique, role in diagnostic pathology and infectious diseases, advantages and disadvantages, modifications of technique such as real time PCR, qPCR etc
Fluorescent In Situ Hybridization (FISH)	Principle, technique, advantages and disadvantages of hybridization procedures. Role in diagnostic pathology and neoplasia, Types of FISH – interphase, metaphase
Other techniques	Southern Blot / Northen Blot and Western Blot techniques

09HLTH09A01-009-C

Cytogenetics

Subject	Knowledge
Tissue culture and karyotyping	Demonstrate familiarity with methods of tissue culture and karyotyping in medical cytogenetics and cancer cytogenetics on peripheral blood culture, amniotic fluid culture, bone marrow aspiration culture Basic cytogenetics nomenclature
Molecular cytogenetics	Advanced technologies of molecular cytogenetics such as FISH, CGH Role of cytogenetics in diagnostic pathology, hematological malignancies, solid tumors and patient management

09HLTH 09A01-010C

Medical Statistics

Subject	Skill	Knowledge
Principles of medical Statistics	Calculate means, standard deviation and standard error from the given experimental data	Demonstrate familiarity with importance of statistical methods in assssing data from patient material and experimantal studies e.g. correlation coefficients, expected versus observed, etc and their interpretation Use of SPSS program

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Library / Information Retrieval / Web Search Engines in medicine

Subject	Skill	Knowledge
	Online access for all journals listed in the curriculum Use of Web based search engines, pubmed for reasearch, case studies and thesis.	To get acquainted with the digital library, its services and the effective use of e – resources information to further their knowledge and to supplement conventional reading

General Pathology Training Schedule

Aims

- Theoretical knowledge of basics of all disease processes

Cell Injury & Death

- Causes of cell injury.
- Reversible and irreversible cell injury.
- Mechanisms of cell injury and Structural changes
- **Necrosis:** definition, types of necrosis
- **Apoptosis:** definition, causes, morphology and mechanisms. Systemic effects of cell injury.

Cellular adaptations to injury

- **Growth disturbances:** atrophy, hypertrophy, hyperplasia, metaplasia, dysplasia.
- **Intracellular accumulations:** fatty change, cholesterol and cholesterolesters, proteins, glycogen.

- **Pigments:** exogenous and endogenous. Lipofuscin, melanin, haemosiderin, bilirubin, haematin.

- **Matrix changes :** Pathology of collagen, elastin, basement membranes. Amyloid. Pathological calcification; dystrophic and metastatic. Crystal depositions - Uric acid deposition.

Tissue Responses to Injury

- **Inflammation**

Definition; Acute /Chronic inflammation. Definition; primary causes, Cells involved; Chemical mediators. Granulomatous inflammation: definition of a granuloma; causes; morphology. Special macroscopic appearances in certain tissues.
Healing, Regeneration & Repair

- **Vascular Disturbances**

Oedema, Hyperaemia and congestion, Haemorrhage, Ischaemia, Thrombosis, Fate of thrombi; Embolism, Infarction, Shock, Atherosclerosis
Neoplasia

- Definition and terminology.
- Definition of benign and malignant tumours
- Nomenclature of neoplasms.
- The biology of neoplasms: immortalisation, DNA abnormalities, mitosis and apoptosis in neoplasms, metabolic abnormalities.
- The molecular basis of cancer: oncogenes, suppressor genes, regulatory genes of apoptosis, DNA repair genes.
- Molecular basis of invasion and metastases.
- Carcinogenic agents
- Multistep hypothesis of carcinogenesis.
- Epidemiology of cancer Host factors in carcinogenesis;
- Host defence, cell mediated and humoral immunity.
- Clinical effects of neoplasia: local effects, general effects; cachexia and paraneoplastic syndromes.
- Ancillary methods is; morphological techniques, excision/biopsy, fine-needle aspiration, cytology, immunocytochemistry, flow cytometry
- Biochemical assays for tumour markers
- Molecular diagnosis
- DNA microarray analysis
- Prognostic factors: type of tumour, grading and staging of tumours. Tumour dormancy.

Infections & Parasitic Diseases

Importance of infections & parasitic diseases.

- Changing patterns; effects of travel, change in the environment, new infectious diseases.

- Methods of identifying organisms in tissues. Types of reaction in tissues to the presence of an organism. Interaction with hosts immune state.

General pathology of diseases caused by bacteria, viruses, fungi, parasites and prions.

Selected examples to illustrate mode of spread, tissue reaction, identification of organism in tissues, type of disease and host modifying factors.

Environmental Pathology

Inhaled pollutants:

- Air pollution and occupational dust diseases (pneumoconiosis)*. * (Covered in lectures on respiratory diseases).
- Enumeration of diseases associated with smoking.

Chemical injury:

- Organic and inorganic compounds, metals, gases, toxic mushrooms.
- The pathology of alcohol (covered in 4th medical year) and drug abuse.
- Adverse reactions of therapeutic drugs.

Physical agents:

mechanical trauma, thermal injury, atmospheric pressure, electrical injury, ultraviolet light, ionising radiation injury (mechanisms and morphological changes, complications of radiotherapy, whole body radiation).

Nutritional Pathology

- Causes and effects of malnutrition. Protein-energy malnutrition. Anorexia nervosa and bulimia.
- Vitamin deficiencies and vitamin toxicity.
- Trace elements and disease.

READING MATERIAL

A complete list of reading material is extremely difficult to provide for the postgraduate student ir Pathology. In any postgraduate course reading should not be limited only to the subject oi specialization. One is expected to acquire as much theoretical and practical knowledge as possible. There can be no set guidelines in this regard. Students must be encouraged to utilise the Internet anc similar information technologies to further their knowledge and to supplement conventional reading The following is an incomplete list of reading material that may be helpful to a postgraduate student o Pathology. The habit of referring to current literature and the method of searching for literature must be made a mandatory component of the training.

11.1 Journals and Periodicals

- Acta Cytologica
- The American Journal of Pathology
- The American Journal of Surgical Pathology
- The American Journal of Hematology
- The American Journal of Clinical Pathology
- Archives of Pathology and Laboratory Medicine
- British Journal of Haematology
- Blood
- Diagnostic Cytopathology
- Histopathology
- Human Pathology
- Indian Journal of Cytology
- Indian Journal of Pathology and Microbiology
- Journal of Pathology
- Journal of Clinical Pathology
- Laboratory Investigation
- Modern Pathology
- Pathology
- Seminars in Hematology
- Seminars in Diagnostic Pathology
- Virchows Archives
- Year Book Series
- Recent Advances Series

The list of journals is incomplete. It is also expected that the students make it a habit to read othe journals because pathology is not confined to pathology journals alone. Specialty journals such as those related to oncology (Cancer, British Journal of Cancer, International Journal of Cancer, Cance Research, Journal of National Cancer Institute, Journal of Surgical Oncology etc.) are excellent sources of information regarding the pathology of tumors. Similarly journals related to Cardiology, Ches Diseases, Dermatology, Endocrinology, Gynecology, Gastroenterology, Hepatology, Nephrology Neurology, Neurosurgery, etc. are invaluable sources of material on the appropriate pathology. Furthe Journals such as Lancet, New England Journal of Medicine, Nature and Science are a must for every postgraduate student who wishes to keep abreast with what is new in medical science and therefore ir pathology.

- Histology for Pathologists. Stephen S. Sternberg (Ed), Raven Press, New York.
- General Pathology JB Walter, MS Israel. Churchill Livingstone, Edinburgh
- Robbin's Pathologic Basis of Disease Ramzi S.Cotran, Vinay Kumar, Stanley L Robbins WB Saunders Co., Philadelphia.
- Pathology Emanuel Rubin, John L Farber. JB Lippincott Co., Philadelphia
- Anderson's Pathology. John M Kissane (Ed). The CV Mosby Co., St. Louis

- Ackerman's Surgical Pathology. Juan Rosai Mosby. St. Louis
- Diagnostic Surgical Pathology. Stephen S Sternberg. Lippincott, William Wilkins. Philadelphia
- Systemic Pathology. W St. C Symmers (Series Ed) Churchill Livingstone, Edinburgh
- Diagnostic Histopthology of Tumours. Christopher DM Fletcher (Ed). Churchill Livingstone. Edinburgh.
- Soft Tissue Tumors. Franz M Enzinger, Sharon W Weiss. Mosby, St. Louis
- Cardiovascular Pathology Malcolm D Silver Churchill Livingstone New York.
- Pathology of Pulmonary Diseases Mario J Saldhana. JB Lippincott Co., Philadelphia
- Spencer's Pathology of the Lung. PS Hasleton. Mc Graw-Hill, New York.
- Dahlin's Bone Tumors. K Krishnan Unni. Lippincott-Raven Publishers, Philadelphia, New York
- Bone Tumours Andrew G Huvos WB Saunders Co. Philadelphia
- Greenfield's Neuropathology. J Hume Adams (Ed) Edward Arnold, London.
- Russell & Rubeinstein's Pathology of the Tumours of the Nervous System. Darrell D Bigna. Roger E Mc Lendon, Janet M Bruner (Eds.), Arnold, London
- Rosen's Breast Pathology. Paul Peter Rosen. Lippincott-Raven Publishers, Philadelphia, New York.
- Pathology of the Gastrointestinal Tract. S-I Chun Ming. Harvey Goldman (Eds.) Williams & Wilkins, Baltimore.
- Haynes and Taylor Obstetrical & Gynaecological Pathology. H Fox, M Wells. Churchill Livingstone New York.
- Heptinstall's Pathology of the Kidney. J Charles Jenette, Jean L Olson, Melvin M Schwartz, Fred G Silva (Eds.). Lippincott-Raven Publishers, Philadelphia, New York.
- Potter's Pathology of the Fetus & Infant. Enid Gilbert-Barnes (Ed). Mosby, St. Louis
- Lever's Histopathology of the Skin, David Elder (Ed), Lippincott-Raven Publishers, Philadelphia, New York
- Theory and Practice of Histological Techniques, Bancroft JD, Stevens A, Turner DR, Churchill Livingstone, Edinburgh
- Histotechnology – A Self Instructional Text, Carlson FL, American Society of Clinical Pathologists Chicago
- Histochemistry Theoretical and Applied. AG Everson Pearse. Churchill Livingstone, Edinburgh
- Manual & Atlas of Fine Needle Aspiration Cytology. Svante R Orell, Gregory F Sterrett, Max NI. Walters, Darrel Whitaker. Churchill Livingstone, London
- Cytopathology. Zuher M Naib. Little Brown and Company, Boston.
- Diagnostic Cytology and its Histopathologic Basis, Koss LG, J.B. Lippincott, Philadelphia
- Comprehensive Cytopathology, Bibbo M, W.B. Saunders Co., Philadelphia
- William's Hematology Beutler E, Lichtmann MA, Coller BS, Kipps TJ, McGraw Hill, New York
- Postgraduate Hematology Hoffbrand AV, Lewis SM, Tuddenham EGD, Butterworth Heinemann, Oxford
- Wintrobe's Clinical Hematology, Lee GR, Foerster J, Lupeus J, Paraskevas F, Gveer JP, Rodgers GN, Williams & Wilkins, Baltimore
- Practical Haematology, Dacie JV, Lewis SM, Churchill Livingstone, Edinburgh
- Bone Marrow Pathology, Bain BJ, Clark DM, Lampert IA, Blackwell Science, Oxford
- Leukemia Diagnosis- A guide to the FAB Classification, Bain BJ, J.B. Lippincott, Philadelphia
- Clinical Diagnosis and Management by Laboratory Methods, Henry JB, WB Saunders.(Indian Edition, Eastern Press, Bangalore).

BACK TO MAIN

होमी भाभा राष्ट्रीय संस्थान

Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
PAREL, MUMBAI – 400 012

SYLLABUS

OF

MD RADIO-DIAGNOSIS

(Program Code: HLTH09A03)

RADIO-DIAGNOSIS — M D

GOAL-

Goal of the course is to orient and train the students on different aspects of diagnostic and interventional radiology in the diseases of various organ systems of the human body. They should be able to apply this training at secondary and tertiary level of medical care.

OBJECTIVES

In order to achieve the goal of this course, following objectives are to be accomplished by the time the candidate completes the 3 years course.

Three broad domains of the objectives are:

1. Cognitive domain (Knowledge)
2. Psychomotor domain (Skills)
3. Attitudinal domain (Human values, ethical practice etc.)

Congnitive Domain (Knowledge)

1. Describe aetiology, pathophysiology, and principles of diagnosis and management of common problems including emergencies, in adults and children.
2. Demonstrate understanding of basic sciences relevant to this specialty.
3. Identify important determinants in a case (e.g. social, economic, environmental) and take them into account for planning therapeutic measures.
4. Recognize conditions that may be outside the area of specialty/competence and to refer them to proper specialist or ask for help.
5. Advise regarding the management (including interventional radiology) of the case and to carry out the management effectively.
6. Update oneself by self-study and by attending courses, seminars, conferences and workshop which are relevant to the field of radio-Diagnosis.
7. Carry out guided research with the aim of publishing his/her work and presenting work at various scientific fora.

Psychomotor Domain (Skills)

1. Take a proper clinical history, examine the patient, perform essential diagnostic/interventional procedures and interpret the results to come to a reasonable diagnosis or differential diagnosis in the condition.
2. Provide basic life saving support service in emergency situations.
3. Undertake complete patient monitoring including the care of the patient.

Attitudinal Domain

1. Adopt ethical principles in all aspects of his/her practice. Professional honesty and integrity to be fostered.
2. Develop communication skills in order to explain the various options available in management and to obtain a true informed consent from the patient.
3. Be humble and accept the limitations of his knowledge and skills and to ask for help from colleagues/ seniors when needed.
4. Respect patient rights and privileges including patient's right to information and right to seek a second opinion.

COURSE CONTENT

09HLTH09A03-001-C BASIC SCIENCES RELATED TO RADIO-DIAGNOSIS

(a) Radiation physics and Radio-Biology.

(b) Radiological anatomy and pathology of various organ systems

(c) Imaging Techniques.

(d) Radiography.

Includes all aspects of: Fundamentals of electromagnetic radiation, X-Ray production, characteristic properties of X-Rays, units of radiation, radiation measurement, X-ray equipments, X-Ray films, intensifying screens, other X-Ray appliances, dark room equipments and procedures, II TV, cine fluorography, tomography.

- Quality assurance.
- Radiation hazards and principle and methods of radiation protection.
- Contrast media : types, chemistry, mechanisms of action, dose schedule, routes of administration, their potential adverse reactions and management.
- Clinical applications of important isotopes and instrumentation in Nuclear medicine with advances in both.
- Physics and applications of advanced imaging i.e., Ultrasound, CT, MRI, Angiography (DSA), PET etc.
- Practical experiments in radiological physics : A list of experiments, which a resident should be able to do and interpret the results, is available in the department, including quality assurance test for radiological equipment

09HLTH09A03-002-C

2. RESPIRATORY SYSTEM

Goal

At the completion of the course the resident should be able to interpret conventional and advanced (CT. MRI) chest examinations. differentiating normal from abnormal cases and be able to recognize specific imaging pattern of different diseases.

Content Coverage

Diseases of the chest wall. diaphragm. pleura and airways: pulmonary infections; pulmonary vasculature: pulmonary neoplasms: diffuse lung disease: mediastinal disease: chest trauma: post- operative lung and X-Rays in intensive care.

Essential Objectives

1. Should be able to localize the chest pathology into one of the following compartments: pulmonary. pleural. mediastinal. extra-pleural. extra-thoracic. diaphragmatic. infradiaphragmatic.
2. Recognize chest pathology that requires urgent or emergency treatment and describe this in an adequate manner: Pneumothorax. traumatic aortic rupture. esophageal rupture. acute pulmonary embolism. CHF and tracheo-bronchial foreign bodies.
3. Recognize acute and chronic patterns of bacterial and viral pneumonia's. occupational diseases. allergic states.
4. Recognize acute and chronic cardiac failure patterns and non-cardiogenic edemas.
5. Understand the radiographic features and precipitating causes of adult and infant respiratory distress syndrome.
6. Recognize and describe appropriately the various manifestations of benign and malignant neoplasm's of the lung.

Evaluation — Annual assessment by an outside exper

- Resident's progress through daily observation of work
- At the end of the rotation an assessment by a small group of faculty.
- Maintain a log book showing techniques learnt during the rotation – to be supervised.

3. GASTROINTESTINAL (GIT) AND HEPATO-BILIARY-PANCREATIC SYSTEM

09HLTH09A03-003-C

Goal

At the completion of this course the resident should be able to interpret both the conventional and other newer (ultrasound. CT. MRI. angiography) examinations. This includes examination of GIT i.e.. esophagus. upper gastrointestinal study. follow through for small bowel (including small bowel enterolysis) and enema (both conventional and double contrast) for colon. It also includes examination of liver. biliary system and pancreas using all the imaging modalities available to a radiologist including specialized investigations like ERCP. PTC and interventional procedures like abscess drainage. Percutaneous Transhepatic biliary drainage (PTBD. internal and external). tumor embolization. Radiofrquency (RF) ablation etc.

During this posting resident also performs other investigations done using fluoroscopic guidance e.g: hysterosalpingography (HSG): fistulogram. sinogram. T-Tube cholangiography. sialography etc. and he/she should be able to perform and interpret studies using these modalities.

Content Coverage

Diseases and disorders of mouth, pharynx, salivary glands, esophagus, stomach, small intestine, large intestine, diseases of omentum, peritoneum and mesentery, acute abdomen, abdominal trauma using conventional and newer imaging methods like CT, MRI, DSA, isotope studies.

Diseases and disorders of hepato-biliary-pancreatic system using conventional & newer imaging methods.

Essential Objectives

1. Learn to evaluate the clinical condition & needs of a patient and to decide the appropriate studies and approach for examining the GIT or hepato-biliary-pancreatic system of a patient.
2. Learn a proper approach to fluoroscopy: this includes developing proficiency in GIT fluoroscopy, mastering the equipment and using proper radiation protection measures (both for the patient and the operator).
3. Learn the basic pathology and patho-physiology of GIT/hepato-biliary-pancreatic diseases.
4. Learn to communicate the findings both at fluoroscopy and in films, in an accurate, succinct and meaningful way.

Evaluation:

- Day to day obseration of residents work including documentation and interpretation
- Assessment by a group of faculty at the end of the rotation.
- Log book will be maintained of the procedures learnt.

4. GENITO-URINARY SYSTEM

09HLTH09AP3-004-C

Goal

At the completion of this course resident should be able to perform, direct the radiography and interpret the conventional radiological examinations of the urinary tract. These includes: excretory urography (intravenous pyelography); cystograms, micturating cystourethrography (MCU) and retrograde urethrography (RGU).

[HSG is included under GIT rotation].

In addition the resident should be able to perform and interpret other diagnostic imaging modalities and procedures which are used to evaluate urinary tract pathology i.e., ultrasound, CT, MRI, angiography, as well as various interventional procedures like percutaneous nephrostomy, kidney biopsy, stent placement, antegrade pyelography, tumor embolization etc.

Obstetrics and gynaelogy ultrasound : separate posting in III year.

Hysterosalpingography : ~~already included with GIT posting~~.

Content Coverage

Imaging : conventional, ultrasound, CT, MRI, angiography; of various diseases and disorders of genito-urinary system. These includes : congenital, inflammatory, traumatic, neoplastic, calculus and miscellaneous conditions.

Essential Objectives

1. Recognize and evaluate emergency conditions involving the urinary tract including trauma, infection, vascular compromise and obstruction.

2. Recognize and understand the patho-physiology of stone disease.
3. Recognize patterns of infectious diseases and the modalities necessary for diagnostic evaluation.
4. Understand the complete evaluation of renal mass lesions and the evaluation of other urinary tract neoplasms. including the detection and staging of the tumor.
5. Recognize the difference between the pattern of diseases affecting the genito-urinary tract of adults and that of children and understand and identify the common conditions affecting the peadiatric genito-urinary system on imaging.

Evaluation:

- day to day, based on daily work assessment
- by a group of faculty at the end of the posting.
- Maintain a log book

5. MUSCULOSKELETAL SYSTEM

09HLTH09A03-005-C

Goal

At the end of the course the resident should be able to correctly interpret all the common abnormalities of the bones and joints. He/She should have a good understanding of the common congenital abnormalities. arthritis. bone and joint trauma. neoplastic conditions. metabolic bone disease and inflammatory diseases. He/She should also have an understanding of the role of CT/MRI in all these conditions and should be able to perform and interpret CT/MRI in diseases of musculo-skeletal system.

Content Coverage

Imaging (Conventional. ultrasound. CT. MRI. angiography. Radio-isotope studies) and interpretation of diseases of muscles. soft tissue. bones and joints including congenital. inflammatory. traumatic. neoplastic and miscellaneous conditions.

Essential Objectives

1. Communicate precisely and cogently radiographic descriptions of bone and joint trauma.
2. Differentiate various forms of arthritis and know correlative laboratory and clinical findings.
3. Enumerate the radiogrphic features that differentiate benign and malignant bone tumors with a basic familiarity of more common tumors.
4. Know radiographic features of acute and chronic osteomyelities and discitis (including tuberculosis).
5. Recognize differential features of osteoporosis (including Bone Mineral Density or BMD assessment techniques e.g: US.CT.Dexa) including various endocrine and metabolic diseases e.g: osteomalacia. hyperparathyrodism etc.
6. Know the application and interpretation of ultrasound/CT/MRI/angiography in one or more of the above situations.

Evaluation

- through daily sessions assessment
- by a small group of faculty at the end of the posting
- Will maintain a log book

09HLTH09A03-006-C

6. CARDIOVASCULAR RADIOLOGY/ECHO CARDIOGRAPHY

Goal

Goal is to provide experience in the role of imaging in cardiovascular diseases by different techniques including cardiac cathaterization and cardiac angiography. Digital subtraction angiography (DSA) and interventional procedures in non cardiac arterial and venous diseases.

Content Coverage

Diseases and disorders of cardiovascular system including congenital conditions and the role of imaging by conventional, ultrasound, Echo, color-Doppler, CT, MRI, angiography (including DSA) and radionuclide studies. It also includes interventional procedures e.g; balloon angioplaty, embolization etc.

Essential Objectives

1. Understand the anatomy and common pathology of congenital and acquired cardiac conditions.
2. Correlate plain film findings of common congenital abnormalities with those shown by angiography and explain the pathophysiology including abnormal pressure measurements.
3. Correlate plain film findings and the echocardiographic studies of patients with acquired valvular diseases and other common pathologic conditions including pericardial pathology.
4. Understand the role of newer modalities like CT/MRI, in aortic diseases e.g., aorto- arteritis, aortic dissection and aortic aneurysm.
5. Should be able to perform fluoroscopy on patients before and after valve replacement and identify those with complications after valve replacement.
6. Understand the principle and logic behind various interventional procedures carried out in the cardiovascular labs e.g; PTCA, balloon dilatation of valvular lesions, septostomy etc.

Evaluation

- day to day assessment
- by a small group of faculty
- Maintain a log book to be checked by faculty in charge

09HLTH09A03-007-C

7. NEURORADIOLOGY

Goal

At the end of the course the resident should be able to demonstrate reasonable proficiency in the assisstance during performance as well as in the interpretation of all neuro-radiological studies. This includes angiograms, both cerebral and non-cerebral studies, transluminal angioplasties, embolization procedures and myelography. They should also be able to perform and interpret CT and MRI of head and spine.

Content Coverage

Includes imaging (using conventional and newer methods) and interpretation of various diseases and disorders of the head, neck and spine covering congenital lesions, infective lesions, vascular lesions, traumatic conditions and neoplasia. It also includes a number of interventional procedures carried out in the department of neuroradiology.

Essential Objectives

1. Know detailed normal neuro-imaging anatomy on different imaging modalities.

2. Identify pathologic conditions (listed under the content) on images acquired using different techniques and communicate the report in a concise manner.
3. Participate in daily neuroradiology conferences held with the neurosurgery or neurology units.

Evaluation

- day to day based on reporting and procedures performed.
- by a small group of faculty.
- Will maintain a log book to be checked by faculty in neuroradiology.

8. GENERAL RADIOLGY

09HLTH09A03-008-C

Goal

as well as computerised / digital radiogr

In this rotation the resident learns to evaluate conventional radiographs. This includes radiographs of : chest, abdomen, pelvis, skull, spine, musculo-skeleton and soft tissues. Resident is posted in OPD and indoor radiography rooms for this purpose.

During indoor posting, he/she will also have the additional responsibility of directing, evaluating and reporting mammographic procedures including related interventional procedures.

Essential objectives

8.1

1. Learns to direct and perform radiography on patients.
2. He/she should be able to decide on further imaging views based on the clinical suspicion and the initial imaging.
3. Write reports on the radiographs obtained in a methodical, concise and precise way and communicate it to the referring unit.
4. Present interesting cases in the departmental meets.

9. ULTRASOUND (INCLUDING GYNAE/OBSTETRICS)

09HLTH09A03-009-C

Goal

At the completion of this rotation the resident should be able to perform and interpret all ultrasound studies. These studies include : abdomen, pelvis, small parts, neonatal head, color-duplex imaging (including peripheral i.e: extremity arterial and venous studies), obstetrics/gynaecology (in the deptt of Gyn/Obstet) and interventional procedures using ultrasound guidance. The resident should have a thorough knowledge of the common abnormalities of the abdominal/pelvic organs, retroperitoneal structures, neck, chest, extremities and small parts (thyroid/parathyroid, scrotum, orbit, breast).

Essential Objectives

1. Determine or select the appropriate diagnostic procedure for the clinical problem.
2. Demonstrate proficiency in patient scanning using appropriate techniques and instrumentation.
3. Modify the procedure, if required, based upon the observed abnormalities (pathology).
4. Analyze the results of the diagnostic procedure, make diagnosis and record the findings.
5. Communicate findings, diagnosis and other relevant information to the referring physician.
6. Present interesting ultrasound cases in the departmental conferences/meetings.

Evaluation

- ongoing basis using day to day work

- presentations in departmental meets
- maintain a log book
- by a group of faculty at end of the rotation

09HLTH09A03-010-C

10. CT

Goal/Objectives

The goals/objectives to be achieved by the end of this rotation are:

1. Select CT protocol according to the clinical diagnosis. He/she should be able to direct and modify (if required) the performance of the CT examination
2. Demonstrate knowldege of the CT findings of the common pathologic conditions occuring in the head, neck, chest, abdomen, pelvis, and in the soft tissues and musculo-skeletal system.
3. Resident should be familiar with both the conventional and different modified CT techniques (High resolution, Dual phase, CT angio, BMD, multislice CT etc.)
4. Interpret conventional and modified body CT examinations (including HRCT, dual/triple phase CT, CT portography, virtual CT etc.) with a reasonable degree of accuracy.
5. Demonstrate proficiency in verbal and written reporting of CT findings and differential diagnosis.
6. Demonstrate knowledge of the limitations (and potential fallacies) of CT imaging of various pathologic conditions and be able to perform correlations with other imaging modalities including formulations of recommendations for additional appropriate imaging procedures.
7. Perform CT guided biopsy procedures under guidance of seniors.
8. Present interesting cases of CT in the departmental meetings.

Essential Objectives

1. The resident will review the daily body CT schedule and based upon the known clinical information and review of other radiologic studies of the same patient done earlier, select the most appropriate CT imaging protocol for the each patient. This may include altering an existing CT protocol to provide the most appropriate examination for an individual patient.
2. Develop a working knowledge of the actual performance of the CT examinations. This includes starting intravenous lines, amount and timing of injecting i.v. contrast, and actual operation of CT machine.
3. Review and report all the completed body CT examinations. Initially this will be under the supervision of the seniors but later independently – but all repots will be signed by the faculty incharge.
4. Participate and present CT cases in departmental and inter departmental meets.

Evaluation

- on daily basis after observing reporting and working in the CT room
- by a group of faculty
- Maintain a log book under the supervision of faculty incharge.

09HLTH09A03-011-C

11. ANGIOGRAPHY AND INTERVENTIONAL RADIOLOGY

Goal

At the completion, the resident should be able to perform the most common non-cerebral angiographic studies. He/she should have a good basic understanding of both; the vascular interventional radiologic procedures such as angioplasty, embolization using various embolizing agents; as well as the various non-vascular interventional procedures such as percutaneous nephrostomy, stenting, abscess drainage, PTC/PTBD, percutaneous biopsy, balloon dilatation of the esophagus etc. He/she should have a good understanding of the various equipment and available catheters and guidewires and other technical aspects of special procedures. In addition he/she should know all the potential risks and complications of these procedures and their management.

Essential Objectives

1. Evaluate the requisition for appropriate clinical information to determine if additional information is needed.
2. Determine or select appropriate diagnostic procedure for the clinical problem.
3. Assisst and perform appropriate procedures under supervision and modify procedures based on observed abnormalities (pathology).
4. Know the potential risks and complications of procedures performed.
5. Know normal vascular anatomy applicable to angiographic procedures performed and know normal anatomy and landmarks to perform other non-vascular procedures.
6. Present interesting cases in the departmental meets.

Evaluation

- day to day evaluation
- by a group of faculty
- Will maintain a log book

09HLTH09A03-012-C

12. PAEDIATRIC RADIOLOGY

Goal

Intention is to train residents to perform common radiologic procedures and to be able to interpret paediatric studies in order that they can apropriately deal with examinations of children in a non paediatric hospital environment.

At the completion the resident should be able to interpret most of the conventional and newer paediatric examinations which includes: upper airways, chest, genito-urinary, gastro-intestinal and musculo-skeletal systems. Resident should be familiar with many of the neurologic conditions encountered in neonates and children. Resident should also be able to perform transfontanelle cranial ultrasound.

Content Coverage:

Common diseases and disorders of different organ systems covering congenital, inflammatory, traumatic, neoplastic and other miscellaneous conditions, using both conventional and newer imaging methods.

Essential Objectives

1. Understand the appropriate indications for various imaging procedures and determine that the patient has been properly prepared for the procedure.
2. Know the standard radiographic views for paediatric examinations.
3. Learn to recognize and evaluate imaging manifestations (on conventional and newer methods) of common paediatric conditions occurring in the head/neck, chest, abdomen/pelvis and in the musculo-skeleton.

4. Perform paediatric fluoroscopic examinations with skill and accuracy.
5. Understand and apply the knowledge and principle of radiation protection, both for the child and the operator.

09HLTH09A03-013-C

13. RADIOLOGY IN EMERGENCY MEDICINE

Goal

At the end of the course, resident should be able to give an evaluation of the emergency radiographic examinations. He/she should also be familiar with medicolegal cases (MLC) procedures.

Essential Objectives

1. Determine and direct radiography in emergency patients and review and interpret the radiographs.
2. If study is incomplete then dertermine additional views or repeat views.
3. Know indications for and limitations of the common emergency imaging procedures.
4. Communicate findings, diagnosis and other releveant information to the emergency room physicion.
5. He/she should be able to perform (some under supervision) and interpret special imaging procedures needed in emergency room e.g: barium studies, excretory urography, CT, ultraound, Doppler and angiography.

09HLTH09A03-014-C

14. ONCOLOGIC RADIOLOGY

Goal

At the end of the rotation the resident should be able to interpret radiological investigations in patients with neoplastic diseases (both benign and malignant). He/she should be able to perform, interpret and diagnose these patients.

Essential objectives

1. Understand pathology and patho-physiology of common neoplasms.
2. Learn the algorithmic approach to image these patients based on the suspected disease, its biological behaviour and potential and limitations of various imaging modalities.
3. Perform appropriate investigation(both conventional and newer methods), interpret the results and reach at a reasonable diagnosis/ differential diagnosis based on the clinical and biochemical results.
4. Learn to communicate the results in a precise way in a written report to the concerned unit.
5. Present interesting cases in the departmental meets.

09HLTH09A03-015-C

15. NUCLEAR MEDICINE /PET

Goal

At the completion of this rotation the resident should be able to interpret common nuclear medicine examinations (including cardiac cases). He /she should be able to evaluate the examinations for completion and determine what further images (including non nuclear medicine) need to be done. He/she should have a good understanding of the physical and biological properties of the commonly used radiopharmceuticals and become familiar with safe handling of isotopes and basic radiation safety measures while dealing with isotopes.

Essential objectives

1. Review all cases performed each day.
2. Interpret the results of the procedures and give an appropriate diagnosis.
3. Observe and help in some common procedures performed in the department (e.g: thyroid, kidney, bone, cardiac scans), understand the principle underlying the procedure and the basis for using a particular isotope in an investigation.

Evaluation

- Day to day by the nuclear medicine staff.

DISSERTATION

Thesis

1. Every candidate pursuing MD degree course is required to carry out work on a selected research project under the guidance of a recognised post graduate teacher. The results of such a work shall be submitted in the form of a dissertation.
2. The dissertation is aimed to train a post graduate student in research methods and techniques. It includes identification of a problem, formulation of a hypothesis, search and review of literature, getting acquainted with recent advances, designing of a research study, collection of data, critical analysis, comparision of results and drawing conclusions.
3. Chief guide will be from the department of Radio-diagnosis while co-guides will be from either the department of Radio-diagnosis or other disciplines related to the dissertation topic.
4. Every candidate shall submit a thesis protocol to the Dean of the Institute in the prescribed proforma containing particulars of proposed dissertation work four months from the date of commencement of the course. The thesis protocol shall be sent through the proper channel.

   Protocol in essence should consist of:-

   (a) Introduction and objectives of the research project.

   (b) Brief review of literature

   (c) Suggested material and methods

   (d) Bibliography

   by Hospital Scientific Review Committee and Hospital ethics committee

5. Such thesis protocol will be reviewed and the dissertation topic will be registered by the Institute. No change in the dissertation topic or guide shall be made without prior approval of the Dean of the Institute.
6. Submission of thesis.

Thesis will be submitted at the end of two and a half (2.5) years.

Thesis should consist of

(e) Introduction

(f) Review of literature

(g) Aims and objectives

(h) Material and methods

(i) Results

(j) Discussion

(k) Summary and Conclusions

(l) Tables

(m) Annexures

(n) Bibliography

7. ~~Two~~ Five copies of dissertation thus prepared shall be submitted to the Dean AIIMS, six months before the final examination.

8. The dissertation shall be valued by two external examiners appointed by the Institute. Approval of dissertation work is an essential precondition for a candidate to appear in the final MD examination.

Dissertation is graded as follows :

- Highly commendable
- Commendable
- Satisfactory
- Rejected

MD (Radodiagnosis), Posting Schedule

Total Duration : 3 years

Applied Physics and Basic Sciences

First Year	Second Year	Third Year
ConventionalRadiolgy (OPD) — 3 months	Ultrasound (with interventions) –2 months	Emergency Radiology (Casualty) –2 months
Genitourinary-3 months	CT (with interventions) –2 months	Oncologic Radiology (IRCH) – 2 months
Conventional Radiology, including Paediatric Radiology (Indoor) – 3 months	Angiography (with interventions) –2 months	Nuclear Medicine – 1 month
Observer Postings:		
1. GIT - 1 month	MRI – 2 months	Obstet Gyn (US)- 15 days
2. Ultrasound-1 month		
3. CT –1 month		
	Cardiac Radology- 2 months	Echocardiography – 15 days
		Ultrasound – 1 Month
	Neuroradiology – 2 months	CT — 1 month
		MRI — 1 month
		Angiography — 1 month
		Elective – 2 months
Dissertation submission at the end of 2 ½ years		

Classes on Statistics : A series of lectures held for every one

BACK TO MAIN

TATA MEMORIAL CENTRE

Departments
of
Radiation Oncology & Medical Physics
(Program code: HLTH09A04)

Structured Training Program Syllabus & Log

Book
for
Post Graduate Training in
Radiation Oncology

Homi Bhabha National Institute
Mumbai, India

TATA MEMORIAL CENTRE

Department of Radiation Oncology

THREE YEAR STRUCTURED POST-GRADUATE
Training Program

	Name	Signature	Date
Trainee			
Guide			
Head of the Department			

Date of Joining Training Programme:	……………………..
Date of Completing Training Programme	……………………..
Date of Theory Examination:	……………………..
Date of Practical Examination:	……………………..
Date result declared:	……………………..

I hear, and I forget.

I see, and I remember.

I do, and I understand.

- Chinese Proverb

Learning is a treasure that will follow its owner everywhere

Chinese Proverb

MEDICAL COUNCIL OF INDIA

(Published in Part III, Section 4 of the Gazette of India dated 06.4.2002)

DECLARATION

(At the time of registration, each applicant shall read and agree to abide by the same)

1) *I solemnly pledge myself to consecrate my life to service of humanity.*

2) *Even under threat, I will not use my medical knowledge contrary to the laws of Humanity.*

3) *I will maintain the utmost respect for human life from the time of conception.*

4) *I will not permit considerations of religion, nationality, race, party politics or social standing to intervene between my duty and my patient.*

5) *I will practice my profession with conscience and dignity.*

6) *The health of my patient will be my first consideration.*

7) *I will respect the secrets which are confined in me.*

8) *I will give to my teachers the respect and gratitude which is their due.*

9) *I will maintain by all means in my power, the honour and noble traditions of medical profession.*

10) *I will treat my colleagues with all respect and dignity.*

11) *I shall abide by the code of medical ethics as enunciated in the Indian Medical Council (Professional Conduct, Etiquette and Ethics) Regulations 2001.*

I make these promises solemnly, freely and upon my honour.

Signature

Date
Name
Place
Address

INDEX

Tata Memorial Centre

Tata Memorial Hospital

DEPARTMENT OF RADIATION ONCOLOGY

THREE-YEAR TRAINING PROGRAMME

OBJECTIVES

General:

The aim of the training is to enable the trainee capable of practicing independently as a competent doctor. The trainee should be compassionate and ethical in their practice of oncology and would also contribute to the future developments in oncology.

Specific:

a. The trainees should acquire a sound working knowledge of the use of ionizing radiation, cytotoxic agents, hormones, biological response modifiers, etc. in the management of cancer.

b. The trainees practice "Evidence Based Medicine" whenever possible, and be familiar with Clinical Trial Methodology.

c. The trainees should become competent in providing and organizing a comprehensive supportive and palliative care in patients with very advanced disease and in terminally ill patients.

d. The trainees should develop the ability of reasoning / logical thinking and decision making in grey areas and in difficult cases.

e. The trainees should become competent to provide guidance and leadership in the 'Cancer Prevention Efforts'.

f. The training should generate awareness and interest in basic and applied cancer biology and whenever possible, experience in the field.

g. The trainees should develop leadership qualities and learn basic management and administration skills.

Three Year Structured Training comprise of the following:

1. Induction program for all trainees.
2. Theory and practical sessions separately for first, second and third year trainees
3. Dissertation
4. Departmental academic activities including seminars, journal clubs, ward rounds, planning meetings etc. as per weekly schedule
5. Joint clinics such as Lymphoma /Gynae /Paediatric /Breast /CNS /Palliative Clinics
6. Clinical data analysis - As instructed by the teacher
7. Rotation posting in other departments /disciplines such as Medical Oncology /

Radio-Diagnosis / Radiation Medicine Centre etc. and presentation of the experience in these postings.

8. Scientific paper presentation at conferences.

For practical the student will maintain individual diary/logbook, which will be reviewed and endorsed by the teacher, under whom the candidate is registered. The individual teacher will be responsible for checking the progress of the candidate.

Trainees should discuss with their teacher regarding topic for presentation at clinical meetings, clinical data analysis and paper for presentation at conferences. Topics for presentations will be from the allotted list displayed on the notice board. The presentation should be on transparencies/slide with neat labeled diagram whenever necessary. The subject should be prepared well in advance and discussed with the individual teacher, minimum of a week before presentation. The literature search from journals and books or Internet is mandatory for second and third year students. Whenever the data from Tata Memorial Hospital is available, should be included in the presentation.

There will be internal assessment / examination (Practical and theory) in the month of January each year and after three years of training and submission of dissertation, the trainees would be eligible for the examination conducted by the university of Mumbai.

ORIENTATION FOR NEW TRAINEES

Within first two weeks of joining

Objective:

The orientation will make familiarize the trainee with the Departments of Radiation Oncology and Medical Physics. The trainee will be acquainted with the various places and the activities in the Department. This will preferably be done on Saturday. The trainee will be taken to following minimum places:

1. General OPD & Joint Clinics
2. Minor Operating Theatre
3. Teletherapy Machines: Accelerators and telecobalt areas
4. Simulators
5. HDR brachytherapy area
6. Mould room
7. Medical Physics TPS area
8. Private OPDs
9. Radiation Oncology in-patient Ward
10. General & Private wards
11. IEC office
12. Digital Library

INDUCTION PROGRAMME

Two Sessions (am or pm) each in the first six to eight weeks

Objective:

The induction programme is intended to give the new trainees a general idea about Tata Memorial Centre [TMC], the nature of work done in various departments and the location of various departments within the five interconnected buildings of TMH and ACTREC. The emphasis will be on the departments of Radiation Oncology, Medical Physics, and frequently used diagnostic and rehabilitative services. The Senior Registrar will introduce and guide the new students to various facilities listed below.

1. Teletherapy Machines (To know about the machines available in the hospital; Energy, accessories, types of treatment possible, operation of machines)
2. Brachytherapy Machines, Operation Theatre (types of brachytherapy procedure done) Learn about radiation protection measures, know the procedures such as CVS, VSA and intracavitary
3. Computer Treatment Planning, Physics (Simple plans, isodose charts)
4. Mould Room & Simulator (Making POP, acrylic and thermoplastic moulds, Alloy blocks, Styrofoam cutter, Tissue compensators, Bolus and surface moulds)
5. Radiotherapy In-patients: (Visit to wards, patient management with IV fluids, care of patients admitted to wards, management of radiation reactions general aspects)
6. I.V. Team & Day care: Various investigations, IV access & chemotherapy administration.
7. Other rehabilitative services such as Palliative care, Occupational and physiotherapy, Medical Social Workers, and voluntary organizations such as CPAA and 'V' Care.
8. Preventive Oncology department
9. Clinical Research Secretariat [CRS].
10. Radio-diagnosis department
11. Histopathology, microbiology, biochemistry and blood bank.
12. Main operation theatre and ICU.

TEACHING CURRICULAM

First Year

Candidates are expected to have wide knowledge of malignant diseases and the management of patients with cancer.

09HLTH09A04-001-C CLINICAL ONCOLOGY [Theory] –I

1. Introduction to Oncology
2. Principles of clinical and pathological staging of cancers
3. Basics of Radiation Therapy
4. Basics of Cancer Chemotherapy, Hormone & Biological therapy
5. Basics of cancer surgery
6. Decision making process in Oncology
7. Combined modality of Radiotherapy and Surgery
8. Combined modality of Radiotherapy and Chemotherapy
9. Basics of Radiation Treatment Planning: Clinical aspects.
10. Radiotherapy Techniques: Patient positioning, Immobilization techniques, Target determination, field arrangements, Tissue compensation, Shielding, Megavoltage techniques, electrons, Dose calculation, Radiotherapy prescription, quality assurance, radiation safety
11. Care of patient and assessment of treatment: Reviews, treatment checks, symptom control, follow-up
12. Drug Therapy: Drug delivery, support techniques, management of acute complications

09HLTH09A04-001-P CLINICAL ONCOLOGY [Practical] –I (Patient Evaluation, Care and procedures):

1. Communication with cancer patients and their relatives.
2. Clinical examination methods like gynecological, laryngeal, breast, neurological and lymph node examination.
3. Obtaining informed consent for routine treatment.
4. Management of treatment complications like mucositis, dermatitis, proctitis, diarrhea, nausea, vomiting, xerostomia, lymphoedema, candidacies etc.
5. Management/Care of patients with fluid electrolyte imbalance, malnutrition, neutropaenic sepsis, raised intracranial pressure, seizures, paraplegia, bed sores, tracheostomy, Nasogastric tube or gastrostomy, bleeding PV or SVC compression.
6. Cervical biopsy, PAP smear, FNAC, Pleural and peritoneal paracentesis, bone marrow and lumbar puncture.
7. Insertion and maintenance of IV lines (butterfly and Venflon types) for blood collection and giving fluids or cytotoxic agents.
8. Patient positioning and immobilization using Thermoplastic, Acrylic and POP Masks
9. Surface marking
10. Simple Simulation techniques of such as single for Bone Metastasis, two or four Field for cervix, AP/PA for Lung, three Field for Esophagus and Bilateral Fields for Head & Neck.
11. CVS and Intrauterine applications.
12. Giving simple chemotherapy drugs like 5-FU, Bleomycin, Cyclophosphamide, low dose methotrexate (CMF), Procarbazene, CCNU, Cisplatin, Adriamycin etc.
13. Interpreting Simple Radiographs like chest x-rays, barium swallows, osseous metastases, bone scan etc.
14. Getting familiar and follow the established principles of bio-safety e.g. MRSA, Hepatitis B and C, HIV etc.

09HLTH09A04-002-C PHYSICS [Theory] –I

1. Electromagnetic radiation & spectrum
2. Atomic structure, electron shells and energy levels, energy quantitization
3. Relation between wavelength, frequency and energy
4. Radioactivity, description of x- and γ- beams (quality, energy, intensity, size etc.)
5. Radioactive sources used in radiotherapy
6. Production of x-Rays: The basic x-Ray tube, characteristics of x-Rays
7. Interaction of x-Rays with matter (Elastic scattering, Common effects, Pair production, Photonuclear interaction, Auger effect, scattering radiation, secondary electrons, range verses energy, Linear Energy transfer etc.)
8. Interaction of sub-atomic particles with matter (Ionization & excitation due to charges particles, collision loss, particle range, Bragg peak, Bremsstrahlung, elastic & inelastic neutrons, proton ionization profile, pions & heavy ions)
9. Radiation Dosimetry (radiation units, exposure and KERMA, Absorbed dose, radiation dose measurement, Methods of measurement
10. Teletherapy machines: Telecobalt & Linac (Superficial & orthovoltage machines, microwave production, waveguide construction, electron production, x-ray production and beam control. Construction of linear accelerator & telecobalt machine, output, Energy range, build up, skin sparing, isodose curves, fixed & isocentric approaches, wedges, output factors, beam geometry)
11. Radiotherapy Simulators (Conventional and CT simulators structure and use)
12. Machine calibration, acceptance test and Quality assurance
13. Mould room Techniques (Beam modifying devices, tissue compensators)
14. Basics of dose calculation (Simple methods, shielding, Clarkson integration, field matching, attenuation coefficient and half value layers)
15. Basics of treatment planning and Dosimetric physical aspects (data required, immobilization techniques, patient & organ movements, tumor localization methods, transportation of patient data, data from MRI, USG and PET, single & multifield planning, Coplanar & non-coplanar planning, isodose dose distribution)
16. ICRU guidelines: Teletherapy & Brachytherapy
17. Principles of radiation protection (Radiation risk, stochastic and non-stochastic process, Quality factor, statutory framework, background radiation , radiation limits, classification of staff and designated areas, controlled areas and screening, guidance notes, protection mechanism (time, distance & shielding), primary secondary barriers, treatment room design, personnel Monitoring, film/TLD badges, dosemeters, Dose reporting mechanism)

09HLTH09A04-002-P PHYSICS [Practical] –I

1. Parts and functions of various Teletherapy and Brachytherapy machines
2. Radioisotope handling, Radiation Protection
3. Calculation of output from ^{60}Co machine
4. Treatment time calculation for simple fields (open, regular)
5. Quality control and machine calibration
6. Isodose curves and manual treatment plans using isodose curves
7. Visit to BARC / BRIT / nuclear installations

09HLTH09A04-003-C MEDICAL STATISTICS & EPIDEMIOLOGY [Theory] –I

1. Sampling: Concept of a population and a sample and the need for statistics, random sampling, standard error, Confidence intervals.
2. Properties of “Normal or Gaussian Distribution” curve
3. Types of data: Paired and Unpaired; Categorical and continuous, Numerical data [discrete & continuous], Bar charts & histograms
4. Comparing mean and median: $\chi 2$, Student ‘t’ test etc.
5. Measurements & tests of association between variables: Correlation & regression scatter plots, sensitivity, and specificity, positive & negative predictive values.

09HLTH09A04-003-P MEDICAL STATISTICS & EPIDEMIOLOGY [Practical] –I

1. Chi-square test on simple data set (degree of freedom 1).

09HLTH09A04-004-C CANCER BIOLOGY [Theory] –I

1. Cellular structure and function
2. Cell membrane and Cytoplasm
3. Nucleus, normal gene transcription, DNA repair mechanism, polymorphism, micro-satellites, Methylation, hypomethylation & methylation reversal
4. Haemopoiesis: Marrow structure, haemopoietic microenvironment, cell lineage & hierarchies
   Cell growth control: Normal cell growth & control, Autocrine, paracrine & endocrine control, signal transduction, cyclin kinases, gene promoters, signal pathways
5. Cell Cycle Control and cancer, basic kinetics
6. Growth disorders: Hyperplasia, dysplasia, *carcinoma-in-situ* and neoplasia
   Causation of Cancer: Environmental factors, carcinogenesis [viral, radiation] Normal tissue damage [early & late],
7. Mechanism of spread, local invasion, metastasis
8. Multistage carcinogenesis and metastatic cascade
9. Tumor vasculature & angiogenesis

09HLTH09A04-005-C RADIOBIOLOGY [Theory] –I

1. Cellular system (hierarchical / flexible), Parallel and Linear systems
2. Cell, tissue and tumour kinetics, Cell survival curve & basis of fractionation
3. Radiation damage at cellular level (membrane, cytoplasmic, nuclear): normal tissue tolerance, effects on different tissues, schemes of reporting normal tissue damage
4. LET, OER and RBE
5. Factors affecting Radio-sensitivity, Radio-sensitizers & Radio-protectors
7. Radiation biology models: monolayer, spheroids, animal [normal & transgenic], re-growth curves, clonogenic assay, MTT
8. Acute and late effects of Whole body irradiation
9. Radiation Carcinogenesis

09HLTH09A04-004-P RADIOBIOLOGY [Practical] –I

1. Using Flow-Cytometry to estimate Ploidy & S-Phase

Internal Assessment / Examination

First Year

Theory: Physics, basic radiobiology and statistics, MCQ.

Practical: Machine operations, various parts of the machines, set-up of the patient, treatment time calculation, calibration, gap calculation, instruments, evaluation of isodose charts, computer plans and related medical physics.

Clinical: Staging of common cancers, examination procedures, simple planning - clinical and simulation, recognition and management of radiation induced reactions.

Evaluation: Logbook, presentations during the year, appraisal scores.

Second Year

09HLTH09A04-006-C CLINICAL ONCOLOGY [Theory] –II

Pathology, Staging, Prognostic factors, Management, Surgery, Radiotherapy, Drug therapy (Cytotoxic chemotherapy, Hormone & Biological) and outcome of the anatomical tumor sites.

1. Head & Neck Tumors: Lip, Oral cavity & Oro-pharynxl, Nasopharynx & PNS, Hypopharynx and Larynx, salivary glands, ear, orbit, Lacrimal gland, Thyroid, Glomas Jugulare & Carotid body tumors
2. Female Genital Tract: Uterine cervix, Endometrium, vagina, ovary, vulva, Fallopian tubes
3. Breast cancers
4. Genito-Urinary: Kidney, prostate, bladder, Ureter, Testis, Urethra and penile cancers
5. Tumors of Chest & Pleura: Lung, Mediastinal tumours, Thymus, Pleura and Trachea
6. Gastro-Intestinal Tract Tumors: Oesophageal, gastric, Small Bowel, Colon & rectum, Anal Canal & perianal region, Pancreas, Liver & Biliary tract
7. Endocrine: Thyroid, Parathyroid, Pituitary, Adrenal
8. CNS Tumours: Brain, Spinal cord, Craniopharyngioma, Chordoma, acoustic neuroma, meninges
9. Bones & Soft-Tissue: Sarcomas, Bone tumors
10. Lymphoproliferative disorders: Hodgkin's & Non-Hodgkin's lymphomas, Plasma cell malignancies, Acute & Chronic leukemias,
11. Skin: Basal cell, squamous cell carcinomas, Malignant melanoma, Cutaneous lymphomas, Mycosis Fungoides, Kaposi sarcomas
12. Oncological emergencies

09HLTH09A04-005-P CLINICAL ONCOLOGY [Practical] –II

1. Knowledge about treatment options and decision making for various cancers
2. Discussing Randomized Trials with patients and obtaining their consent
3. Management of patients with Renal failure, G.I. obstruction, SVCO, TOF, Cord Compression, severe vaginal bleeding, neutropaenic sepsis, hypercalcaemia, necrosis, pathological fractures etc.
4. Management of patients in severe pain and of dying patients, palliative care.
5. Hospice care: visit to 'Shanti Avedana Ashram', use of Morphine
6. Use of divergent blocks (Mantle, Inverted Y, Rectum, Brain etc), Electron cut outs.
7. Simulation Techniques e.g. Conservative Breast, Mantle, Inverted-Y, Dog leg, Pancreas, Nasopharynx, PNS, Vocal Cord, Brain, Planning CT Scans
8. Magna-field Irradiation: Hemi Body irradiation, Total Body Irradiation, Whole Abdomen
9. Computer Treatment Planning: Parallel opposed, Antero-lateral, 3 or 4-field beam arrangement with equal and unequal weight. Intracavitary and simple interstitial brachytherapy plans of breast, template, buccal mucosa
10. Organizing and maintaining central lines (Hickman's), Parental Nutrition, Cytotoxic drugs such as Doxorubicin, Vincristine, Mitoxantrone, Cisplatinum etc.
11. Assisting Interstitial Implants/ ILRT/ EBRT procedures. Performing simple procedures like intracavitary, CVS etc.
12. Retrieving information from Medline, Internet etc.

09HLTH09A04-007-C PHYSICS [Theory] –II

1. Radiation Dosimetry & Calibration methods (Ionization chambers, Geiger counter, diodes, Chemical methods, films, Thermo-luminescence [TLD], Scintillation counters, calorimetry)
2. Electron beam therapy (energy range, percent depth dose, factor affecting depth dose, build-up, effect of surface obliquity & inhomogeneity, internal shielding)
3. Principals of CT planning (data acquisition, image manipulation, defining volumes, plan verification, DVH, element of inverse planning & Intensity Modulated Radiation Therapy)
4. Treatment Planning (Arc & rotation, non-coplanar planning, conformal, in homogenous media, volume definition, dose prescription, defining beam geometry, collimators, penumbra, beam quality,

Wedge & applicators, Multi-leaf collimators)

5. Evolution of brachytherapy dosage systems
6. Modern brachytherapy dosage calculation
7. Radioactive Sources (Isotopes, radioactive decay, parent & daughter decay series, half-life, characteristics of radiation, types of sources & their construction, requirement for clinical use, dose distribution around sources, sealed & unshielded sources and their storage, safety devices)
8. Physics principles in clinical use (Distribution rules & dose calculations, Gynecological brachytherapy systems, principle and types of after-loading)
9. Remote after-loading LDR, HDR and PDR machines
10. Computer Treatment planning systems
11. Use of unsealed sources (Isotopes, shelf-life, physical & biological life, radiopharmaceuticals, use in imaging & therapy, clinical applications and dose calculations)
12. Principles of CT, MR, PET and USG imaging

09HLTH09A04-006-P PHYSICS [Practical] –II

1. Manual localization of brachytherapy sources from orthogonal x-Rays and estimation of the Basal Dose Rate and Reference Dose Rate as per 'Paris' rules.
2. Complex field shapes and modified beams. Computer treatment planning teletherapy (AP/PA; 3 or 4 fields, anterior/lateral; weighting)
3. Computer treatment planning brachytherapy (CVS, Intracavitary, Breast, Buccal Mucosa, Template)
4. Simple Conformal plans; Conformal blocks, CT Planning.
5. Radio-Isotope waste disposal; Functions of RSO.
6. HDR & LDR Surface mould treatment execution.

09HLTH09A04-008-C MEDICAL STATISTICS & EPIDEMIOLOGY [Theory] –II

1. Principles of statistical inferences: Hypothesis testing, Sample size, Type I & II errors, interpretation of p-values, statistical & clinical significance.
2. Survival analysis in cancer: Types of time-to-event data, Kaplan-Meier & Actuarial Survival Curves,
3. Comparing groups: Log rank test, use of Cox's proportional hazards regression model, Hazard ratio and their interpretation
4. Clinical trial methodology: Phase I-IV trials, Randomization & stratification methods, problem with non-randomized studies & historical controls, Blinding/masking, Design of clinical trials, Contents of trial protocols, ethics & informed consent, Sample size calculation, Interim analysis
5. Measures of response: Tumor regression, Morbidity, Local/regional recurrence, Distant Metastasis, Death, Quality of Life. Intent-to-treat analysis
6. Epidemiology: Retrospective (case control studies) & Prospective (Cohort studies), Odds ratio & relative risks, Mortality rates, cancer registration & follow-up, Trends in cancer incidence.

09HLTH09A04-007-P MEDICAL STATISTICS & EPIDEMIOLOGY [Practical] –II

1. Actuarial Survival Curves for a given data set
2. Estimating Sample size for given type I and II error

09HLTH09A04-009-C CANCER BIOLOGY [Theory] –II

1. Genetic Predisposition to Cancer
2. Proto Oncogenes and Tumour suppressor genes, Protine-protein interaction
3. Principles of molecular biology techniques (PCR, FCM, Electrophoresis, cloning etc.)
4. Tissue culture techniques and Clonogenic assays
5. Cancer Genetics: Genes associated with cancer, Inherited syndromes associated with cancer [ataxia telangiectasia, xeroderma pigmentosa, Nijmegin break syndrome, Li-Fraumeni, Lynch, Cockayne's familial polyposis coli, inherited breast cancer syndromes], Linkage analysis, genetic counseling.

6. Human Genome Project

09HLTH09A04-008-P CANCER BIOLOGY [Practical] –II

1. Basic Tissue Culture Techniques
2. Nucleic acid analysis including electrophoresis, hybridization, blotting, PCR, sequencing, transfection

09HLTH09A04-010-C RADIOBIOLOGY [Theory] –II

1. Molecular Biology of Radiation Damage & Repair: molecular process in radiation damage repair, time course of repair, chemotherapy drug resistance, damage [lethal, sublethal, potentially lethal]
2. Acute & Late responding tissue and dose response relationship
3. Time Dose Fractionation and the evolution of Bioeffect models
4. Hyperfractionation, accelerated fractionation and hypofractionation, influence of gaps and time on radiation response
5. Methods of identifying hypoxia
6. Isoeffect curves, α/β ratio and relevance to acute & late responding tissues
7. Linear Quadratic Model
8. Predictive assays of Radiation response
9. Radiation effect on embryo & Foetus

09HLTH09A04-009-P RADIOBIOLOGY [Practical] –II

1. Calculation of Biologically Effective Doses for tumour control, acute and late effects using the LQ model.
2. Clonogenic assays and Survival Fraction (SF2)
3. Using Radio-sensitizers or Radio-Protectors (e.g. Amifostine, 2-Deoxy-Glucose, Curcumin).

09HLTH09A04-011-C CHEMOTHERAPY & CLINICAL PHARMACOLOGY [Theory] –II

1. Mechanism of action of Cytotoxic drugs: Mechanism of action, Phase & cell cycle specific drugs, Mechanism of cell death, Mechanism of cell death, Drug resistance modifiers, drug interaction.
2. Pharmacokinetics and Pharmacodynamics: General Principles, Route & timing of administration, Plasma concentration, AUC, Drug activation, metabolism & clearance, Protein & tissue binding, Drug concentration at target site.
3. Principal of Clinical use: Dose response curves, Dose intensity, Single agent & combination chemotherapy, Adjuvant & neo-adjuvant therapy, high dose chemotherapy, continuous infusion, intrathecal treatment.
4. Toxicity of Chemotherapy: Mechanism of toxicity, Dose limiting & common toxicities, Dose related & idiosyncratic toxicities, Early, intermediate & late toxicity, factors modifying toxicities, safe handling of Cytotoxic drugs.
5. Clinical pharmacology of analgesics, steroids & anti-emetics: Morphine & derivatives, drug interactions.
6. Endocrine Therapy: Mechanism of action, resistance, common side effects and combination with other therapies.
7. High dose therapy: Clinical methods (clinical trials), Protection & rescue of stem cells, unusual toxicities [veno-occlusive disease].

Internal Assessment / Examination

Second Year

Theory: Physics, radiobiology, statistics and clinical science, MCQ.

Practical: Computerized treatment plan assessment and discussion. Divergent blocks, calculation of ERD/BED etc., complex time calculations.

Clinical: Case presentation - long and short cases, assessment of examination and diagnostic skills, doctor-patient relationship, decision making ability.

Evaluation: Logbook, presentations during the year, appraisal scores.

Third Year

09HLTH09A04-012-C CLINICAL ONCOLOGY [Theory] –III

1. Paediatric solid tumours
2. Cranial & Extracranial Stereotactic Irradiation
3. Radiotherapy of Non-Malignant diseases
4. Advances in Interstitial and Intracavitary Brachytherapy, Endovascular Irradiation
5. Hyperthermia
6. Photodynamic therapy
7. AIDS related malignancies
8. Problem solving in grey areas & difficult cases
9. Supportive & Palliative Care: Pain relief, Symptom control in advanced cancer (nausea, vomiting, anorexia, dysphagia, depression and anxiety), Care of the dying patients & the Hospice care, The 'Truth' about cancer: When to tell, How much to tell & to whom?
10. Quality of Life: QoL assessment tools for clinical trials & routine practice, outcome measures
11. Medical ethics: A clinician's perspective, ethics in biomedical research, Professional values, Legal considerations
12. National Cancer Control Programme
13. Screening for common cancers : Pragmatic approaches for our country
14. Rehabilitation of cancer patients
15. Investigational Techniques in clinics and laboratory, Technology assessment and outcome measures, Economics in Radiation Oncology
16. Setting up Radiotherapy departments in India. Equipment and facilities needed?
17. Oncologists as managers of Health care system
18. Communication and publications

09HLTH09A04-010-P CLINICAL ONCOLOGY [Practical] –III

1. Complex Simulation and treatment techniques e.g. asymmetric beam, TSET, Craniospinal Irradiation, Paediatric tumours, TBI.
2. Treatment Planning (mixed beam, matching fields, electrons, head and neck implants)
3. Intracavitary, ILRT and simple implants
4. Preparing Surface Moulds
5. Assisting EBRT, Head/Neck Implant, Templates
6. Cytotoxic drugs (Taxenes, BCNU, High dose Methotrexate, Interferon, G-CSF, Leuprolide etc.)

09HLTH09A04-013-C PHYSICS [Theory] –III

1. Use of PET and SPECT
2. Special techniques principles & practice (Total Body Irradiation, Total Skin Electron Therapy, IMRT/IGRT, Stereotactic radiation)
3. Dosimetric aspects of Magna field therapy.
4. Complex field arrangements & mixed beams, electron arcs, Matching fields, asymmetric fields.
5. Recent developments and future trends in RT planning and treatment delivery
6. Quality Assurance in Radiotherapy (Quality Assurance & quality control, Monitoring accuracy,

verification parameters, megavoltage imaging, tolerance limits, Legal requirements)

09HLTH09A04-011-P PHYSICS [Practical] –III
1. 3-Dimensional conformal planning
2. Electronic portal imaging
3. Networking
4. Quality assurance tests in radiotherapy

09HLTH09A04-014-C MEDICAL STATISTICS & EPIDEMIOLOGY [Theory] –III
1. Role and function of cancer registries
2. Multivariate analysis
3. Meta-Analysis
4. Writing research articles for journals

09HLTH09A04-012-P MEDICAL STATISTICS & EPIDEMIOLOGY [Practical] –III
1. Designing and writing protocols for Phase I, II and III studies

09HLTH09A04-015-C CANCER BIOLOGY [Theory] –III
1. Molecular basis of radiation sensitivity
2. Molecular basis of cytotoxic drug action and drug resistance
3. Immunological aspects of cancer and cancer vaccines: Antigen recognition, Dendritic cells, immunological surveillance, tumor immunology,
4. Antisense and Gene therapy
   Basic principles of Hyperthermia

09HLTH09A04-013-P CANCER BIOLOGY [Practical] –III
1. Understanding micro-array technique
2. Transgenic models

09HLTH09A04-016-C RADIOBIOLOGY [Theory] –III
1. Dose rate effect in Brachytherapy
2. How to compensate for missed treatment days?

09HLTH09A04-017-C CHEMOTHERAPY & CLINICAL PHARMACOLOGY [Theory] –III
1. Drug Design and development: Novel therapeutic targets, New drug discovery & development, Preclinical assessment of candidate compounds and phase I-IV studies.
2. Biological & Novel therapies: Biological therapies mechanism & combination, Mode of action of interferons, interleukins, growth factors, gene therapy & immunotherapy, Novel targets, cell signal control, Oncogene products, Cancer vaccines.

Internal Assessment / Examination
Third Year

Theory: Comprehensive knowledge of clinical oncology, optimal combination of surgery, radiotherapy, chemotherapy and hormones. Value of support services such as pathology, cytology, occupational therapy and preventive oncology. Medical statistics and design of clinical trial.

Practical: Update of previous years, use of MLC, IMRT CT planning, complex time calculations, pathology slides, pathology specimens, chemotherapeutic drugs, procedures, e.g. ILRT, ICA.

Clinical: Case presentation - Long and short cases, assessment of examination and diagnostic skills, doctor-patient relationship, decision making ability.

Evaluation: Logbook, Thesis / dissertation, paper presentations during the year, appraisal scores, publications.

Final Examination after completing three years of training

होमी भाभा राष्ट्रीय संस्थान
Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
PAREL, MUMBAI – 400 012

SYLLABUS

OF

MD MICROBIOLOGY

(Program Code: HLTH09A05)

M.D. (MICROBIOLOGY)

The aim of this course is to train the students of Medicine in the field of Medical Diagnostic Microbiology. Knowledge and practical skills shall be acquired by the candidates in the sub-specialities of Bacteriology including Mycobacteriology, Virology, Parasitology, Immunology, Serology & Mycology so as to be able to deal with diagnosis and prevention of infectious diseases in the community. They will be trained in basic research methodology including molecular biology so that they are able to conduct fundamental and applied research. They will also be trained in teaching methods so that they can take up teaching assignments.

GOAL:

The goal of the postgraduate medical education shall be to produce a competent specialist and Medical teacher:

- Who shall recognize the health needs of the community and carry out professional obligations ethically in keeping with the objectives of the national health policy;
- Who shall have mastered most of the competencies, pertaining to Medical diagnostic Microbiology that are required to be practiced at the secondary and the tertiary levels of the health care delivery system;
- Who shall be aware of the contemporary advances and developments in the field of medical and diagnostic Microbiology
- Who shall have acquired the spirit of scientific inquiry and is oriented to the principles of research methodology and epidemiology
- Who shall have acquired the basic skills of teaching of the medical and paramedical professionals.

EDUCATIONAL OBJECTIVES:

KNOWLEDGE:

At the end of the course the students shall be able to:

1.State and explain the clinical features, etiology, pathogenesis and methods of laboratory diagnosis of infectious diseases and apply that knowledge in the treatment, prevention and control of communicable diseases caused by micro-organisms.

2.State and explain the principles of immunity and immunological phenomenon which help to understand the pathogenesis, laboratory diagnosis of infectious and non-infectious diseases.

3. Establish and practice "laboratory medicine" for diagnosis of infectious diseases in hospitals and community in the field of bacteriology, parasitology, virology, mycology, serology and immunology in the light of clinical findings.

4. Organize the prevention and control of communicable diseases in the community.

5. Understand and practice the principle of prevention and control of health

care associated infections and rational antibiotic policy.

6. State the recent advances in the field of Medical Microbiology and apply this knowledge in understanding aetiopathogenesis and diagnosis of diseases caused by micro-organisms.

7. Carry out fundamental or applied research in the branches of medicine involving microbiological work.

8. Develop specialization in any of the above subspecialities.

9. Undertake teaching assignments in the subject of medical Microbiology.

(B) Skills

At the end of the course the student shall be able to

1. Plan the laboratory investigations for the diagnosis of infectious diseases

2. Perform laboratory procedures to arrive at the etiological diagnosis of infectious diseases caused by bacteria, fungi, viruses and parasites including the drug sensitivity profile.

3. Perform and interpret immunological and serological tests.

4. Operate routine and sophisticated instruments in the laboratory.

5. Develop microteaching skills and Pedagogy

6. Successfully implement the chosen research methodology

COURSE CONTENT (SYLLABUS)

DURATION OF COURSE:

The minimum period of training shall be three calendar years and the candidates can be admitted to this training after their full registration with the Medical Council. No exemption shall be given from this period of training of three years either for doing housemanship or for any other experience or diploma.

TRAINING PROGRAM:

The candidates joining the course must work as full time residents during the whole period of their postgraduate training. They will be required to attend a minimum of 80% of training period. Candidate shall be given full time responsibility and assignments and their participation in all facets of the educational process assured.

Postgraduate students must maintain a record book of the work carried out by them and the training undergone by them during the period of training. These record books shall be checked and assessed by the faculty.

TEACHING /LEARNING METHODS:

Learning in M. D. (Microbiology) will essentially be self-learning.

Following teaching-learning methods shall be followed-

Group teaching sessions:

- Journal review
- Subject seminar presentation
- Group discussion
- Slides seminars
- Clinical case presentations pertaining to infectious diseases
- Presentation of the findings of an exercise on any of the sub-specialities
- Participation in CME programs and conferences

Hands on experience (practical training)

Practical training shall be imparted by posting the students in various sub-specialities (sections) as detailed in the intrinsic and extrinsic rotation.

Student shall be actively involved in day to day working of all the sections. He/she will be trained under the guidance of teachers in all the aspects of Clinical Microbiology and applied aspects of laboratory medicine including collection and transport of specimens, receiving of samples, preparation of requisite reagents, chemicals, media and glassware, processing of specimens, performing required antimicrobial susceptibility testing and reporting on the specimens, interpretation of results, sterilization procedures, bio-safety precautions, infection control practices, maintenance of equipments, record keeping and quality control in Microbiology.

Suggested schedule of rotation:

Intrinsic rotation:

1. Bacteriology(Aerobic and anaerobic)	6 months
2. Mycobacteriology	3 months
3. Hospital infection surveillance	3 months
4. Serology/Immunology	6 months
5. Mycology	3 months
6. Virology/HIV	3 months
7. Parasitology	3 months
8. Clinical Microbiology(OPD)	2 months
9. Molecular Diagnostics	1 month

Extrinsic rotation:

Clinical Pathology	3 months
*Elective posting	3 months
Total	36 months

Emergency duty:

Student shall be posted for managing emergency laboratory services in Microbiology. He/she will deal with all the emergency investigations in Microbiology.

Training in research methodology:

Training in research methodology shall be imparted by planning of a research project by the student under the guidance of a recognized guide to be executed and submitted in the form of a dissertation.

The dissertation is aimed at training the candidate in research methods and techniques. It will include identification of a research question, formulation of a hypothesis, search and review of relevant literature, getting acquainted with recent advances, designing of research study, collection of data, critical analysis of the results and drawing conclusions.

The topic shall be communicated to the university within six months of registration and at least 12 months should be spent on the research project.

The dissertation shall be completed and submitted by the student six months before appearing for the final university examination.

Teaching experience:

Student shall be actively involved in the teaching of undergraduate students. He/she will be trained in teaching methods and use of audiovisual aids.

BROAD AREAS OF STUDY

General Microbiology; Systematic Bacteriology, Mycology, Virology, Parasitology; Serology,Immunology, molecular diagnostics and Applied Clinical Microbiology including recent advances in Microbiology.

09HLTH09A05-001-C **GENERAL MICROBIOLOGY**

1. History and pioneers in Microbiology
2. Microscopy
3. Morphology of bacteria and other micro-organisms.
4. Nomenclature and classification of microbes.
5. Growth and nutrition of bacteria.
6. Bacterial metabolism.
7. Sterilization and disinfection.
8. Biomedical waste disposal
9. Bacterial toxins.
10. Bacterial antagonism: Bacteriocins.
11. Bacterial genetics, gene cloning.
12. Antibacterial substances used in treatment of infections and drug resistance in bacteria.
13. Bacterial ecology-normal flora of human body, hospital environment, air, water and milk
14. Host parasite relationship.
15. Quality control and Quality Assurance in Microbiology.
16. Laboratory Biosafety
17. Health care associated infections- prevention and control

09HLTH09A05-002-C **IMMUNOLOGY AND APPLIED ASPECTS**

1. The normal immune system.
2. Innate immunity.
3. Antigens.
4. Immunoglobulins.

5. Complement.
6. Antigen and antibody reactions.
7. Hypersensitivity.
8. Cell medidated immunity.
9. Immunodeficiency.
10. Autoimmunity.
11. Immune tolerance.
12. Transplantation immunity.
13. Tumour immunity.
14. Prophylaxis and immunotherapy
15. Measurement of immunity.
16. Immunity and immunopathogenesis of specific infectious diseases
17. Molecular Biology Techniques. For e.g. PCR, DNA probes.

09HLTH09A05-003-C **SYSTEMATIC BACTERIOLOGY**

1. Isolation, description and identification of bacteria. The epidemiology, pathogenesis, antigenic characteristics and laboratory diagnosis of disease caused by them
2. Staphylococcus and Micrococcus; Anaerobic Gram positive cocci.
3. Streptococcus and Lactobacillus.
4. Neisseria, Branhamnella and Moraxella.
5. Corynebacterium and other coryneform organisms.
6. Bacillus: the aerobic spore-bearing bacilli.
7. Clostridium: the spore-bearing anaerobic bacilli.
8. Non-sporing anaerobes
9. The Enterobacteriaceae.
10. Vibrios, Aeromonas, Plasiomonas, Campylobacter and Spirillum,H.pylori
11. Erysipelothrix and Listeria
12. Pseudomonas.
13. Chromobacterium, Flavobacterium, Acinetobacter and Alkaligens.
14. Pasteurella, Francisella.
15. Haemophilus and Bordetella.
16. Brucella.
17. Mycobacteria.
18. The spirochaetes.
19. Actinomyces, Nocardia and Actinobacillus.
20. Mycoplasmatales: Mycoplasma, Ureaplasma and Acholeplasma.
21. Rickettsiae.
22. Chlamydiae.
23. Emerging bacterial pathogens.

09HLTH09A05-004-C **VIROLOGY**

1. The nature of viruses
2. Classification of viruses
3. Morphology :virus structure
4. Virus replication
5. The genetics of viruses
6. The pathogenicity of viruses
7. Epidemiology of viral infections
8. Vaccines and antiviral drugs
9. Bacteriophages
10. Pox viruses
11. Herpes viruses
12. Vesicular viruses
13. Togaviridae

14. Bunyaviridae
15. Arenaviridae
16. Marburg and Ebola viruses
17. Rubella virus
18. Orbi viruses
19. Influenza virus
20. Respiratory disease: Rhinoviruses, adenoviruses, corona viruses
21. Paramyxoviridae
22. Enteroviruses : Polio, Echo, Coxsackie viruses
23. Other enteric viruses
24. Hepatitis viruses
25. Rabies virus
26. Slow viruses
27. Human immunodeficiency viruses
28. Oncogenic viruses
29. Teratogenic viruses
30. Viruses of gastroenteritis
31. Prion diseases
32. Emerging viral infections – SARS, Avian influenza

09HLTH09A05-005-C **PARASITOLOGY**

1.Protozoan parasites of medical importance : Entamoeba, Giardia, Trichomonas, Leishmania, Trypanosoma, Plasmodium, Toxoplasma, Sarcocystis, Cryptosporidium, Balantidium,Isospora, Cyclospora,Microsporidium etc.

2. Helminthology : All those medically important helminths belonging to Cestoda, Trematoda and Nematoda.

Cestodes : Diphyllobothrium, Taenia, Echinococcus, Hymenolepis, Dypyllidium, Multiceps etc.

Trematodes : Schistosomes, Fasciola, Gastrodiscoides, Paragonimus, Clonorchis, Opisthorchis etc.

Nematodes : Trichuris, Trichinella, Strongyloides, Ancylostoma, Nicator, Ascaris, Toxocara, Enterobius, Filarial worms, Dracunculus, etc.

3. Ectoparasites : Common arthropods and other vectors viz.,Mosquito, Sandfly, Ticks, Mite, Cyclops.

09HLTH09A05-006-C **MYCOLOGY**

1. The morphology and reproduction of fungi and antimycotic agents
2. Classification of fungi
3. Contaminant and opportunistic fungi
4. Fungi causing superficial mycoses
5. Fungi causing subcutaneous mycoses
6. Fungi causing systemic infections
7. Antifungal agents

09HLTH09A05-007-C **APPLIED CLINICAL MICROBIOLOGY**

1. Epidemiology of infectious diseases
2. Hospital acquired infections
3. Infections of various organs and systems of the human body
4. Molecular genetics as applicable to Microbiology
5. Automation in Microbiology
6. Rapid diagnostic techniques for microbial diseases.
7. Vaccinology : principle, methods of preparation, administration of vaccines
8. Outbreak investigations & disaster management
9. Biological warfare

PRACTICALS (SKILLS)

09HLTH09A05-001-P **BACTERIOLOGY**

Must acquire:

1. Care and operation of Microscopes viz. Light, Dark ground, Phase contrast, Inverted, Fluorescent microscopes.
2. Preparation of stains viz. Gram's, Albert's, Ziehl- Neelson and other special stains - performing of staining and interpretation of stained smears.
3. Washing and sterilization of glassware including plugging and packing.
4. Operation of incubator, autoclave, hot air oven, inspissator, distillation plant, filters like Seitz and membrane and sterility tests.
5. Care and maintainance of common laboratory equipments like water bath, centrifuge, refrigerators, incubators etc.
6. Preparation and pouring of liquid and solid media - Nutrient agar, Blood agar, MacConkey agar, sugars, TSI agar, Robertson's cooked meat, Lowenstiein- Jensen's, selective media.
7. Preparation of reagents – oxidase, Kovac, etc.
8. Tests for beta-lactamases including ESBLs.
9. Collection of specimens for Microbiological investigations such as blood, urine, throat swab, rectal swab, stool, pus, OT specimens.
10. Preparation, examination and interpretation of direct smears from clinical specimens,viz. Sputum for AFB – ZN & auramine O, slit smears for *M..leprae,*-ZN stain, conjunctival smear for Chlamydiae – Giemsa/Iodine.
11. Techniques of anaerobiosis – Gaspack system,anaerobic jars-evacuation & filling with H_2, CO_2
12. Identification of bacteria of medical importance upto species level (except anaerobes – upto generic level)
13. Quantitative analysis of urine by pour plate method and semiquantitative analysis by standard loop test for significant bacteriuria.
14. Plating of clinical specimens on media for isolation, purification identification and quantitation.
15. Tests for motility: hanging drop, Craige's tube, dark ground microscopy for Spirochaetes – Treponema & Leptospira.
16. In-vitro toxigenicity tests – Elek test, Nagler's reaction
17. Special tests – Bile solubility, chick cell agglutination, sheep cell haemolysis, niacin and catalase tests for mycobacterium, satellitism, CAMP test, catalase test and slide agglutination tests, and other as applicable t identification of bacteria upto species level
18. Preparation of antibiotic discs; performance of antimicrobial susceptibility testing by Kirby-Bauer disk diffusion method; estimation of Minimum

inhibitory /Bactericidal concentrations by tube/plate dilution methods. Tests for drug susceptibility of Mycobacterium tuberculosis

19. Skin tests like Mantoux, Lepromin etc.
20. Testing of disinfectants- Phenol coefficient and 'in use' tests.
21. Quality control of media reagents etc. and validation of sterilization procedures.
22. Aseptic practices in laboratory and safety precautions.
23. Disposal of contaminated material like cultures.
24. Bacteriology of food, water, milk, air
25. Maintenance of stock cultures.

Desirable to acquire:

1. Care and breeding of laboratory animals viz. Mice, rats, guinea pigs and rabbits.
2. Techniques of withdrawal of blood from laboratory animals includingsheep.
3. Inoculation of infective material in animals by different routes.
4. Animal pathogenicity /toxigenicity tests for *C.diphtheriae, Cl.tetani, S. pneumoniae, S.typhimurium, K. pnumoniae etc.*
5. Performance of autopsy on animals.
6. Isolation of plasmids and Conjugation experiments for transfer of drug resistance
7. Serum antibiotic assays eg. Gentamicin
8. Phage typing for staphylococci, *S.typhi etc.*
9. Bacteriocine typing eg. Pyocine, Proteocin etc.
10. Enterotoxigenicity tests like rabbit ileal loop, intragastric inoculation of mouse, Sereny's test.
11. Mouse foot pad test for *M.leprae*

09HLTH09A05-002-P

IMMUNOLOGY/ SEROLOGY

1. Collection of blood by venepuncture, seperation of serum and preservation of serum for short and long periods.
2. Preparation of antigens from bacteria or tissues for widal, Weil-Felix, VDRL, etc. and their standardisation.
3. Preparation of adjuvants like Freund's adjuvant.
4. Raising of antisera in laboratory animals.
5. Performance of serological tests viz. Widal, Brucella tube agglutination, indirect haemagglutination, VDRL, Paul-Bunnel, Rose-Waaler, IFA.
6. Immunodiffusion in gels, counter immunoelectrophoresis- visualization and interpretation of bands.
7. Performance and interpretation of Enzyme linked immunosorbant assay.
8. Latex and staphylococcal co-agglutination tests.

Desirable to acquire:

1. Leucocyte migration inhibition test.
2. T-cell rosetting.
3. Flow Cytometry
4. Radial immunodiffusion.
5. Immunoelectrophoresis.
6. Neutrophil phagocytosis.

09HLTH09A05-003-P MYCOLOGY

Must acquire:

1. Collection of specimens for mycology.
2. Direct examination of specimens by KOH, Gram, Kinyoun's, Giemsa, Lactophenol cotton blue stains.
3. Examination of histopathology slides for fungal infections.
4. Isolation and identification of pathogenic yeasts and moulds and recognition of common laboratory contaminants.
5. Special techniques like Wood's lamp examination, hair baiting, hair perforation, paraffin baiting and slide culture.
6. Maintenance of stock cultures.
7. Animal pathogenecity tests viz. Intracerebral and intraperitoneal inoculation of mice for cryptococcus.

09HLTH09A05-004-P PARASITOLOGY

Must acquire:

1. Examination of faeces for parasitic ova and cysts etc. by direct and concentration methods (salt floatation and formol – ether methods)and complete examination for other cellular features.
2. Egg counting techniques for helminths.
3. Examination of blood for protozoa and helminths by wet mount, thin and thick stained smears.
4. Examination of other specimens for e.g. urine, C.S.F., bone marrow etc. for parasites.
5. Histopathology sections – examination and identification of parasites.
6. Performance of stains – Leishman, Giemsa, Modified Acid Fast, Toluidine Blue O.
7. Identification of common arthropods and other vectors viz. Mosquito, sand fly, ticks, mite and cyclops.
8. Collection of specimens.
9. Preservation of parasites – mounting, fixing, staining etc.

Desirable to acquire:

1. In-vitro culture of parasites like entamoeba, leishmania, P.falciparum.
2. Maintainance of toxoplasma gondii in mice.
3. Preparation of media – NIH, NNN etc.
4. Copro-culture for larva of hook worms.
5. Antigen preparation viz. Entamoeba , Filarial , Hydatid for serological tests like IHA and skin test like Casoni's .
6. Permanent staining techniques like iron haematoxylin

09HLTH09A05-005-P VIROLOGY

Must acquire:

1. Preparation of glassware for tissue culture(washing, sterilization)
2. Preparation of media like Hanks, MEM.
3. Preparation of clinical specimens for isolation of viruses.
4. Serological tests-ELISA and rapid tests for HIV, RPHA for HbsAg, Haemagglutination inhibition for influenza, AGD and

couterimmunoelectrophoresis for detection of viral antigens or antiviral antibodies.

5. Chick embryo techniques- inoculation and harvesting.
6. Handling of mice, rats, guinea pigs, rabbits for collection of blood, pathogenicity test etc.

Desirable to acquire:

1. Preparation of Monkey Kidney Cells (Primary) maintenance of continuous cell lines by subcutures. Preservation of cell cultures.
2. Recognition of CPE in tissue cultures.
3. Performance of haemadsorption, haemagglutination, immunofluorescence, neutralization tests for identification of viruses.

SUGGESTED READING:
BOOKS:

Reference books (Please refer the most recent edition)

1. Topley and Wilson's Microbiology and Microbial infections. 8 volumes 2005, 10th edition
2. Color Atlas and Textbook of Diagnostic Microbiology: Elmer W Koneman -2006, 6th edition
3. Mandell, Douglas and Bennett's Principles and Practice of Infectious Diseases -2004, 6th edition
4. Microbiology and Clinical Practice: Shanson-1999, 3rd edition
5. Immunology: Janis Kuby- 2003.
6. Basic Clinical Immunology.
   Fudenburg, Stites, Caldwell, Weils.
7. Control of Hospital Infection- A practical handbook (most recent edition)-2000, 4th edition
8. Bailey and Scott's Diagnostic Microbiology.
9. Text book of Parasitology.
   Chatterjee K.D.
10. Microbiology in Clinical Practice.
    Shanson D.C.
11. Beaver's Parasitology Textbook

Further Reading

1. Mycology - Rippons
2. Essentials of Immunology- Roitt
3. Virology- Clinical Virology by Rich
4. Gradwohl's Clinical Laboratory Methods and Diagnosis.
5. Biochemical tests for the Identification of Medical Bacteria- MacFaddin JF
6. Manual of Clinical Microbiology- ASM press

Journals

1. Indian Journal of Medical Microbiology
2. Clinical Microbiology Reviews
3. Journal of Clinical Microbiology
4. Journal of Medical Microbiology
5. Journal of AIDS
6. Journal of Hospital Infection
7. Indian Journal of Tuberculosis and Lung Diseases.

8. Indian Journal of Medical Research
9. JAAC
10. Parasitology Today
11. Journal of Infection
12. Infection Control and Hospital Epidemiology
13. Indian Journal of Tuberculosis
14. Journal of Associations of Physicians of India
15. Lancet-Infectious Diseases
16. Emerging Infectious Diseases-online
17. New England Journal of Medicine- online
18. British Medical Journal
19. Scandinavian Journal of Infectious Diseases
20. ICMR Bulletin
21. AIDS Research & Review
22. MMWR
23. Tubercle
24. WHO Bulletin
25. Journal of American Medical Association
26. Paediatric infectious diseases
27. Indian Journal of Leprosy
28. International Journal of Leprosy
29. Immunology
30. American journal of Epidemiology

Important Websites:

1. Center for Disease Control -**www.cdc.gov**
2. World Health Organization- **www.who.int**
3. Infectious Disease Society of America- **www.idsociety.org**
4. United Nations Program on HIV/ AIDS- **www.unaids.org**
5. Johns Hopkins Infectious Diseases- **www.hopkins-id.edu**
6. National Library of medicine- **www.pubmed.com**
7. MD Consult- **www.mdconsult.com**
8. Global Infectious Disease epidemiology network- **www.gideononline.com**
9. National AIDS Control Organization- **www.nacoindia.org**
10. Tuberculosis Research Centre- **www.trc-chennai.org**

BACK TO MAIN

BARC

Syllabus for MD (Nuclear Medicine)
(Program Code: HLTH09A06)

01HLTH09A06-001-C Paper I - Basic Sciences & Instrumentation – 100 marks

01HLTH09A06-002-C Paper II - Diagnostic Radiopharmaceuticals & In-vitro Techniques – 100 marks (includes Radiation Physics, Radiation Biology & Radiation Protection)

01HLTH09A06-003-C Paper III- Clinical Nuclear Medicine Paper I – 100 marks

01HLTH09A06-004-C Paper IV - Clinical Nuclear Medicine Paper II – 100 marks

Basic Sciences for Nuclear Medicine

01HLTH09A06-001-C

1. Atomic structure & Periodic table — 2 Lectures

Atom and sub atomic particles,Rutherford's atomic structure and its limitations,Bohr's atomic structure.Quantum numbers,Isotope, Isobar and Isotone,Periodic properties like atomic radius, ionic radius, Electro negativity, Ionisation potential, Electron affinity.

2. Introduction Human Anatomy and Physiology — 10 Lectures

Human Anatomy, Brief introductory anatomical features of: Cardiovascular system, Respiratory system, Alimentary system, Renal system, Central nervous system, Endocrine systems, Reproductive system, Musculoskeletal system. Haematology. Human Physiology and Pathophysiology.

3. General Cell Biology & Cellular Physiology — 2 Lectures

The basic structure of eukaryotic and prokaryotic cell and their internal environment. cell wall, cell membranes. Functions of endoplasmic reticulum, mitochondria, golgi complex, lysosomes. Transmembrane potential of mitochondria and its implications in transport and intramitochodrial localization of isonitrile compounds. Transport across cell membranes, Functional systems in the cells, Cell reproduction;Concept of Cell doubling time and its implication in Oncology; Warburg effect and its implications in metabolic imaging; Apoptotic pathway and role of AnnexinV.

4. Basic Electronics — 8 Lectures

Fundamentals of electricity and electronics, Coulombs law,Ohms law,Ohmic & non ohmic devices,Kirchoff"s law,regulated power supply, Semiconductor physics,PN junction diode,LED,rectifiers,transistors(PNP&NPN),Feedbacks,operational amplifiers,Oscillators,binary,octal,hexadecimal number system, logic circuits,CRO ,ADC and DAC. Defibrillator circuit and uses.

5. Basic Mathematics — 12 Lectures

Numbering system, Accuracy and Precision, Significant figures, Matrices, Mathematical Constants. Linear and Polynomial Equations, Linear and Quadratic Equations and Identities, , Slope, Roots, Relation Between Roots and Coefficients. **Logarithms** Definition, Laws of Logarithms, Rule for Change of Base, Common and Natural Logarithms, **Permutations and Combinations** Probability, Permutation and Combination, Factorials. **Calculus** Relations and functions, Limits, Definition of Derivative, Physical Significance -Differentiation of Simple Functions, Differential Equations, integration and Summation, Definition of Trigonometric Functions, Identities.

Introduction to Mathematical Transformation: Fouriers Transform, Laplace transform.

6. Chemistry relevant for radiopharmaceuticals **10 Lectures**

Concept of BOHR model, Hybridization with example of Methane, Ethylene and acetylene etc, Solvent strength, acid base , pH, buffers, titrations, Organic Chemistry, resonance effect, steric effect, dielectric constant, various type of organic solvents, mesomeric effect, determination of organic acid base strength and other organic phenomena utilizing the basic principle, various type of organic reactions, Nucleophilic Substitution reactions in details, Aromatic substitution reactions, ^{99m}Tc-chemistry, Core structures of various common ^{99m}Tc-radiopharmaceuticals, labelling techniques, importance of ^{99m}Tc-kit components, peptide chemistry with respect to ^{68}Ga/^{177}Lu-DOTATOC, DOTA-TATE etc. Principle of radionuclide choice for imaging and therapy with example of ^{68}Ga, ^{177}Lu, ^{90}Y, ^{18}F, ^{99m}Tc etc. Principle of TLC &HPLC w.r.t. radiochemical purity (RCP).

7. Introduction to Immunology: **4 Lectures**

Structure and function of immune system, Immune response – humoral and cell-mediated immune response – primary and secondary responses. antigens, antibodies, structure of Ab's, classification of antibodies, antigen-antibody interaction, and monoclonal antibodies. New generation antibodies. Implications in molecular imaging & therapy.

8. Basic Biochemistry and Molecular biology **10 Lectures**

Introduction to carbohydrates, proteins, nucleic acids, enzymes, lipids. Protein structure and protein 3-dimensional shape, structure-function relationship, proteins purification, Nature of enzyme catalyzed reactions, their regulation, inhibition and mechanisms. Structure and function of carbohydrates and their importance in central metabolism. Structures and nature of fatty acids and lipids found in biological membranes. Lipid Metabolism. Nucleic Acids and Biological Information Flow. Related Biochemical and molecular biology techniques. Aptamers with radiolabelled apatamers for Nuclear imaging and therapy.

9. BIOSTATISTICS **12 Lectures**

Basic Concepts: Probability, a Priori and posteriori Probabilities. Statistical significance of probabilities Sample and Population, Variables, Classification of Variables, Nominal, Ordinal, interval and Ratio, Fixed and Random,

Population Distributions: Binomial distributions and Poisson distributions – their properties, parameters and applications.Normal and 't' distributions – Population and Sample Parameters Measures of central tendency, measures of dispersion, Variance, degrees of freedom, confidence limits and intervals. Probability of occurrence – use of Z and t tables.

Sampling, Estimates and Hypothesis testing: Sampling methods, Random sampling and estimates of population parameters from samples. Sample statistics, Hypothesis testing. Drawing inferences and confidence limits. P values. Students t test for comparing means. General and paired t tests. Special cases where Variances are unequal. Central Limit Theorem.

Analysis of Variance:F-Distribution - Test for Homogeneity of Variance One Way ANOVA, Comparison of Means of Multiple Groups By Partitioning of the total Sum of Squares as within and between Sum of Squares, Assumptions in ANOVA, Missing Values, Two Way ANOVA; Design of Experiments.

Correlation and Regression:

Pearsons' Product Moment Correlation Coefficient, comparison of Correlation Coefficients, Partial and Multiple Correlation, Linear Regression Analysis. Interpretation of Regression Coefficients. Application of Correlation and Regression in Method Comparison and Evaluation

Nonparametric Statistics: Spearman's Coefficient of Rank Correlation, Chi Square Test. Nonparametric Methods for Hypothesis Testing Based on Ranks. Mann Whitney U Test, Wilcoxon Signed Rank T Test

Clinical Statistics: Cohort Studies, Case Control Studies, Sample Size calculations, Clinical Trials, Meta analysis.

Demonstration of application Softwares in Statistics.

10. Introduction to Biology of cancer **2 Lectures**

Neoplastic processes. Inflammatory & Degenerative processes. Classification and nomenclature of neoplasms.Concept of Cell doubling time and its implication in Oncology; Warburg effect and its implications in metabolic imaging; Apoptotic pathway and role of AnnexinV.

11. Basic Medical Terminology **2 Lectures**

Descriptive – describing shape, color, size, function, etc, and eponyms. Word root for eg. Myocarditis (prefix)(root)(suffix). Prefix change, Suffix change. -itis, -osis, -ectomy, -otomy, -ostomy, a/an -, micro -, macro -, mega -/ -megaly, -scopy/ -scopic with examples. Pathological Nomenclatures Specially For Tumours.

12.Introduction Common hospital practices **2 Lectures**

Pathogens, Disinfection methods, Sterilisation, Communicable diseases, Nosocomial infections, Hepatitis, HIV, Biohazards, Principles of asepsis - handling of contaminated swabs, used syringes and needles, Bio-waste management. Policy for management of Niddle stick injury/Exposure to blood or body fluids.

01HLTH09A06-002-C

Radiation Physics, Radiation Biology & Radiation Protection

Origin & Types of Radiation **4 Lectures**

Fundamental constituents (quarks, leptons) and interactions of matter according to the "Standard Model", Properties of Nuclear Forces, Phenomenological Nucleon-Nucleon Potentials, Stability of nuclides - binding energy forces and nuclear forces, Spin, electric and magnetic moments, Experimental Nuclear Moments, Size, Parity and Isospin of Nuclei, Laws of radioactivity, Units of radioactivity. Decay modes, Stability of atom,Mass defect,Binding energy,The basis of radioactivity (N/Z ratio).Types of radioactivity depending on N/Z ratio Types of radiation (α[one body theory of alpha decay, microscopic theories of alpha decay], β[theory of beta decay; types of weak interaction; selection rules in beta decay; parity non conservation in beta decay], γ, X-ray, n). Theory of gamma decay, Experimental gamma ray transition rates: isomeric states; Vibrational motion (theory of Nuclear vibrations); Rotational motion (theory of Nuclear roatation); Interacting Boson models; Clustering (especially in context of alpha particles); Recent developments (qantum chromodynamics, pertubation theory, meson field theory and chiral perubation theory), radionuclide chart, . Laws of successive transformations, Theories of alpha, beta and positron emission; beta particle spectrum; K shell electron capture; Cerenkov radiation, characteristic radiation, Auger effect, Bremsstrahlung radiations, Metastable state and isomeric transition, internal conversion.Nuclear reactions, Nuclear reaction cross section, neutron activation with thermal neutrons, Nuclear isomerism, nuclear fission, fission products, nuclear reactors.

1. Interaction of radiation with matter **5 Lectures**

Gamma ray interactions - Excitation, ionization, photoelectric effect, Compton effect, pair production, annihilation radiations, specific ionization and linear energy transfer; Charged Particle interactions: range of charged particles, , Interaction of neutrons with matter, Elastic scattering. Importance of these interactions in radiology and nuclear medicine.

2. **Radiation Quantities and units** **3 Lectures**

Exposure, absorbed dose, radiation weighting factor, concept of radiation weighting factor W_R, Sievert, equivalent dose, concept of tissue weighting factor W_T, effective dose, committed equivalent dose, committed effective dose, ICRP and AERB dose limits . Use of dose constraints for staff, and comforter. Annual Limit of Intake and derived air concentration. Reference levels: Recording levels, Investigation levels and Action levels.

4. Gas filled detector **3 Lectures**

Theory of ionization chamber, design consideration in an ionization chamber, operating voltage, theory and construction of condenser type of chambers and thimble chambers; gas multiplication, pulse mode detector for single ionizing events, Proportional Counters - design and characteristics, Geiger-Mueller Counters - design consideration, dead time and recovery time, characteristics of organic and inorganic quenchers, operation.

5. Scintillation detectors – (Organic and inorganic) **3 Lectures**

Atomic basis of scintillation. Scintillation process. Dopants. Inorganic and Organic Scintillators, Comparison of properties by comparison of characteristics like stability, light output, decay time, intrinsic efficiency, dead time, considerations on fabrication and cost.

6. Gamma Ray Spectrometry **5 Lectures**

Construction of a Gamma Ray Spectrometer. Components of GRS. Detection principle – light collection, light guide, and Photomultiplier tubes. Coincidence & anti coincidence circuits. Single channel analyzer, multi channel analyzer. Study of gamma ray spectrum: photopeaks, Compton valley, edge and plateau, characteristic X-ray peak, backscatter peak, Iodine escape peak, annihilation peak, coincidence peak. Gamma ray spectrometer – calibration, energy resolution, integral and differential counting, linearity, counting efficiency.

7. Statistics of counting: **3 Lectures**

Poisson distribution, Poisson approximation to radioactive decay, measures of counting error. Accuracy and precision, standard error, counting in low background and high background scenarios, net count rates and standard deviation of count rates. Gaussian distribution and propagation of errors. Distribution of counting times to minimize errors.

8. Semiconductor detectors: **2 Lectures**

Semiconductors junction and surface barrier detectors, Diode detectors, Ge(Li) detectors, High Purity Germanium detectors, their response and characteristics, energy calibration and detector efficiencies, cadmium-zinc- telluride detector.Room temperature semiconductor diodes.Advantages and disadvantages of semiconductor detectors

9.Liquid Scintillation Counters **2 Lectures**

Composition of liquid scintillator, scintillation cocktail: primary solute, secondary solute and organic solvent (toluene, 1, 4 dioxane, anthracene) and solublizing agents for tissues, PM tubes, Coincidence circuits and count display systems. Quenching, Quench corrections methods: Internal standard method, external standard method and channel ratio. Discrimination of alpha, beta by liquid scintillations.

10. Radiation Biology **10 Lectures**

Radiolysis of water, interactions of free radicals, Direct versus indirect effects. Influence of LET, oxygen and various compounds on free radical forming reactions Target Theory, Multitarget theory, Target size, Multi hit theory, Multitarget multi hit theory.

Radiation effects on macromolecules, cell membrane, chromosomes. Chromosomal type aberrations. Radiation effects on cell division. Radiation effects on microorganisms and independent cell systems.

Differential cell sensitivity. Criteria of sensitivity, Factors affecting sensitivity. Anti-oxidative enzymes: Super Oxide dismutase, Catalase, Glutathione reductase, Glutathione -S-transferase, Monoamine oxygenase, Glutathione peroxidase.

Radiation effects on major organ systems: hematopoietic system, digestive system, reproductive system, nervous system. Effects of Ionizing Radiation on the Embryo and Fetus. Teratogenic and delayed effects.

Linear Energy Transfer, Relative biological effectiveness, Dose rate effect, chronic irradiation, factors influencing radiation response - oxygen concentration, Temperature etc.

Acute radiation effects: Lethality, Stochastic and Nonstochastic effects of radiation: Late effects in normal tissue systems and organs, Radiation carcinogenesis, genetic effect of radiation, radiation induced mutations, dose effect relationship, pre-natal effects of radiation, types of genetic disorders, risk estimation, direct method, doubling dose method, uncertainties. Basis for ICRP dose limits for occupational exposure, embryo / fetus, members of the public, risks associated with recommended limits,Biodosimetry,Bioassays,Extrimity dosimetry

Low Dose Exposure to Ionizing Radiation: Medical, Natural background, Radon. Radiation Hormesis; BERT

11. Personnel monitoring devices **4 Lectures**

Film badges, Ring badges, Thermoluminescent dosimeters (TLD's), Pocket dosimeters. Characteristics of TLD phosphors, Glow curves, dose and energy response, sensitivity and application in dosimetry and personnel monitoring devices. Other types of dosimeters - radiation calorimetry, photographic dosimetery, chemical dosimetry.

12. Radiation Protection: **6 Lectures**

Types of exposure: internal and external exposure, Routes of internal exposure Principles of radiation protection, time, distance, shielding

Exposure rate & shielding calculations by defining types of materials, and thickness needed using attenuation coefficients. Concept of Half value layer and tenth value layer. Work place monitoring: Radiation field, contamination and airborne radioactivity monitoring. AERB directive for derived working levels for radioactive contamination, airborne radioactivity and Radiation field. Radiation protection in diagnostic nuclear medicine, therapeutic nuclear medicine (with AERB directives for discharge of patients) and Medical cyclotron.

13. Radiation dosimetry **7 Lectures**

Metabolic pathways of radioisotope deposition, beta particle dosimetry; Equilibrium Dose rate equation. Gamma dose calculation, Specific gamma ray constant (Γ) and average geometrical factor. MIRD method of internal dose calculation, Absorbed Fraction and calculation of absorbed dose.

14. Transport of radioactive material: **2 Lectures**

Classification of radioactive materials, general packing requirements, transport documents, Type of package, Transport Index, Category of package, approval requirements, TREMCARD.

15. Radiological emergency and preparedness **1 Lecture**

Major spillage, loss of radioactive source, Misadministration, Medical emergencies involving radioactive patients and Death of therapy in-patient. AERB directives to handle the cadaver. Radioactive decontamination.

16. Radioactive waste management: **2 Lectures**

Philosophy of radioactive waste management, Management of solid waste, liquid waste and gaseous waste. AERB directives for safe disposal of radioactive waste. Concept of Exclusion, exemption and clearance of radionuclide in solid materials.

Diagnostic Radiopharmaceuticals & In-vitro Techniques

1. **Radionuclides in Nuclear Medicine**: **3 Lectures**

Radioactive decay, Physical Half-Life, Activity, Decay Constant, Mode of radioactive decay, Alpha particle decay, Beta particle decay, Gamma ray, Requirements for Radiotracers, Radionuclides used in Nuclear Medicine, Radionuclide Considerations, Type and Energy of Emissions, Specific Activity, Radionuclidic Purity, Chemical Properties, Economics, Production of radionuclides, Radiopharmaceuticals, Ideal radiopharmaceuticals, Important characteristics of a radionuclide to be used in imaging.

2. **Production of reactor & accelerator produced radionuclides** **5 Lectures**

Successive decay and radioactivity equilibrium, Equation for radionuclide production Reactors and charged particle accelerators. Nuclear reactors: neutron energy and neutron flux, neutron cross section, targets and specific activities, mathematical principles, general radiochemistry. Charged particle accelerators: physics of linear accelerator, cyclotron, synchro-cyclotron, isochronous cyclotron. Medical cyclotron: threshold energy, nuclear cross section, q value, RF frequency, magnets, beam focusing and extraction, target design. Types and makes. Cyclotron produced radionuclides, cyclotron based generator.Chemical processing of reactor and accelerator targets; Separation techniques using precipitation, solvent extraction, distillation, gas evolution, ion exchangers; Structure of cation and anion exchangers; relative affinity of ions in exchangers; Use of exchangers in ion exchange columns; other column separation techniques.

3. Compartmental Analysis **4 Lectures**

Compartmental analysis and its applications in Nuclear Medicine, Assumptions in Compartmental model, Single compartment model, The Continuously stirred tank reactor (CSTR); Single Compartment model: The Charged Capacitor; Single Compartment model: Discrete time analogues for two compartment systems; Occupancy theorem. Application of Differential equations, Open and closed models, Single compartment, two compartment and multicompartment models, reversible and irreversible exchanges, Mammary and Caternary models, Problems on radioactive generators, biological elimination processes of radiopharmaceuticals. Distributed Models.

4. **Generator produced Radionuclides** **5 Lectures**

Need for Generator, Advantages of generator system, Definition, Properties of Ideal Generator, Basic Principle, Principles of generator system, Parent Daughter Growth –Decay Relationship, Parent Daughter Equilibrium, Transient Equilibrium, Secular equilibrium. Various generator systems.

a) Gamma emitting radionuclidic generators: ^{99}Mo - ^{99m} Tc, ^{113}Sn – ^{113m}In, Special emphasis on ^{99}Mo - ^{99m} Tc generator: Production of parent, Decay Scheme, Characteristics of Daughter Radionuclide, Types of generators – column generator, solvent extraction generator, gel generator, sublimation generator, Various generator suppliers, Applications of Daughter Radionuclide.

b) Beta emitting radionuclidic generators: ^{188}W -^{188} Re, ^{90}Sr-^{90}Y, ^{194}Os -^{194}Ir, ^{132}Te – ^{132}I. Production of parent, decay Scheme, characteristics of daughter radionuclides, generator suppliers, applications of daughter radionuclide.

c) Positron emitting radionuclidic generators: ^{68}Ge – ^{68}Ga, ^{82}Sr - ^{82}Rb : Production of parent, Decay Scheme, Characteristics of Daughter Radionuclide, Various generator suppliers, Applications of Daughter Radionuclide. d) Alpha emitting radionuclidic generators and Complex Systems: ^{225}Ac - ^{213}Bi, ^{224}Ra/^{212}Pb/^{212}Bi.

5. Radiopharmaceutical Chemistry **2 Lectures**

General physicochemical properties of radioactive compounds: distinction between radionuclide, radiochemical and radiopharmaceuticals, carrier concept (carrier-free, carrier added, no carrier added). Chemistry of tracer radionuclide metals: hydrolysis, reduction-oxidation, concentration methods, radiolytic decomposition.

Study of Phosphorous (P), Chromium (Cr), Cobalt (Co), Iron (Fe), Indium (In), Thallium (Tl), Technetium-99m (Tc), Iodine (I), Yttrium (Y), Strontium (Sr), Rhenium (Re), Samarium (Sm), Lutetium-177 (Lu), radioactive gases (i.e. Xenon Xe-133, Xe-127, Kr-81m) & positron emitting nuclides like Fluorine (F), Oxygen (O), Carbon (C), Nitrogen (N), Copper (Cu), Rubidium (Rb), Gallium (Ga)

6. Development of radiopharmaceuticals **1 Lecture**

Empirical and Rational approaches to design, charge and size of the molecule, protein binding solubility, stability and bio-distribution. Structure- activity relationship. Biological properties of radiopharmaceuticals, pharmacokinetics, distribution, metabolism, excretion.

7. **Modes of localisation:** **2 Lectures**

Mechanism of localisation with respect to each radiopharmaceutical. Ideal characteristic of RP for localisation in organ of interest for diagnostic and therapeutic purposes. Various modes of localisation: Active and passive modes of localisation. Substrate specific radiopharmaceutical localization, Receptor mediated, biochemical, metabolic trapping, enzyme substrate, antibodies to tumor associated antigens. Filtration, Phagocytosis, Cell Sequestration, Capillary blockade, ion Exchange, Chemisorption ,Cellular migration

8. **Methods of radiolabeling:** **2 Lectures**

Definition of a Radiopharmaceutical. Ideal Radiopharmaceutical. Availability. Short Effective Half-Life Particle. Emission Decay by Electron Capture or Isomeric Transition. High Target-to-Nontarget Activity Ratio.

Design of New Radiopharmaceuticals. General Considerations. Factors Influencing the Design of New Radiopharmaceuticals. Methods of Radiolabeling. Isotope Exchange Reactions . Introduction of a Foreign Label . Labeling with Bifunctional Chelating Agents. Biosynthesis . Important Factors in Labeling . Efficiency of the Labeling Process. . Chemical Stability of the Product. Denaturation or Alteration . Isotope Effect. Carrier-Free or No-Carrier-Added State . Storage Conditions . purification analysis, shelf life.

9. **Specific methods of labelling: Radioiodinated Radiopharmaceuticals: 2 lectures**

Introduction, Isotopes of Iodine, Production of Isotopes with Physical properties, Principle of radioiodination, methods of radioiodination, Iodination of organic compounds – Chemistry of Iodine, chemical properties, Oxidation, Methods to minimize oxidation, Various Radioiodinated radiopharmaecuticals –1)^{131}I-NaI, 2)^{131}I-OIH, 3) ^{131}I-Rose Bengal, 4)^{131}I-IMP (n-isopropyl, p-iodo amphetamine), 5)^{131}I-HIPDM (NNN'-trimethyl,N'(2-hydroxy,,3-methyl,5-iodobenzyl)1,3propane diamine), 6) ^{131}I-mIBG, 7)^{131}I-Fibrinogen, 8)^{131}I- lipiodol, 9)^{131}I-19-Iodocholesterol, radioiodination of peptides, proteins, antibodies/monoclonal antibodies, Methods of labeling, Applications, Advantages, Disadvantages, Dose Administration etc.

10. Specific methods of labeling – Technetium labeling (4 Lecture

Chemistry of Technetium with respect to oxidation states, reduction methods, technetium tin-ligand reactions in aqueous solution, hydrolysis, re-oxidation, complexation, carrier effects, radiolytic decomposition.

Labelling with ^{99m}Tc: formation of ^{99m}Tc-complexes by ligand exchange, structure of ^{99m}Tc-complexes, oxidation states of ^{99m}Tc in radiopharmaceuticals and kits for ^{99m}Tc-labeling-: DTPA, GHA, DMSA, MIBI, MAG_3, MDP, phytates, ECD, EC, IDA compounds and Sulfur Colloid. Dextran colloid and labeled particles. Metal chelate and congugates, ^{99m}Tc-tricarbonyl core, ^{99m}Tc-nitrido compounds, ^{99m}Tc-Hynic-TOC.
Kit formulation of radiopharmaceuticals and their classification. Additives, stabilisers and preservatives

11. Radiolabeling of Cells: **2 Lectures**

Methods of labeling for blood pool studies and detection of gastrointestinal bleeding - Tc-99m red blood cells (i.e. In-vitro, In-vivo and modified In-vivo), Tc-99m RBC's (denatured) for spleenic imaging, Tc-99m / In-111 - Leucocytes (i.e. Methods of radiolabeling for inflammation / abscess localization), Cr-51 red blood cells (i.e. Methods of radiolabeling for blood volume measurement & Splenic Sequestration studies), In-111platelets (i.e. Methods for radiolabeling).

12. Altered biodistribution related to improper preparation of Rps. **1 Lecture**

Radiopharmaceutical formulation problems, problems caused by radiopharmaceutical administration technique and procedure, changes in biochemical and phathophysiology, previous medical procedure such as surgery, radiation therapy and dialysis, drug interactions.

13. PET radiopharmaceuticals: **6 Lectures**

Positron emitters and radiochemistry to produce, ^{18}F-Sodium Fluoride, ^{18}F-Fluorodeoxyglucose (FDG) , ^{18}F-Fluorodopa , ^{18}F-Fluorothymidine (FLT), ^{18}F-MISO, ^{18}F-FAZA, ^{18}F-FET, ^{18}F-FBA, ^{11}C-Sodium Acetate, $^{13}NH_3$ and $H_2{}^{15}O$._FDG synthesis and QC Details of automated steps involved during synthesis, QC done before supply for patient's use.

14. Molecular Imaging probes: Target specific radiopharmaceuticals **1 Lecture**

Basics of molecular imaging, methodology of molecular imaging, Classification of radiopharmaceuticals, Blood flow/membrane transport rps, Metabolism based rps. Receptor & transport mediated rps. Receptors, receptor binding, design of rps, bifunctional approach, chelating agents, radiolabeling, Ideal rps, Various receptor imaging agents SSTR, Bombesin, Vasoactive intestinal peptides, α-Melanocyte-Stimulating Hormone, Neurotensin, Substance P (SP), Cholecystokinin (CCK), Neuropeptide Y (NPY) reporter genes for imaging.

15. Quality control of Radiopharmaceuticals **4 Lectures**

General Schemes, Physicochemical tests: physical characteristics, pH and ionic strength, radionuclide purity, radiochemical purity, chemical purity, radio assay,

QC of kits – radiochemical purity, sterility check, membrane filtration, chromatography, pyrogen test, bio-distribution studies, Mo break through test. Breakthrough of methyl ethyl ketone, alumina. QA of PET radiopharmaceuticals by TLC scanner, HPLC and gas chromatography (GC). QC in hospital radiopharmacy practices - includes aseptic practices & pharmaceutical safety aspects. Good manufacturing practice (GMP), ISO and ISI standards in radiopharmaceuticals. Adverse reactions to and altered biodistribution of radiopharmaceuticals, iatrogenic alterations in the biodistribution of radiopharmaceuticals Regulations, ethics and registration of radiopharmaceuticals.

16. Therapeutic applications of radionuclides **2 Lecture**

Radionuclide therapy (RNT), definition, Problems for development of therapeutic RP, Uptake Mechanisms of Therapeutic Radiopharmaceuticals, types of preparation, Properties of ideal therapeutic radiopharmaceuticals, Selection of appropriate radionuclides includes particle emission, Half-life, Sp. Activity, decay characteristics, Characteristics of the Ideal Therapeutic Radiopharmaceutical,

Ranges of Emitted Particle Radiation in the Tissue: Beta particle emitting Radionuclides: Response of beta particle radiation on tumor, Classification of b- particles, Alpha particle emitting Radionuclides, Auger-electrons emitting Radionuclides, Properties of Auger-electron-emitting radionuclides, Dosimetry in therapy by Radiopharmaceuticals: Absorbed radiation dose, Patient Specific Dosimetry.

17. Radioisotopes: Beta particle emitting radioisotopes **3 Lectures**

Phosphorus-32, Samarium-153, Holmium-166, Thulium-170, Rhenium-186, 188: Rhenium Chemistry, Rhenium-188, Production and Physical Characteristics, Issues with Column Generator Production, Uptake and Biokinetic Properties, Rhenium RPs.

Lutetium-177 : Production and Physical Characteristics, Influence of production mode for 177Lu, 176Lu-route versus 176Yb-route, Uptake and biokinetic properties, Peptide receptor radionuclide therapy, Dosimetry.

Yttrium-90: Production and physical characteristics, 90Sr/90Y generators, Uptake and Biokinetic Properties, Uses of 90Y Radiopharmaceuticals: microspheres, MAA, Antibodies, Dosimetry.

18. Alpha emitting Radioisotopes for therapy **1 Lecture**

Radium-223: Alpharadin, (Generator prod. RP 227Ac-223Ra), Bismuth-212, (212Bi is produced by chemistry generator from 224Ra), Bismuth-213 (213Bi is produced by chemistry generator from 225Ac), Astatium-211: (cyclotron produced RP. 209Bi (α, 2n) 211At), Actinium 225: Cyclotron produced RP. 226Ra (p,2n) 225Ac. Production and Physical Characteristics, Uptake and biokinetic properties, Dosimetry. **Auger-electrons emitting Radioisotopes**: Indium-111 (111In) : Production and Physical Characteristics, Uptake and biokinetic properties, Dosimetry.Application of therapeutic radiopharmaceuticals : Bone pain palliatiation, Radiosynovectomy, Radioimmunotherapy

19. Nanotechnology **2 Lectures**

Concepts and its biomedical applications, liposomes, aerosols, nanoparticles, immuno-liposomes, drug delivery systems, Introduction to Nanotechnology and their application in nuclear medicine for diagnostic and therapeutic purposes. Different types of drug delivery nanocarriers for diagnostic and therapeutic purposes (Liposomes, micelles, phytosomes, Chitosan Nanoparticles etc) and their advantages over present drug delivery systems. Methods of preparation of Nanocarriers and quality control procedures. Mechanism of localisation of nanodrug delivery systems. Future applications in Nuclear Medicine.

20. Design of Radiopharmacy laboratory: **2 Lectures**

Regulatory requirements, Pharmaceutical aspects, Radiation protection aspects, Local constraints, Design of hospital pharmacy, stocking of consumables and labels, disposable materials. Laminar airflow (LAF) hood, its testing and maintenance.

Centralized Nuclear Pharmacy, Considerations & layouts. Automated Modules.
Licenses & Procurement of Radiopharmaceuticals. Trace of delayed shipments, surveys, wipe tests, packaging, disposal, storage requirements, and record keeping logs.

21. Diagnostic In-vitro Techniques: **7 Lectures**
Principle of RIA, Immunoradiometric assay (IRMA), Enzyme linked immunosorbent assay (ELISA), Fluorescent immunoassay (FIA), Chemiluminescent Immunoassay (CLIA), Methods of receptor assays. In-vitro Uptake studies, In-vitro radiorespirometry, Quality Control Parameters and methods and Applications for hormones & drugs, example of assays for T_3, T_4, TSH, free hormones, thyroid antibodies and thyroglobulin, other hormones and drugs.

Instrumentation & Imaging Technology - Paper - IV

1. QC of Radiation Protection Instruments **2 Lectures**
QC of - Ionization chamber Type, Geiger-Muller Counter, pocket dosimeter, Dose calibrator, Scintillation type Gamma ray spectrometer, Zone monitors.

2. Medical Cyclotron-Radionuclide Production **4 Lectures**
Reactors and charged particle accelerators. Physics of linear accelerator, cyclotron, synchro-cyclotron, isochronous cyclotron. Medical cyclotron: threshold energy, nuclear cross section, q value, RF frequency, magnets, beam focusing and extraction, target design. Types and makes their advantages and limitations. Safety Concerns. Cyclotron produced radionuclides, Cyclotron based generators.

3. Collimator Systems **4 Lectures**
Counting Geometry & Need for Collimator, Types of Collimator- Parallel Hole, Slant Hole, Rotating Hole, Focusing, Convering Hole and Diverging Hole Collimators, Material design with regards to Cost, Geometric Efficiency and Resolution. Pinhole Collimator and its Adaptation in Gamma Camera. Fanbeam collimator, Slit collimator, Slit slat collimator, Collimator in 2D PET.

4. Probe systems **2 Lectures**
Thyroid uptake probe, basic components, system set-up and calibration, flat field collimator, iso-response curve and working distance. All qc parameter including iso-response curve, and working distance. Its significance or application in non imaging procedures

5. Rectilinear scanner: **2 Lectures**
Block diagram, principle of working, effect of scanning speed, dot factor, time constant, line spacing, film density, information density, photo recording display, contrast enhancement and clinical applications. Focal plane and depth of focus.

6. Gamma Camera: **5 Lectures**
Scintillation camera, Basic principles of gamma camera, collimators, NaI (T) detector, position determining circuits, Display. Gamma camera-computer interface- ADC/DAC. Correction Circuits. Criteria of Selection & installation of Gamma camera, Frontiers of Gamma Camera Technology, LSF, MTF, Avalanche photodiodes, CZT detectors.

7. Application of Computers in Nuclear Medicine **3 Lectures**

Image Acquisition Matrix, Byte Mode and Word Mode, Frame Mode Acquisition, List mode, Static, Dynamic and Gated Acquisition, Image Display methods, Image Perception and Analysis, Image Manipulations and Presentations, Background Correction Methods, Image Interpolation, Region of Interest Analysis, Time Activity Curves and General Filters and Normalization methods, Automated ROI's and Computational methods.

8. Single Photon Emission Computerized Tomography: 5 Lectures
Principles of Tomography, longitudinal and transverse or axial tomography, Theoretical aspects of image acquisition & reconstruction techniques, filters, artifacts in SPECT, effect of scatter & scatter correction, noise, role of collimators, rotating gamma camera, single or multiple detector devices, data collection, SPECT acquisition – step & shoot/continuous. Whole body SPECT. SPECT v/s planar camera, SPECT v/s other modalities (CT, MRI, Ultrasonography)

9. Positron Emission Tomography Equipment: 5 Lectures
Gamma camera for PET imaging. Dedicated and hybrid PET systems. Principles of PET imaging, detectors assembly, various corrections in PET, 2-D and 3-D acquisitions, performance of PET imagers, sensitivity, spatial resolution. PET Detectors, Attenuation correction, TOF concept, instrumentation, data collection, data correction, data storage, reconstruction, quality control, Performance characteristics, NECR, NEMA specifications, PET v/s SPECT, PET Protocols.

10. Multicrystal Gamma Camera and Intraoperative probes 2 Lectures
Emerging designs and considerations of Multicrystal Gamma Camera and Intraoperative probes. Its relevances in nuclear medicine, Discussions on Standards and Quality Control. Small animal imaging systems.

11. Overview of Whole body counting system: 1 Lecture
Whole body counting: principles of whole body counting, design of whole body counting system, stationary systems, single and multiple crystal systems, shadow shield geometry, moving systems, calibration of whole body system, clinical and other applications of whole body counters.

12. Medical Informatics: 2 Lectures
Image Formats, Concept of DICOM (Digital image communication in medicine) and DICOM-RT and etc, DICOM and interfile conversion software, Interfacing; TCP/IP protocols, PACS (Picture Archiving and Communication System); Telemedicine.

13. Biomedical Ultrasound 2 Lectures
Ultrasound generators, properties of ultrasound waves and its propagation in biological tissues, Pulse echo techniques, Scan types. Doppler principle.

14. Magnetic Resonance Imaging (MRI) 2 Lectures
Basic Magnetism, Physics of magnetic resonance, MRI equipment its advantage over CT / Ultrasound, – Image artifacts – MRI safety. Principal of FMRI (functional magnetic resonance imaging), MR spectroscopy, MRI contrast, Limitations and uses of MRI. Configuration of machines available, PET/MRI fusion problems and solutions.

15. Radiological Instrumentation - CT scanner 4 Lectures

Discovery - Production - Properties of X-rays, basic requirements for diagnostic tubes, Classification of tubes, Filters, Measurement of kV and mA, CT detectors, CT acquisition, CT reconstruction, CT attenuation correction, CT dose index, dose length product, Radiation dose, CT-PET fusion, Quality Control of CT, Scanner design, Spiral Computed Tomography, Difference between conventional single slice, multislice, spiral and electron beam CT. Comparison of patient radiation doses and effects of slice thickness.

16. **Advanced Molecular Imaging:** Optical,Molecular MR,PEM. 1 **Lecture**

01HLTH09A06-003-C

Clinical Nuclear Medicine Techniques

1. Non-imaging applications of radionuclides **4 Lectures**

^{51}Cr labeled RBC's for blood volume, red cell volume measurement, spleen uptake, red cell survival studies. Schilling's test using ^{58}Co/^{57}Co for vitamin B12 absorption, applications of ^{14}C radiorespirometry for H.Pylori ulcers, Ferrokinetic studies using radioisotopes of Iron.

Important: ***Common in all In-Vivo Techniques is a discussion on choice of radiopharmaceuticals and its dose, choice of equipment, imaging considerations, patient preparation & instruction, selection of imaging parameters, interventional approaches, quantitative data analysis, display, filming or its report generation.***

Clinical Nuclear Medicine Techniques in two parts

i) One by the technologists emphasizing the **technical part** and (ii) the other by the Clinical Staff.

2. Thyroid studies **3 Lectures**

Thyroid imaging and uptakes (^{99m}Tc and ^{131}I), Perchlorate discharge test, T_3/T_4 suppression test, TSH stimulation test. ^{131}I whole-body imaging. Post Therapy Scans.

3. Lung imaging studies **4 Lectures**

Ventilation lung imaging studies using gases (^{133}Xe, ^{81m}Kr), Inhalation imaging using aerosols, aerosols generators, mucociliary clearance, COPD, Pulmonary permeability using DTPA, perfusion imaging using MAA, Microsphere, and pulmonary embolism.

4. Liver-spleen imaging **2 Lectures**

Liver imaging for Diffuse and Focal liver diseases, Dynamic Liver studies, Quantitative methods for Hepatic Perfusion Index, Blood pool liver studies. portosystemic shunt evaluation by Per-rectal Scintigraphy.

5. Hepatobiliary imaging **3 Lectures**

Hepatobiliary imaging protocols, Neonatal hepatitis versus Biliary atresia, Gall bladder dynamic studies using IDA compounds. Deconvolution analysis, Hepatic Extraction Fraction, Interventional methods. Bile leak studies

6. Gastrointestinal studies **5 Lectures**

Conventional imaging modalities used for GI studies. Advantages and disadvantages of these modalities over scintigraphy Oesophageal transit time studies, Gastric oesophageal reflux, gastric emptying time, Duodeno-gastric reflux, Meckel's diverticulum imaging, GI bleeding with ^{99m}Tc-RBC, 99mTc-S.Collide.Advantages and disadvantages of each method

7. Cardiac studies **6 Lectures**

ECG ,First pass study (shunt detection), Importance of Electrocardiogram (ECG), gated blood pool study, MUGA, Ejection fraction,Wall motion analysis, Infarct avid imaging, Rest / Stress myocardial imaging, Gated SPECT, Pharmacological stress, Bulls Eye analysis, Severity scores. Use of ^{201}Tl, ^{18}FDG and $^{13}NH_3$ for cardiac studies.

8. Bone imaging **3 Lectures**

Routine bone (whole body and spot) imaging, bone flow study, quantitative bone scan-sacroiliac index, 3-phase bone scans, Bone SPECT. Bone imaging in Metabolic Disorders. MDP retention studies, ^{18}F-Fluoride Bone Scans.

9. Renal imaging studies **10 Lectures**

Standard Renogram, Diuretic renogram, Captopril renogram, Renal Perfusion analysis, Differential function, GFR estimation by Gates Method, Renal transplant studies, Background subtraction methods, Rutland Patlak-Plot, Plasma Sampling methods, Advantages and Disadvantages of various GFR estimation methods, Uretic reflux study, Interventional methods, Direct and indirect radionuclide cystography, Cortical Renal Scans using 99mTc-GHA &99mTc-DMSA,Differential function by Geometric Mean.

10. Brain imaging **3 Lectures**

Cerebral blood flow dynamic studies, Blood Brain Barrier imaging, Perfusion Imaging, Brain SPECT, Interventional methods, Cisternography, CSF leak,PET brain imaging.

11. Tumour Imaging: **2 Lectures**

^{18}F-FDG PET Scans for Oncologic Staging and Evaluation of Post therapy status. Imaging for Medulary Carcinoma of Thyroid, Neural Crest Tumours, Apoptotic Imaging. Post Therapy Scans. Organ specific(cold spot,hot spot),nonspecific(Ga-67 Citrate,201 Tl,MIBI,Tetrofosmine,FDG),Tumor type specific(131 I for papillary and follicular carcinoma,131ImIBG(adrenal cortex),NP59 for adrenal medulla,Mebro for hepatocellualar ca,Antibody(111In Oncoscint,99mTc CEA,111In Prostascint, 99mTc-Verluma, peptide (^{111}InSomatostatin,^{68}Ga DOTATATE).

12. Lymphoscintigraphy & Sentinel Node Scintigraphy **2 Lectures**

13. Infection and inflammation **2 Lectures**

Use of Labelled Leukocyte, ^{99m}Tc-Ciprofloxacin, ^{68}Gallium for detection of Infectious foci. Discussion of imaging preferences.

14. Salivary gland imaging **1 Lecture**

Imaging for parenchymal and obstructive diseases of salivary glands. Post Radiation Xerostomia evaluation.

15. Parathyroid Imaging **1 Lecture**

Dual isotope technique and Subtraction scans. ^{99m}Tc-MIBI wash out studies.

16. Bone marrow imaging **1 Lecture**

Imaging techniques for visualisation of Bone marrow infiltration

17. Lymphoscintigraphy & Sentinel Node Scitigraphy **2 Lectures**

Infrequently performed studies in Nuclear Medicine

18. Scrotal Imaging **1 Lecture**

19. Dacryoscintigraphy **1 Lecture**

20. Scintimammography **1 Lecture**

Early and Delayed Imaging. Special Positions and Restraining means.

21. Hysterosalphingography **1 Lecture**

22. Contrast Agents **2 Lectures**

Contrast media agents: Oral, IV – ionic/nonionic, Rectal, Intrathecal, Catheters, Types/indication/chemical makeup etc. Iodinated contrast materials, Characteristics of iodinated contrast materials, Water solubility and hydrophilicity, Osmolality, High osmolar contrast media (HOCM), Low osmolar contrast media (LOCM), Advantages of LOCM, Disadvantages of LOCM, Viscosity, Calcium binding, Iodine concentration, Adverse reactions. Substitution of barium based contrast instead of iodinated oral contrast, Indications for steroid premedication, Contraindications for steroid premedication.

23. Radiation protection in NM - Regulatory Aspects **8 Lectures**

Guidance level for diagnostic administration, misadministration and preventive measures, reporting of misadministration.

Layout of Nuclear Medicine Laboratory, Design of radiation labs, types of labs, Security of Sources and radioactive cautions signs and labels. The Atomic Energy Act, Rules issued under the Act, Surveillance procedures issued under the Rules, Notifications issued under RPR, 2004, AERB Safety Directive, Safety code for NM facility, Duties of RSO, Regulatory clearance-Approval of NM Lab, Physician & RSO, Regulatory consent, authorisation- for disposal of radioactive waste and safe transport of Radioactive materials. Radiation Safety Program, Radiation Safety Officer and duties of Radiation Safety Officer, Radiation Safety Committee, Responsibilities for Implementation of Basic Safety Standards Requirements, AERB Regulation Related to Medical Cyclotron and PET

Practicals

01HLTH09A-06-001-P

A. Practicals – Physics

1. To measure Half Value Layer of β and γ emitters and to measure the absorption coefficients of different materials with gamma rays and beta particles.
2. To study back scatter.
3. To determine the half life of a radioactive material.
4. To study the change in activity of a sample consisting of two independently decaying radioisotopes (or a mixture of isotopes)
5. To determine the plateau of GM tube and find out the dead time/ resolving time of GM counter.
6. To determine the efficiency of GM counter and find out the activity of the given unknown radioactive source.
7. Gamma ray spectrometry of ^{137}Cs with a single channel analyzer.
8. To find out the spectrum of energies emitted by a radioisotope by using gamma ray spectrometer. (e.g. ^{131}I)
9. To study the statistics of radioisotopic measurements and observe the effect of background on the counting statistics.
10. To determine the energy resolution of spectrometer
11. To study the energy linearity of given spectrometer
12. To observe gamma ray spectrum of the given two radionuclide sources (A and B) and identify composition of a tube containing mixture of these two radionuclide sources by evaluating scatter fraction.

13. To identify unknown radionuclide on the basis of its principal energy by using scintillation counter.
14. To study iso- response curve of Flat Field Collimator. To perform QC and calibration of uptake probe
15. To study the line spread function of a parallel hole collimator at various depths.
16. To perform Quality Control of Planar Gamma Camera and assess (intrinsic/extrinsic) uniformity, resolution by 4 quadrant bar phantom and assessment of linearity.
17. To study the counting errors originating from sample geometry and determine Critical Volume for counting in a well counter.
18. To estimate pipetting error and Estimation of Unknown Volume by Dilution principle
19. To perform Tomography with Jaszczak Phantom and evaluate the results.
20. Gamma Spectrometry with HPGe detector :Energy calibration,Efficiency and Identification of Unknown radionuclides
21. Biodistribution study of radiopharmaceuticals.

01HLTH09A06-002-P

Practicals - Radiopharmaceutical & *In-vitro* Techniques

1. Perform Radioimmunoassay & IRMA.
2. To perform quality control of Dose Calibrator
3. Radiopharmacy procedure: Elution of generators and Determination of Impurities (a) Radionuclidic (^{99}Mo breakthrough in ^{99m}Tc), (b) Chemical (Alumina Breakthrough) and (c) Radiochemical (TcO4 paper chromatography)
4. Q.C. of radiopharmaceuticals by paper chromatography & to determine the Rf of ^{99m}Tc and the given labeled compounds by using ascending chromatography including Rapid determination of radiochemical purity of radiopharmaceuticals.
5. QC of ^{68}Ga and ^{177}Lu labeled radiopharmaceuticals by ITLC and paper chromatography
6. Q.C. of PET radiopharmaceuticals by TLC scanner and HPLC
7. Q.C. of radiopharmaceuticals by paper chromatography & to determine the Rf of ^{99m}Tc and the given labeled compounds by using ascending chromatography.
8. Rapid determination of radiochemical purity of radiopharmaceuticals..
9. Biodistribution study of radiopharmaceuticals.

(*Demonstration*)....

1. Quality Controls of SPECT/CT system (once SPECT/CT is procured)
2. Quality Controls of PET/CT system (Uniformity, Attenuation correction, Partial volume effect, Co-registration evaluation of SPECT/CT & PET/CT, SUV measurements, CT QC)
3. Biological Quality control (a) ST (b) BET,
4. CPCR (Cardio-pulmonary & cerebral resuscitation
5. Visit to BARC(Reactor, whole body counter,TLD reader,biodosimetry),
6. Visit to BRIT.
7. Visit to NM centres to see special studies and instruments.

Apprentice Program:

Several contact hours (3 years of Apprentice in various areas of Nuclear Medicine @5hrs per day in the last last 2.5 years)

01HLTH09A06-004-C

Clinical Nuclear Medicine

1. **CNS system** **10 Lectures**
BRAIN PERFUSION AND METÀBOLISM: Evaluation of cerebrovascular disease, Presurgical localization of epileptogenic foci, Dementia, Traumatic brain injury, Inflammation, Assessment of brain death
DOPAMINE TRANSPORTER: Differentiate neurodegenerative parkinsonian syndromes from patients with parkinsonian symptoms unrelated tneurodegeneration (essential tremor, vascular parkinsonism, side effects of neuroleptica), Early diagnosis of Parkinsonian syndroms
BRAIN METABOLISM: Identify the grade of malignancy of brain tumors, suspected relapse of brain tumor, Assess transformation of low-grade glioma to high-grade
CISTERNOGRAPHY AND CSF LEAK: Hydrocephalus patients with normal-pressure hydrocephalus to determine whether the patient might benefit from CFS shunting or not. Shunt patency, Cerebrospinal fluid leak.

2. **Skeletal system** **7 Lectures**
MDP AND 18F BONE SCAN: Neoplastic disease, Post-traumatic assessment, Arthritides, Reflex sympathetic dystrophy, Osteomyelitis, Unexplained bone pain

3. **Cardiovascular system** **10 Lectures**
MYOCARDIAL PERFUSION: Depict the distribution of blood flow in the myocardium at rest and or during stress to assess myocardial ischemia and scar.
MYOCARDIAL VIABILITY: Identify myocardium with potentially reversible contractile dysfunction in patients with chronic CAD
Equilibrium radionuclide angiography: Measurement of left and right, diastolic and systolic, global and regional ventricular function. The most commonly measured parameter being the Left ventricular ejection fraction (LVEF)

4. **Respiratory system** **6 Lectures**
LUNG SCINTIGRAPHY: Pulmonary embolism diagnosis, Quantify regional lung function prior to surgery or radiation therapy, Evaluate cystic fibrosis.

5. **Gastrointestinal system** **8 Lectures**
SALIVARY GLAND SCINTIGRAPHY: Sjögren's disease, Pleomorphic adenoma, Wharton tumour, Adenoid cyctic carcinoma, Mucoepidermoid carcinoma
OESOPHAGEAL TRANSIT SCINTIGRAPHY: Achalasia, Diffuse esophageal spasm, Scleroderma, Diabetes mellitus
GASTRO-ESOPHAGEAL REFLUX SCINTIGRAPHY: Gastro-esophageal reflux evaluation IN GERD
GASTRIC EMPTYING SCINTIGRAPHY: Dumping syndromes, Gastroparesis (diabetic, post-surgical or idiopathic), Functional dyspepsia, Pyloric stenosis
GASTROINTESTINAL BLEEDING SCINTIGRAPHY: Lower or upper gastrointestinal tract bleeding assessment
MECKEL'S DIVERTICULUM SCINTIGRAPHY: Assesment of ectopic gastric mucosa (Meckel's diverticulum)

6. **Hepatobiliary system** **7 Lectures**

HEPATOBILIARY SYSTEM: Evaluating hepatic biliary system function and patency. Calculation of gallbladder ejection fraction (GBEF). Assessment of biliary enteric bypass (Kasai procedure). Bile leakage, Biliary atresia, Sphincter of Oddi dysfunction. Enterogastric (duodeno-gastric) reflux assessment. Chronic cholecystitis. Hepatic perfusion in planning selective internal radiation or drug therapy in the liver tumors.

7. **Nephro-urinary and genital system** **8 Lectures**

ASSESSMENT OF RENAL FUNCTION AND TRANSIT: Estimation of differential renal function, Assessment of renal and pyelocalyceal transits, Anterograde (descending or direct) radionuclide cystogram

RENAL CORTICAL IMAGING: Estimation of differential renal function, Assessment of renal and pyelocalyceal transits, Anterograde (descending or direct) radionuclide cystogram

RETROGRADE (ASCENDING OR DIRECT) RADIONUCLIDE CYSTOGRAM: Detection (during feeling and voiding) and quantification of vesicoureteral reflux

CLEARANCE METHODS (PLASMA AND URINARY METHODS):

Measurement of glomerular filtration rate (GFR) with 51Cr-EDTA, 99mTc-DTPA

Estimation of the plasma renal flow rate (ERPF) with 99mTc EC/MAG3.

8. **Endocrine system** **10 Lectures**

THYROID IMAGING AND FUNCTION:Evaluation of thyroid nodules (mainly in low TSH state) and goiter, Locating ectopic thyroid tissue, Determining the function of thyroglossal cyst

131I iodine: Planar imaging thyroid and/or whole body scan additional SPECT/CT when indicated

PARATHYROID LOCATION IN HYPERPARATHYROIDISM: Planar imaging of neck and mediastinum (with either co-registration or subtraction when using either 99mTc pertechnetate or 123I for double radionuclide technique) SPECT or SPECT/CT recommended. PET/CT for 11C-Methionine

ADRENAL MEDULLA TUMOR LOCATION: Pheochromocytoma, Paraganglioma, Neuroblastoma

ADRENAL CORTEX IMAGING:Cushing's syndrome, Primary aldosteronism, Hyperandrogenism

9. **Infection and Inflammation** **5 Lectures**

Osteomyelitis, Infected Joint Prosthesis, Inflammatory Bowel Disease, Pulmonary Infection

10. **Radionuclide therapy** **16 Lectures**

Thyroid disease, Neurendocrine Tumor, Neuroblastoma, Skeleton and Liver lesions, Lymphoma

11. **Oncology: Positron Emission Tomography** **16 Lectures**

Breast, Lung, Lymphoma, Melanoma, Prostate, Head and neck cancer, Colonic cancer etc

12. **Molecular Imaging and Advanced Imaging** **8 Lectures**

Hypoxia-F MISO, Angiogenesis- RGD, Hormone Receptors- FES, Apoptosis- peptide annexin V

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SYLLABUS

OF

MD NUCLEAR MEDICINE

Under TMC
(Program code: HLTH09A06)

GUIDELINES FOR COMPETENCY BASED POSTGRADUATE TRAINING PROGRAMME FOR MD IN NUCLEAR MEDICINE

(MCI-2011-2012 FORMAT)

Preamble:

Nuclear medicine is a multi-disciplinary practice and the training of medical doctors is critical to the performance of a Nuclear Medicine department. Successful trainees are awarded a final certificate, degree or diploma that is recognized by the government, local health authority and hospital employer as an assurance of specialist competence in Nuclear Medicine. Post graduate training programme in Nuclear Medicine consists of an integrated training course of three years duration and would enable the candidate to practice nuclear medicine safely.

The **goal** of the programme is to enable the candidates to run Nuclear Medicine practice, teaching and research independently and fulfill the manpower needs of ever expanding new branch of diagnostic and therapeutic medicine.

SPECIFIC LEARNING OBJECTIVES

At the end of the training programme, the student should have achieved the following competencies:

1. Should have knowledge of basic principles of radiation physics and its subsequent applications.
2. Should have knowledge of radiation protection principles.
3. Safe handling of radionuclides and their disposal.
4. Should have knowledge of International Commission for Radiological Protection (ICRP) and National Regulatory guidelines pertaining to nuclear medicine practice.
5. Should have knowledge of diagnostic tests, interpretation of results and pitfalls.

6. Good clinical practice of therapeutic nuclear medicine and dosimetry.
7. Should be able to conduct clinical research and write a thesis/dissertation under supervision.
8. Should develop good working relationship with user specialties and handling inter-specialty referrals

CURRICULUM

Post Graduate Training will consist of:

Theoretical Training and Practical Training

SUBJECT SPECIFIC THEORETICAL COMPETENCIES

This part of the curriculum may be divided into the following four parts:

1. Basic Science aspects of Radiation Physics and its application to diagnostic/ therapeutic Nuclear Medicine
2. Diagnostic Nuclear Medicine and its applications
3. Therapeutic Nuclear Medicine and its applications
4. Recent Advances in Nuclear Medicine

09HLTH09A06-001-C: Basic Science related to Nuclear Medicine

1.1 Radiation Physics and Instrumentation

a. Structure of atom, Natural and artificial radioactivity.
b. Modes of Radioactive decay.
c. Interaction of radiation with matter.
d. Principles of radiation detection and detectors.
e. Basic principles of production of radionuclides by reactors and cyclotrons.
f. Nuclear Medicine Instrumentation including Gamma Cameras, Single Photon Computed Tomography (SPECT), Positron Emission Tomography (PET), Hybrid Imaging Systems like PET/CT and PET/MR
g. Counting Systems: Well counters, liquid scintillation counters, spectrometers, Radioactive Iodine Uptake (RAIU) probe and radiation monitoring devices.

h. Quality control of Nuclear Instruments, as in (f and g).
i. Collimation of radiation detectors and the characteristics of various collimators, their response to point, line and plane sources.
j. Electronic instruments, such as pulse amplifiers, pulse height analyzer, count rate meters and computer interfaces including gating systems.
k. Software and hardware fusion technology, Digital Imaging and Communications in Medicine (DICOM) technology and Picture Archiving and Communication System (PACS).

1.2 Mathematics, Statistics and Computer Sciences.

a. Basic Mathematical concepts, counting statistics, probability distribution, Baysian and McNemmar statistics, parametric and non-parametric statistics.
b. Compartmental analysis and mathematical models of physiologic systems.
c. Basic aspects of computer structure, function and programming.
d. Computer applications with emphasis on digital image acquisition, analysis, processing and enhancement, tomographic reconstruction, display and recordings of findings.
e. Fundamental of filters, their applications and uses.

1.3 Radiation Biology

a. The biological effects of radiation exposure with emphasis on the effects of low level exposure.
b. Methods of reducing unnecessary radiation exposure to patients, personnel and environment.
c. Dosimetry, MIRD, reference man, techniques for estimation

d. ICRP recommendations and their amendments from time to time and other international recommendations, environmental regulations. regarding limits of radiation exposure, handling of radioactive patients, transport of radioactivity material and disposal of radioactive wastes.
e. The diagnosis, evaluation and treatment of radiation over exposure in any form.

09HLTH09A06-002-C: Diagnostic Nuclear Medicine

2.1 Radiopharmaceuticals

The chemical, physical and biological properties of radiopharmaceuticals used in Nuclear Medicine investigations; production, Quality Control and Regulations of hospital based-Nuclear Pharmacy.

The emphasis will be on:

a. Physical and chemical characteristics of radionuclide used in diagnostic Nuclear Medicine
b. Criteria for selection of radionuclide for diagnostic purposes
c. Biological behavior of radiopharmaceuticals
d. Quality control
e. Mechanism of localization
f. Positron Emitting radionuclides, target reactions and their radiopharmaceuticals chemistry, various synthetic modules.
g. Specific topics on Radiopharmaceuticals: Bone seeking, hepatobiliary, brain and cerebrospinal fluid (CSF), renal, thyroid, parathyroid, infection imaging, Tumor Seeking, cardiac imaging etc.
h. Good Manufacturing Practice (GMP) and Laws pertaining to in-house manufacturing of Radiopharmaceuticals.
i. Radiopharmaceuticals for Research.

2.2 *In vivo* Diagnostic Imaging

a. General clinical Indications for organ imaging; normal and altered anatomy, physiology, biochemistry and metabolism of various organs. Must learn the technical aspects of performing the procedure including proper patient preparation and patient management before, during and after the procedure.

b. *In vivo* imaging and/or functional studies including brain Single Photon Emission Computed Tomography (SPECT), tracing of cerebrospinal fluid pathways, thyroid imaging, salivary glands, lungs, heart, gastrointestinal, hepatobiliary system, spleen, kidney, adrenal, bone and joints, bone marrow evaluation etc.

c. The use of physiologic gating techniques for functional studies and patient monitoring during intervention, both physical exercise and using pharmacological stress agents

d. Cellular kinetics, absorption and excretion analysis, nuclear hematology and metabolic balance studies using radiotracers.

e. Comparative analysis of Nuclear Medicine procedures with X-ray, Ultrasound, Echo, MRI, CT and angiography etc.

f. Nuclear Cardiology: Stress and redistribution studies using $Thallium^{201}$ and other myocardial perfusion agents; myocardial viability, Gated SPECT studies, etc.

g. Positron Emission Tomography (PET): All indications for use of PET imaging in oncology, cardiology, neurosciences and psychiatric disorders.

h. hybrid imaging with CT & MRI –protocol,interpretation & incremental value

i. IV & oral contrast for CT- techniques, safety and treatment of adverse reaction

2.3 *In vitro* Studies

a. Principles of Radioimmunoassay (RIA), quality control and data analysis for various hormones and drugs assays.
b. Glomerular Filtration Rate (GFR) estimation, Red Cell Survival, Red Cell Mass using chromium and C^{14} urea Breath test.

09HLTH09A06-003-C: Therapeutic Nuclear Medicine

3.1 Principles of Internal Dosimetry: Calculation of the radiation dose from internally administered radionuclide

3.2 Characteristics of Radionuclides/Radiopharmaceuticals for radionuclide therapy

3.3 Radiation protection in therapeutic set up: Design of Isolation ward as per the norms of Atomic Energy Regulatory Board (AERB)

3.4 Principles of OPD and in-door therapy administration

3.5 Therapy in thyroid disorders; benign thyroid diseases, aetiology of hyperthyroidism, various modalities of treatment and follow up strategy, long-term outcome and various national and international regulations pertaining to therapeutic administration of radionuclides.

Aetiopathology, classification and diagnosis of thyroid malignancy; various modalities of treatment and follow-up strategy, long-term outcome and various national and international regulations pertaining to therapeutic administration of radionuclides.

3.6 Bone pain palliation using various radionuclides such as P^{32}, Sr^{89}, Sm^{153}, Lu^{177} etc.

3.7 Radiosynevectomy

3.8 Radiopeptide therapy and Radioconjugate therapy

3.9 Radioimmunotherapy

3.10 Locoregional internal radiation therapy

3.11 Research agents in radionuclide therapy

09HLTH09A06-004-C: Recent Advances in Nuclear Medicine

Covering all aspects of the following areas:

4.1 Instrumentation

4.2 Radiopharmaceuticals

4.3 Diagnostic procedures

4.4 Therapeutic procedures

SUBJECT SPECIFIC PRACTICE BASED OR PRACTICAL COMPETENCIES

Practical Training:

09HLTH09A06-001-P: Basic Sciences Experiment:

1. Practicals related to Physics, Instrumentation and its quality Control.
2. Preparation of radiopharmaceuticals and their quality control.
3. Concept of contamination and detection.
4. Characterization of unknown isotopes.
5. Management of spillage.

09HLTH09A06-002-P: Clinical Experiment:

1. GFR Estimation.
2. Esophageal transit time.
3. Gastric emptying time.
4. Renal transplant evaluation.
5. Determination of Ejection Fraction and RWMA (wall motion).

TEACHING AND LEARNING METHODS

Theoretical Training (General Programme):

1. Didactic lectures in physics related to Nuclear Medicine, radiopharmacy, radioisotopes techniques, instrumentation, data processing and quality control.
2. Participation in the daily routine work of the department including work rounds of patients admitted for radionuclide therapy.
3. Presentation of cases in the reporting sessions of the department
4. Active participation in the combined clinical meetings with other departments for case discussions.
5. Apprenticeship in :
6. Radio-diagnosis *4months [CT 3 mo and MR 1 mo]*
7. Cardiac stress lab/i*ccu* *01 months*
8. Regular participation in department journal clubs, Seminars and other periodical CME programmes.
9. Participation in the Seminars and CME programme of allied departments.

The year-wise schedule of training would be as follows:

Year 1

(a) Scientific principles:

- Basic physics and mathematics,
- Instrumentation,
- Principles of computing,
- Basic radiation biology and radiation protection,
- Basic radiopharmacy and radiochemistry,
- Principles of tracer technology.

(b) Clinical Nuclear Medicine:

- **Diagnostic**: Normal and abnormal appearances of images, mode of pharmaceutical uptake; normal variants and common artifacts in bone, heart, lung, kidney, brain, thyroid, tumour and infection images.
- Principles of radiology including ultrasound, computerized tomography and magnetic resonance imaging
- **Therapeutic**: Basic principles of radionuclide therapy; treatment of hyperthyroidism, thyroid cancer and metastatic bone pain.
- **Principles of radiation protection**: ALARA (as low as reasonably achievable) ALARP (as low as reasonably practicable).

Year 2

(a) Requirements of Year 1 in greater depth:

- Tracer kinetics;
- Computing and image processing;
- Radiobiology including the biological effects of high and low level radiation;
- Linear hypothesis and the threshold hypothesis of the biological response to low level radiation;
- The effective dose equivalent and the calculation of radiation dose from radiopharmaceuticals.

(b) Radiopharmacy:

- Properties of commonly used diagnostic and therapeutic radiopharmaceuticals;
- Production of radionuclides by reactors, cyclotrons and radionuclide generators;
- Quality assurance and quality control of radiopharmaceuticals.

Year 3

(a) Requirements of Year 2 in greater depth:

- Advanced, computerized tomography and magnetic resonance imaging.

- Co-registration of nuclear medicine images and those from other imaging techniques.
- Diagnostic: special investigations in cardiology, lung disease, gastroenterology, hepato-biliary diseases, nephro-urology, neurology and psychiatry, endocrinology, haematology, oncology and infection.

(b) Therapeutic applications:

- Treatment of bone metastases, neural crest tumors, polycythemia, solid malignancies;
- Use of radionuclide monoclonal antibodies and radionuclide labeled peptides for tumor therapy.

(c) Further practice and experience of work accomplished in years 1 to 3:

- Legal and regulatory requirements,
- Audit,
- Departmental management,
- Research techniques and evaluation,
- Teaching and training.

Practical training

Post graduate trainees are obliged to play an active 'in-service' role in the practice of Nuclear Medicine to familiarize themselves with all the techniques required as a nuclear medicine practitioner, such as:

- Protocols of *in vivo* and therapeutic procedures;
- Data acquisition and processing with various equipments, quality control of instruments and labeled agents;
- Interventional procedures, including physiological, pharmacological, and mental stress for diagnostic application, and all therapeutic interventions;
- *In vitro* protocols and procedures, if appropriate.

Since trainees will take on the responsibilities of a nuclear physician, they must pass a qualifying test that covers both theoretical knowledge and practical abilities in the daily practice of nuclear medicine. A board of examiners selected by the university or similar form of authority will award a certificate to successful trainees.

SUGGESTED SCHEDULE FOR POST-GRADUATE TRAINING

Subject	Duration (hrs)	Suggested content of teaching	Recommended practice and time period
Nuclear physics	40	Decay features, spectrum, Radioisotope production & detection	Reactor-cyclotron generator, Radioisotope identification (5-7 days)
Radiochemistry	40	Labelling, technical design & quality control, interaction, kinetics	Synthesis, labelling, quality control, animal test (3-4 wks)
Radiobiology	40	Dosimetry, bio-modelling, tracer technology, radiation protection	Dosage-effect, molecular biology, radiation injury (4 wks)
Instrumentation	100	Scintillating camera, SPECT, imaging procedure, computer	Daily operation and quality control, trouble shooting (4 wks)
Related fields	50	Medical imaging modalities, epidemiology, statistics	Short round (6 wks)
Clinical use	240-300	Cardiology, neurology, GI tract, respiratory, endocrine, bones, haematology, tumour and infection	Clinical practice, image interpretation etc. (12-18 months)
In-vitro use	10	RAIU, RBC mass, survival, hypersplenism GFR measurements	RAIU practice (2 wks) GFR estimation (4 weeks)
Therapy	60	RIT, palliation,	Ward duty (3-4 months)

Posting in CT scan and MRI rooms is recommended as an aid to PET Scan imaging.

ASSESSMENT

FORMATIVE ASSESSMENT, ie., during the training would include:

Case presentation,
Case work-up,
Case handling/management,
Presentation at seminars and journal clubs,
Understanding the principles of procedures to be routinely evaluated by Faculty members, during each posting.
Continuous assessment is needed.
A logbook should be maintained and assessed.

END ASSESSMENT, ie., namely assessment at the end of the training

Each training programme should contain a standard against which the progress of the trainee can be assessed. For each year of training, each element of the syllabus, appropriate for that year of training should be available to the trainee. The assessor should preferably be external to the department that is providing the training, such as a consultant in nuclear medicine from another hospital or other senior person. The assessment may take the form of an interview, a written paper, an essay, a set of multiple-choice questions, or an oral examination of displayed images of various nuclear medicine techniques in clinical practice. Continuous assessment is another alternative. At the end of each year, internal assessment should carry a score that indicates how the candidate has progressed against the set target.

1. Thesis :

Each candidate has to submit a thesis which should be accepted by the Board of Examiners before appearing in the final examination.

Thesis Evaluation:

The thesis should reflect substantial work for the advancement of scientific knowledge, design or development or applied work. It should show competence in critical analysis of scientific data as well as through familiarity with background literature.

I. The evaluation of the thesis will consist of :

Thesis is to be submitted by each candidate at least 6 months before the date of commencement of the theory examination. The thesis shall be examined by a minimum of three examiners, one internal and two external examiners, who shall not be the examiners for theory and practical; on the acceptance of the thesis by two examiners, the candidate shall appear for the final examination.

a) Oral examination of the candidate on the thesis at the time of clinical and practical examinations.

II. In his/her report, each examiner should highlight the salient features of the thesis and make a clear recommendation regarding its acceptance or rejection for MD Degree. If one of the examiners has given a definite recommendation against the award of the degree, reference to a third examiner will be made. If the report from the third examiner is positive, the oral examination will be held. If his/her report is negative, the thesis will be rejected.

III. If two examiners recommended against the award of the degree, the thesis will be rejected.

Reports of Examiners:

1. Each examiner will be requested to send his report within 02 months of the receipt of the thesis to the registrar. The reports must contain a critical evaluation of the thesis and a clear recommendation as to whether it has attained the standard of MD or not.
2. In case the examiners are unable to make a definite recommendation they should indicate one of the following alternatives:
   a) Minor revisions which does not involve retyping or binding of the thesis.
   b) Major revisions involving rewriting of one or more sections but not involving additional research.
   c) Rewriting the thesis; if the candidate's work justifies another opportunity being given to him to do further research and rewriting the thesis (this will be treated as a new examination).

2. Theory papers:

There will be 4 theory papers:

Paper I: Basic Sciences related to Nuclear Medicine
Paper II: Diagnostic Nuclear Medicine
Paper III: Therapeutic Nuclear Medicine
Paper IV: Recent advances in Nuclear Medicine

3. Practicals

Final Clinical & Practical Examination: - Total 300 marks
There shall be two internal and two external examiners.
There shall be:

1. One long case and two short cases. - 100 marks

2. Two practicals consisting of one in basic science and one in clinical science. - 70 marks
3. Spots - 30 marks
4. viva-voce & scan reading - 100 marks

Recommended Reading:

Books

1. Thyroid cancer – a comprehensive guide to clinical management- Leonard Wartofsky
2. Physics in Nuclear Medicine Cherry, Sorenson
3. Nuclear Medicine technology: Procedures & quick references second edition- Pete Shackett
4. Gopal B Saha- Physics & Radiobiology of Nuclear Medicine
5. Gopal B Saha-Fundamentals of Nuclear Pharmacy
6. Neuro PET by Herholz
7. Molecular anatomic Imaging by Von Schulthess
8. Principles and Practice of Nuclear Medicine by Paul, J. Early, D. Bruce Sodee
9. Diagnostic Nuclear Medicine by Sandler and Gottchalk

10 Nuclear Medicine in Clinical Diagnosis and Treatment by Ell and Gambhir

11 Pediatric Nuclear Medicine –STTreves – third edition

Positron Emission Tomography by Valk, Bailey, Townsend

12. Practical FDG Imaging A teaching File by Debelke, Martin, Patton, Sandler.
13. Functional Cerebral SPECT and PET Imaging
14. CT and MR Imaging of the whole body Haaga, Lanzieri, Gilkeson
14. Multidetector CT : Principle Techniques and Clinical Applications by Fishman Jeffrey
16. Normal Lymph node Topography. CT atlas by Richter Feyerabind

Journals

1. Journal of Nuclear Medicine.
2. European Journal of Nuclear Medicine and Molecular Imaging.
3. Seminars of Nuclear Medicine.
4. Clinical Nuclear Medicine.
5. Journal of Labeled compounds & radiopharmaceuticals.
6. Quarterly Journal of Nuclear Medicine.
7. International Journal of applied radiation & Isotopes.
8. International Journal of Radiation Biology.
9. Indian Journal of Nuclear Medicine.
10. Annals of Nuclear Medicine
11. Thyroid
12. Journal of Clinical Endocrinology and Metabolism
13. International Journal of Nuclear Cardiology
14. World Journal of Nuclear Medicine
15. Nuclear Medicine Communications
16. Journal of Nuclear Medicine Technology
17. Radiology
18. Radiographics
19. Indian Journal of Radiology & Imaging
20. PET clinics

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SYLLABUS

OF

MD PALLIATIVE MEDICINE

Under TMC

(Program code: HLTH09A07)

CURICULLAM OF MD (PALLIATIVE MEDICINE)

MD in Palliative Medicine specialty training will consist of core and higher specialty training. Core training provides the doctor:

09HLTH09A07-001-C Cognitive Domain

General Principles

- Definitions of: palliative care; general palliative care; specialist palliative care; hospice; palliative medicine; supportive care, termainl illness .
- Re-adaptation and rehabilitation.
- Societal expectations and perceptions in progressing and advanced disease, death.
- Differing concepts of what constitutes quality of life (including measurement) and a good death.
- Describe the evolving nature of palliative care over the course of an illness, including integration with active treatment, and the significance of transition points
- Demonstrate an understanding of palliative care as a generic skill and duty of all healthcare professionals; and the need for appropriate inter professional communication
- Demonstrate appropriate communication skills, breaking news and breaking bad news
- Demonstrate an awareness of the range of palliative care services available
- Discuss the history, progress and place of Palliative Medicine.
- Discuss the advantages, disadvantages and relevance of different models of palliative care in the

Indian Context:

- Hospital based services , Hospices, Home visit programmes ,National Rural Health Mission and other Community participation
- Describe the importance of Teamwork, Networking in Palliative Care

Basic sciences

- Describe the anatomical, physiologic and biochemical basis of pain including pain pathways, receptors, neurotransmitters and central sensitization.

- Anatomic and physiologic pathways and neurotransmitters involved in emesis.
- Understand the patho-physiologic basis of symptoms like constipation, malignant bowel obstruction, spinal cord compression, raised intracranial tension etc
- Discuss the pharmacology, pharmacokinetics, pharmaco-economics and drug interactions relevant to Palliative Care

Physical Care

- Initial assessment - detailed history and examination;
- Judgment of benefits and burdens of investigations,
- Patho-physiology of a symptom (due to concurrent disorders and treatment related as well as cancer related aetiology)
- Treatments options, non intervention.
- Management of adverse effects of treatment
- Need for regular review of symptom response
- Methods of assessment of symptom response
- Management of intractable symptoms – recognition and support for patients,
- Need for, and skills in reassessment and review.
- Anticipation and pre-emption of problems
- Recognition of transition points during course of illness.
- Recognition of dying process.
- Crisis management.
- Shared care with other specialties – benefits, difficulties, facilitation

Psycho-social responses to illness

At the end of the course, the student will be able to:

- Describe the psychological responses to bad news and discuss the role of coping mechanisms
- Describe the nature, stages and variations of grief
- Demonstrate an understanding of when grief becomes abnormal or complicated requiring intervention
- Describe theories of bereavement including the process of grieving, adjustment to loss and the social model of grief
- Describe the responses of children at different stages of grief and bereavement.
- Epidemiological impact of bereavement
- Risk factors for adverse outcomes of bereavement
- Discuss the difference between sadness and clinical depression
- Describe the different responses and emotions expressed by patients and caregivers, including fear, anxiety, guilt, anger, sadness and despair
- Identify psychological responses as a source of additional problems

- for patient and family and as potentially obstructing the goals of care.

- Deal with
  - Anger and strong emotions
  - Anxious preoccupation
  - Transference
  - Collusion and conspiracy of silence
  - Denial
- Demonstrate an awareness that hope is important and give hope appropriate to the stage of the illness
- Demonstrate an awareness of other disciplines who could help patients to deal with psychological issues
- Demonstrate the ability to recognize unhelpful and potentially harmful psychological responses
- Understand the impact of insensitive delivery of bad news
- List potentially therapeutic interventions: psychological techniques, drug treatment and creative therapies including behavioural therapy, counseling,
- Demonstrate strategies for dealing with difficult questions or situations including uncertainty and prognosis
- Counselling for patients with HIV and their families
- Demonstrate an awareness of the importance of good communication between team members to ensure patients receive a consistent message
- Recognize the importance of documentation of all input with patients and families to ensure good communication with all team members
- Demonstrate awareness of
  - The ill person in relation to his/her family, work and social circumstances
  - The impact of illness on interpersonal relationships
  - Impact of illness on body image, and role
  - Understanding of the concepts of resonance, family scripts, homeostasis in
  - families and the impact of illness and loss on the family system
  - Awareness of transference and counter-transference in professional
  - relationships with patients and family members
- Assess the response to illness and expectations among family members
- When and how to use family meetings
- Ways to accommodate needs of partners and families in provision of palliative care in both an inpatient unit or home setting
- Palliative care provision in relation to the homeless
  - Illness in people with dementia or pre-existing psychological or psychiatric
  - problems
  - Demonstrate an awareness of ways in which bereaved families could be supported economically
  - Accessing benefits, grants and allowances available to patients and families
- The role of the social worker and/or welfare benefits officer
- The financial implications of treatment and pharmaco-economics
- Discuss the importance of personal values and belief systems, and how these influence professional judgments and behaviours

- Recognize and manage the emotional and psychological impact of palliative care on oneself , the team and colleagues
- Discuss what makes a team work well and how to recognize when a team is struggling
- Demonstrate an awareness of healthy strategies for dealing with conflict among colleagues
- Demonstrate self awareness
- Awareness of own skills and limitations, and effect of personal loss or
- difficulties
- Ability to ask for help or hand over to others where necessary
- Potential sources of conflict in the doctor-patient relationship and how to deal with these including:
  - Over-involvement
  - Personal identification
  - Negative feelings/personality clash
  - Demands which cannot be met
  - Recognition and management of the emotional and psychological impact of
  - palliative care on oneself, the team and other colleagues
  - Being a supportive colleague to other members of staff
  - Recognition of ways staff support can be offered/co-ordinated.
  - Discuss the importance of not imposing personal beliefs and attitudes, or those of the team, on patients or their families
- Understand the importance of life review and restoration of dignity as a means of spiritual support
- Discuss the distinction between an individual's spiritual and religious needs
- Knowledge of the major cultural and religious practices that relate to death and bereavement.
- Remain present with patients as they journey through spiritual and existential distress

Spiritual Care

- Ability to distinguish between an individual's spiritual and religious needs
- Ability to elicit spiritual concerns appropriately as part of assessment
- Spirituality issues in relation to life-threatening physical illness and the role of spiritual care
- Ability to acknowledge and respond to spiritual distress, including referral to others
- Knowledge of pastoral systems within different religious groups and work with their representatives within the multidisciplinary team
- Knowledge of the major cultural and religious practices which relate to medical practice, dying and bereavement.

Culture, language, religion and spirituality

- Recognition of cultural influences on the meaning of illness for patient and

family
- Acknowledgement and accommodation of differences in belief and practice to ensure thorough assessment and acceptable care
- Awareness of personal beliefs and attitudes and the importance of not imposing these on others
- Ability to recognise and deal with conflicts of beliefs and values within the Team

SPECIFIC DISEASE PROCESSES:

Non communicable diseases

- Understand the pathological process and principles of management of Non-communicable diseases, including
  - End-stage lung disease
  - End-stage liver disease
  - End-stage renal disease
  - End-stage heart disease
  - End-stage metabolic diseases including diabetes
  - Other non-communicable diseases
  - Cancer, including principles, practices and problems associated with the principles of cancer management.
  - The presentation, paths of spread and current management of all major malignancies.
  - Radiotherapy
  - Chemotherapy
  - Surgery
  - Hormone treatment
  - Immunotherapy, hormone therapy, drugs, physical therapies,
  - Psychological interventions, complementary therapies).

Communicable diseases

- Understand the pathological process and principles of management of Communicable diseases
- HIV-AIDS, including principles and problems associated with anti-retroviral therapy (ART)
- Other communicable diseases

SPECIFIC SYMPTOMS AND THEIR MANAGEMENT

Pain

At the end of the course, the student should be able to:

- Assess pain systematically (Nature, Site, Severity, Radiation, Palliating and provoking factors, temporal factors and meaning of the pain for the patient)
- Identify common pain syndromes
- Describe the WHO analgesic ladder and identify its key components
- Discuss the relative benefits/ indications/ contra-indications of different analgesics
- Discuss the role of adjuvant analgesics

- Identify physical, psychological, social and spiritual factors influencing pain
- Understand the relevance of non-drug measures in pain management
- Enumerate steps towards management of refractory pain

Gastrointestinal symptoms

- Evaluate and manage common GI symptoms including nausea, vomiting, constipation, anorexia, bowel obstruction, hiccups, diarrhea, ascites, dysphagia and jaundice.
- Appropriate use of nasogastric tube
- Alternative methods of nutrition and hydration
- Give nutritional advice on end-of-life situation
- Understand the problems of force-feeding
- Understand the role of role of surgical procedures, GI interventions e.g stenting, NJ feed, feeding Gastrostomy and Jejunostomy.
- Understand stoma management in ostomies
- Liver failure

Cardio-respiratory symptoms

- Enumerate the common causes of breathlessness, cough, haemoptysis and orthopnoea
- Assess and manage
    - pleural and pericardial effusions
    - stridor,
    - superior venacaval obstruction
- Understand appropriate vs inappropriate use of oxygen and invasive ventilation
- Use opioids in dyspnoea
- Understand and manage terminal respiratory
- Understand breathing techniques as a therapeutic tool
- Understand the relevance of plurodesis
- Understand Prevention and management of pulmonary embolism
- COPD and common respiratory disorders
- Thromboembolic disease
- Ischaemic heart disease, heart failure, arrhythmias, hypotension
- Peripheral vascular disease

Genitourinary symptoms

- Manage vaginal discharge and bleeding per vaginum.
- Renal failure
- Diagnose rectovaginal, rectovesical and vesicovaginal fistulae, and understand indications for surgery
- Diagnose and manage bladder spasms
- Manage urgency and dysuria/anuria
- Understand the advantages and disadvantages of various methods of management of urinary retention and incontinence including
- Identify and manage issues related to sexuality

Neurological symptoms

- Early diagnosis of spinal cord compression and appropriate action
- Peripheral neuropathy
- Autonomic neuropathy
- Manage
- Raised intracranial pressure,
- Seizures,
- Delirium
- Non –invasive ventilation

Psychiatric Manifestation

- Diagnose And Manage The Following Conditions Within The Domain Of Palliative Medicine
- Depression,
- Dementia
- Anxiety,
- Panic,
- Confusional States,
- Insomnia,
- Hallucinations
- Pre-Existing Drug Dependance

Oedema

- Describe the causes, prevention and management of different types of oedema
- Diagnose and manage lymphoedema
- Diagnose and manage deep vein thrombosis,
- Diagnose and manage acute inflammatory episodes and lymphorrhoea
- Bandaging
- Use of compression garments

Other symptoms

Diagnose and plan management of

- Pathologic fractures, osteoporosis
- Itching,
- Pressure sores,
- Fungating wounds,
- Malodour,
- Candidiasis,
- Sore mouth,
- Anaemia and Fatigue
- Infections and infection control measures
- Diabetes mellitus
- Pre-existing chronic pain.
- Hyper and hypothyroidism, adrenal failure, pituitary failure
- Dermatological problems
- Anxiety and depression, psychoses

Metabolic disorders

- Assess and manage
- hypercalcemia
- hyponatremia
- SIADH
- hypokalemia
- hypoglycemia
- dehydration

Rehabilitation

- Principles of rehabilitation related to illnesses with gradually increasing disability
- Concept of maintenance of function through exercise and therapies
- Recognition of changing goals during the course of an illness
- Dealing with patient / family conflict in relation to unrealistic goals
- Facilities available for rehabilitation
- Appliances available in the home
- Use of disablement centre for artificial limbs and appliances
- Support services available in the home

Care of the elderly

- Understand, assess and manage
- Medical conditions specific to the elderly
- Psychological problems common in the elderly
- Social issues that are relevant to the care of the elderly
- Principles and practice of palliative care in the elderly
- Integration of palliative care into geriatric medicine

Pediatric Palliative Care

- Understand, assess and manage
- Reactions of children to health issues specific to various age groups including relevance of parental separation
- Medical conditions requiring palliative care in childhood including neo-nates
- Procedure related pain in children
- Pain and other symptoms in children
- Psycho-socio-spiritual issues in children
- Family support and bereavement support

Emergencies

- Assess and manage emergencies including
- Bleeding
- Spinal cord compression
- Intestinal obstruction
- Breathlessness and Others

Care of the dying patient and their family

- Recognition of the dying phase
- Initial assessment of the dying patient

- Providing ongoing care for dying patients and their families:
- Assessment of required medications
- Recognising when to discontinue further investigations and treatment
- Managing symptoms in the dying phase
- Management of mouth care and bowel care
- Psychological care of the family
- Knowledge of major cultural and religious customs which relate to medical practice, dying and bereavement
- Understanding of ethical dilemmas in the dying phase
- Understanding pharmacology in dying patients, including use of a syringe driver

Death

- Prognosticate death
- Demonstrate awareness of a care pathway
- Assess and manage end of life situations including
- Terminal delirium
- Secretions and "rattles"
- Conflicts in family regarding end-of-life decisions
- Unrelieved symptoms
- Evaluate and reduce medications as appropriate
- Prepare the family for the changes that are likely to happen
- Understand the indications, role and modalities of Palliative Sedation Therapy

PHARMACOLOGY AND THERAPEUTICS

General

- Analysis of therapeutic possibilities, weighing up benefits and burdens of treatment or intervention.
- Communication about therapeutic goals and possible adverse effects with patients and carers; enabling their input to decision making
- Communication about the above with others in the clinical team
- Compliance and non-compliance with treatments – reasons for noncompliance and ways of increasing compliance

Drug specific

- General principles of pharmacodynamics and pharmacokinetics
  - Routes of administration
  - Absorption, metabolism, excretion
  - Half-life, usual frequency of administration
  - Adverse effects and their management
  - Use in syringe drivers stability and miscibility
  - Interactions with other drugs
  - Possibility of tolerance, dependence, addiction and discontinuation reactions
- Adjustment of dosage in frail, elderly and children
- Adjustment of dosage in altered metabolism, disease progression and last few days of life.

- Drug formularies in palliative care
- Managing a pharmacy budget; issues of cost versus benefit
- Prescribing – legal issues, generic prescribing
- Use of drugs on a named patient basis
- Use of drugs outside their product licence
- Use of drugs in clinical trials
- Problems of polypharmacy
- Helping patients and carers to understand and manage tablets

Access to essential medicines including opioids

- WHO pain ladder
- Understand the relevance of affordability of treatment measures, particularly in the context of the developing world.
- Describe the barriers to access to controlled medications particularly those that relate to the Narcotic Drugs and Psychotropic Substances (NDPS) act
- Describe the principle of balance
- Describe the measures that can be taken to ensure uninterrupted access to controlled medications
- Opioid availability:
  - Barriers to opioid availability
  - Legal status of opioid use in India
  - Obtaining opioids under NDPS act of 1985
  - The recent action to improve opioid availability and its impact
  - Procuring opioids under amended narcotic regulations.
  - Storing, dispensing and documentation for opioid use.

Ethics

- Theoretical ethics
  - History of medical ethics, with emphasis on evolving philosophy and codes of practice.
  - Critical analysis of current theoretical approaches to medical ethics including 'four principles (beneficence, nonmaleficence, justice and respect for autonomy).
- Applied ethics in clinical practice of palliative care:
- Acknowledgement of ethical issues in daily clinical practice and teamwork
- Consent
- Giving information
- Confidentiality
- Competence to make particular decisions
- Non-autonomous or incompetent individuals
- Best interest judgements
- Conflicts of interest between patient and their relatives
- Responsibility for decisions (doctors, patients & teams)
- Resource allocation (including of oneself)
- Withholding and withdrawing of treatment (including hydration / extubation)
- Euthanasia

- Physician-assisted suicide
- Doctrine of double effect
- CPR decisions
- Research / clinical trials

Legal Frameworks

- Common laws related to health and in relation to end of life medical care including euthanasia and physician assisted suicide.
- Death
  - Certification of death procedures, including definition and procedure for confirming brain death.
  - Cremation regulations.
  - Procedures for relatives following a death.
  - Procedures around post mortems.
- Organisational
  - Corporate law relating to charities/trusts e.g responsibilities/liabilities of
  - trustees and employers
  - Laws & regulations relating to hospitals
  - Employment law
  - Discrimination – gender, race, disability, age

09HLTH09A07-002-C Psychomotor Domain

In practice a Student should be able to

- Use a syringe driver
- Use the subcutaneous route for drugs
- Perform peritoneocentesis
- Perform rectal examination
- Manage bowel in paraplegics and other bed-bound patients
- Counsel families regarding stoma management
- Perform pleurocentesis
- Manage Tracheostomy care
- Use nebulisers
- Reassure a patient and family in presence of breathlessness
- Insert urinary catheter
- Teach intermittent self-catheterisation to patient
- Perform basic neurologic examination
- Use a screening tool for identification of delirium
- Use screening tools for diagnosing depression and anxiety
- Teach the patient and family techniques for prevention and simple lymphatic drainage
- Apply compression bandages and garments
- Teach Wound care including low cost dressings, Mouth care, and pressure sore care to patient and family
- Instruct a family in using sub-cutaneous fluids in the home setting

- Counsel the patient and family in a life-threatening emergency
- Management of stomas
- Management of non-invasive ventilation
- Management of epidural catheters
- Simple nerve blocks
- TENS application

Communication skills

- Demonstrate skills in empathic listening
- Elicit concerns across physical, psychological, social, and spiritual domains
- Demonstrate the ability to deliver bad news sensitively and at an appropriate pace for the individual
- Discuss the importance of communication between professional, family and patient
- Common barriers to communication for both patients and professionals
- Management of difficult questions and information giving sensitively and as
    - appropriate to wishes and needs of the individual

Perform role plays in

- Assessment of emotional status of a patient who has just been told he has cancer or another life threatening disease
- Empathic listening
- Delivering bad news
- Dealing with collusion
- Empowering a patient in exercising autonomy in decision making
- Interviewing the patient regarding personal relationships
- Counseling regarding financial implications
- Supporting a bereaved family member
- Spiritual support for a terminally ill person of no faith or a different faith n spiritual support for a terminally ill person of no faith or a different faith
- Communicating with a patient who asks for euthanasia
- Explaining advanced care directives to a patient
- Awareness and practice of a range of structures and styles of consultations
- Critical evaluation of own consulting skills

Miscellaneous

- Demonstrate skills in empowering the patient to exercise autonomy in decision making
- Be a supportive colleague to other members of staff
- Demonstrate the ability to communicate with and support bereaved and grieving person
- Demonstrate the ability to elicit spiritual concerns and spiritual pain and respond appropriately including referrals to others if necessary.

- Discuss the importance of changing goals during the course of an illness and the need for realistic goals
- Identify important situations in which physical measures for rehabilitation will be useful and indicated
- Know how to access support for such services

- Know how to provide/access measures of social rehabilitation including vocational rehabilitation
- Recognize the special needs of children in the patients’ families including support for schooling.
- Demonstrate the ability to apply an ethical framework to issues, incorporating the following ethical frameworks:
    - respect for the patient- autonomy
    - Patient confidentiality – assessing patient competence to make decision
    - weighing up the benefits and burdens of treatment- beneficence
    - assessing the risks versus benefits of each decision- non-maleficence
    - doctrine of double effect
    - balancing the rights of individuals and of society- justice
    - Demonstrate an awareness of guidelines produced by the Indian Society of Critical Care Medicine for end of life care
    - Describe the procedures involved in verification and certification of death and management of the dead body
    - Ethical guidelines in clinical research including Good Clinical Practice guidelines.
- Describe Advanced Care Directives
- Describe when and how artificial life support measures should be and can be withheld or withdrawn
- Know when and how to obtain an informed consent for any procedure
- Have clear understanding about the concept of euthanasia and its distinction from palliative sedation

Research and Education

- Perform a literature search on a selected subject
- Prepare a PowerPoint presentation
- Demonstrate a presentation each for the public and for fellow professionals
- Prepare a research question
- Identify important peer-reviewed journals on palliative care
- Know how to access literature
- Gather knowledge related to basic and clinical trial methodology
- Understand and able to conduct-different phases of clinical trails,e.g.Phase I,II,III,IV and their implications in Palliative Medicine
- Identify the levels of evidence among published research
- Demonstrate the ability to analyze the quality and implications of medical literature and apply new knowledge in the delivery of health care

- Know important recent advances in the field
- Demonstrate understanding of different teaching methods and structure, including lecturing, problem based learning, role play, bedside teaching
- Demonstrate understanding of teaching contexts (eg. Size of group, professional or otherwise, undergraduate or postgraduate,
- Demonstrate understanding of selection, preparation and presentation of teaching materials
- Demonstrate understanding of how to make a lecture interactive
- Demonstrate understanding of the role of supervision, mentoring, learning contracts, critical appraisal and feedback, experiential learning.
- Plan learning aims, objectives, methods and outcomes.
- Demonstrate understanding of the concept of continuing professional development.
- Demonstrate understanding of framing suitable specific learning objectives.
- Conducting clinical sessions for undergraduate medical students, nurses and paramedical workers
- Prioritize core competencies in curriculum planning
- Demonstrate an interest and ability to identify future areas of inquiry in medical research
- Utilize knowledge of population based and evidence based medicine in making patient management decisions.
- Have familiarity with basic research methodology, epidemiology, basic information technology skills
- Plan the protocol of a research project, execute it and prepare final report.
- Understand the ethical principles guiding medical research
- Demonstrate knowledge of study design and relevance of sample size

Medical Statistics

- Demonstrate knowledge of:
- Basic concepts of medical statistics
- Mean, median, mode, standard deviation, analysis of variance and correlations
- Student's T test
- Chi square test
- Fisher's exact test
- Non-parametric tests of significance
- Multivariate analysis
- Survival analysis-log rank test

09HLTH09A07-003-C Affective Domain

Communication skills

- Understand the basic principles of communication including the purpose, active listening and what not to do.
- Describe the steps in effective communication
- Understand possible reactions of patients and families to bad news and respond appropriately
- Understand reasons for collusion within the family and deal with it sensitively

Team work

- Theories of teamwork, e.g. psychological, psychodynamic, managerial
- Identification of oneself in relation to these differing theoretical models of teamwork

  - Understand the importance of teamwork in this setting and have an appreciation of the skills and contributions of different members of the team
  - Identify the role and responsibilities of doctors and other members in multiprofessional teams.
  - Understand the skills and contributions of other members of the multi-professional team.
- Team dynamics in different situations and over time
- Forms of team support
- Strategies which facilitate team functioning, and those which do not.

- Understand the inevitability of conflict within a team, and strategies to manage this.
- Understand Skill mix of a team, particularly in relation to the appointment of new members.
- Know the basics of chairing of team meetings.
  - Balancing the needs of the different or overlapping teams of which the doctor may be a member at any one time
  - Wide application of teamwork to include all the professionals and organisations involved in the care of a particular patient, including nurses, statutory and voluntary organisations
  - The impact on patients and carers of the number of professionals who may be involved in their care.

Role Of Supervision And Mentoring
Leadership skills

Demonstrate understanding of:

- Management of change
- Writing a job description and person specification
- Short-listing and interviewing skills
- Writing a reference
- Induction and training
- Mentoring skills
- Assessment of trainees/junior colleagues
- Motivating and leading a team
- Management styles
- Goal setting
- Short and long term strategic planning
- Negotiating, directing and delegating
- Principles of advocacy with Government and media
- Principles of involving the community in care

Management of work

- Time management

- Working with a secretary
- Budget setting and management
- Planning, implementing and evaluating change

Information management

- Patient data collection.
- Data protection act, including rights of access for patients to information held
- on them
- Computer security and backup systems

Management structures of the organization

- Running a palliative care unit
  - Supply of drugs to hospices, stock lists, financing and regulations for
  - controlled drugs
  - registration
  - Storage and retrieval of case notes
  - Health and safety issues
  - Equipment safety and maintenance
  - Role and management of staff and volunteers
  - Disposal of bodies
  - Awareness, training and networking with the community volunteers.
- Financial management
  - Public and charitable health funding structure
  - Interacting with fundraisers
  - Understanding accounts
- Clinical Governance
  - Responsibilities of doctors; professional and organisational goals
  - Quality assurance in relation to service and organisation
  - Service review and accreditation of palliative care services

होमी भाभा राष्ट्रीय संस्थान

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SYLLABUS
OF
MD in IMMUNO-HEMATOLOGY & BLOOD TRANSFUSION MEDICINE

Under TMC
(Program code: HLTH09A08)

COURSE CONTENT (SYLLABUS)
MD IMMUNO-HEMATOLOGY & BLOOD TRANSFUSION MEDICINE

DURATION OF COURSE:

The minimum period of training shall be three calendar years and the candidates can be admitted to this training after their full registration with the Medical Council. No exemption shall be given from this period of training of three years either for doing housemanship or for any other experience or diploma.

TRAINING PROGRAMME:

The candidates joining the course must work as full time residents during the whole period of their postgraduate training. They will be required to attend a minimum of 80% of training period. Candidate shall be given full time responsibility and assignments and their participation in all facets of the educational process assured. Postgraduate students must maintain a record book of the work carried out by them and the training undergone by them during the period of training. These record books shall be checked and assessed by the faculty.

TEACHING / LEARNING METHODS:

Learning in M.D. (Immunohaematology & Blood Transfusion) will essentially be self-learning.

Following teaching-learning methods shall be followed:

Group teaching sessions:

- Journal review
- Subject seminar presentation
- Group discussion
- Clinical case presentations pertaining to transfusion therapy.
- Presentation of the findings of an exercise on any of the sub-specialities
- Participation in CME programs and conferences.

Hands on experience (practical training)

Practical training shall be imparted by posting the students in various sub-specialties (sections) as detailed in the intrinsic and extrinsic rotation. Students shall be actively involved in day to day working of all the sections.

He/She will be trained under the guidance of teachers in all the aspects of practice of transfusion therapy and basic blood banking techniques including blood collection processing, storage of blood products, component preparation, pre-transfusion testing, apheresis, screening of blood products and haemotherapy including stem cell transplantation and all emergencies related to Blood Banking.

Suggested schedule of rotation:

Intrinsic rotation:

The candidates will be rotated through various sections of the department as under:

A) Blood donor management — 6 months

Donor counseling, recruitment & motivation
Blood Donor selection
Phlebotomy
Post donation care of donor
Outdoor blood donation camps

B) Component preparation, Aphereis & Quality Management — 6 months

Preparation of various blood components
- PRBC, FFP, PC, Cryo, Leuco – poor

Irradiation of blood components
Storage & quality control
Apheresis
- Donor apheresis
- Therapeutic plasma exchange

C) Transfusion transmitted infection screening — 5 months

Screening of carious markers
- HIV, HCV, HBsAg, Syphilis

Methodology
- ELISA, Spot, Rapid, Automated analyzer

Molecular techniques

D) Immunoheamatology **6 months**

Diagnosis & Transfusion support in
- AIHA
- PNH
- Transfusion reaction
- Antenatal serology
- Multi – transfused patients

Secretor status
Minor red cell antigen typing
Antibody screening

E) Pre transfusion testing & Cross matching **6 months**

ABO grouping & Rh typing
Weak D testing,. Genotyping
Irregular antibody screening & identification
Cross – matching techniques

F) Quality control / computers / records **1 month**

G) PBSCT, Umbilical cord stem cells Bone marrow stem cells **1 month**

Harvest
CD 34 counts
Cryopreservation

Total **31 months**

Training in Allied departments

A) Dept of Pathology / Haematology **1 month**
- Complete haemogram
- Reading of peripheral smear
- Coagulation work up
- Hemolytic Anemia work up
- Bone – marrow smear – Aspiration & Trephine
- Hematological disorders – work up

B) Dept of Microbiology & Virology **1½ month**
- Isolation of lymphocytes
- CD4 / CD8 counts
- Special molecular techniques
- Bacterial culture
- Grams staining

C) Dept of Anesthesiology		**½ month**
Residents may undergo rotation in various OTs including specialized OT's Intra-operative haemodilution Blood salvage Intra-operative transfusion		
D) Dept of Clinical Haematology & BMT		**1 month**
E) Advanced Training in Immunohaematology		**1 month**
HLA Typing Immunophenotyping including flowcytometry Immunofluoresence		
	Total	**5 months**
Grand Total		**36 months**

Clinical Department, Subjects:

1. Transfusion support for thalessemia, hemophilia, hemato-oncology patients
2. Bedside management of transfusion reactions
3. Bedside management of transfusion in AIHA patients
4. Bedside transfusion support in BMT patients
5. Bedside transfusion support in Medical Emergencies

Emergency duty:

Student shall be posted for managing emergency transfusion services in the department. He/she will deal with all the emergency investigations in transfusion medicine.

Training in research methodology:

Training in research methodology shall be imparted by planning of a research project by the student under the guidance of a recognized guide to be executed and submitted in the form of a dissertation. The dissertation is aimed at training the candidate in research methods and techniques. It will include identification of a research question, formulation of a hypothesis, search and review of relevant literature, getting acquainted with recent advances, designing of research study, collection of data, critical analysis of the results and drawing conclusions. The topic shall be communicated to the university within six months of registration and atleast 12 months should be spent on the research project. The dissertation shall be completed and submitted by the student six months before appearing for the final university examination.

Teaching experience:

Student shall be actively involved in the teaching of undergraduate students / paramedical staff. He/she will be trained in teaching methods and use of audiovisual aids.

BROAD AREAS OF STUDY

09HLTH09A08-001-C: HISTORY OF TRANSFUSION MEDICINE

Scientific landmarks in its development
Impact of world wars on its development
Development of PVC bags.

09HLTH09A08-002-C: SCIENTIFIC BASIS OF TRANSFUSION

A. Biochemistry & Physiology of elements of blood

2.0. Process of cell production and life span
- 2.1. Red cells
- 2.2. White blood cells
- 2.3. Platelets

3.0 Red cells
- 3.0 Haemoglobin structure & function
- 3.1 Metabolic pathways
- 3.2 Membrane structure & function

4.0 White cells
- 4.0 Structure, function & kinetics

5.0 Platelets
- 5.0 Structure, function & kinetics

6.0 Physiology of Haemostasis
- 6.0 Role of platelets
- 6.1 Coagulation pathways
- 6.2 Fibrinolysis

7.0 Hemodynamics of blood flow & volume

8.0 Iron metabolism

9.0 Bilirubin metabolism

10.0 Immunology

- 10.0 Principles of Basic Immunology

- 10.1 Antigen, Antibody, Complement, Immunoglobulin
- 10.2 Antigen/antibody reaction
- 10.3 Lymphocytes in Humoral & Cellular immunity

11.0 Role of Hybridoma technology in Immunology

12.0 Immunology of transplantation

13.0 HLA & genetic control of immune response

14.0 Transfusion Immunology

B. Blood Group System

15.0 Blood Group System

- 15.0 Major Blood Group System

- 15.1 Minor Blood Group System

C. Genetics

16.0 Principles of basic genetics

17.0 Genetics of Blood Groups

- 17.0 Phenotypes & genotypes
- 17.1 Principles of blood group inheritance
- 17.2 Population genetics of blood groups

D. Molecular Biology

18.0 Molecular Biology

- 18.0 Molecular Biology of the cell
- 18.1 Molecular Biology of the Gene
- 18.2 Molecular Genetics

E. Microbiology

19.0 Transmissible Diseases

20.1 Sterility Testing

F. Biochemistry

20.0 Plasma Proteins – separation & purification

21.1 Immunoglobulins – estimation & typing

09HLTH09A08-003-C: ANTIGEN SYSTEMS IN FORMED ELEMENTS OF BLOOD

21.0 Red Cell antigens including

- 21.0 Lectins and their biology
- 21.1 Adsorption and Elution methods

22.0 Leucocyte antigens

23.0 Platelet antigens

09HLTH09A08-004-C: BLOOD COLLECTION, PROCESSING, COMPONENT PREPARATION

A. Management of Blood Donation

24.0 Donor recruitment

- 24.0 Voluntary blood donation system
- 24.1 Categories of blood donors
- 24.2 Education & awareness of prospective donors
- 24.3 Use of Information Technology for Donor Recruitment

25.0 Acceptability criteria of blood donors

26.0 Care of blood donors

- 26.0 Pre-donation
- 26.1 Mid-donation
- 26.2 Post-donation
- 26.3 Prevention & management of complications of blood donation

27.0 Blood collection
- 27.1 Anticoagulants & preservatives
- 27.2.1 Procedure
- 27.2.2 Blood donation camps

B. Blood Components

28 Components
- 28.1 Types
- 28.2 Methods of preparation
- 28.3 Indications, dosage & administration
- 28.4 Leuco-depletion
  - 28.4.1 Various methods
  - 28.4.2 Quality Control

29 Storage of blood & blood components
- 29.1 Whole blood
- 29.2 Red cell concentrate
- 29.3 Plasma
- 29.4 Granulocyte
- 29.5 Cryoprecipitate
- 29.6 Stem cells
  - 29.6.1 Peripheral blood stem cells
  - 29.6.2 Cord blood stem cells

30 Plasma fractionation

30.1 Viral inactivation
30.2 Newer methods

09HLTH09A08-005-C: PRE-TRANSFUSION TESTING

31 Compatibility testing
  31.1 ABO grouping & Rh typing
  31.2 Antibody screening
  31.3 Methods of cross matching
  31.4 Newer methods of cross matching
    31.4.1 Solid Phase
    31.4.2 Gel technology
  31.5 Antiglobulin testing

32 Screening for Transfusion Transmitted Infections
  32.1 Methodology
  32.2 Nucleic acid amplification techniques
  32.3 Newer emerging pathogens
    32.2.1 Prions
    32.2.2 Lyme disease
    32.2.3 Others

33 Selection of blood components & plasma products for transfusion

CLINICAL ASPECTS OF IMMUNOHAEMATOLOGY & BLOOD TRANSFUSION

09HLTH09A08-006-C: ADVERSE EFFECTS OF BLOOD TRANSFUSION (Acute and delayed complications following Blood Transfusion)

34 Clinical presentation, pathophysiology, investigations, management
  34.1 Hemolytic transfusion reaction
  34.2 Non hemolytic transfusion Reaction

35 Transfusion Transmitted Infections

36 Transfusion Associated – Graft versus Host Disease (TA-GVHD)

37 Transfusion Related Acute Lung Injury (TRALI)

38 Others

  38.1 Haemosiderosis
  38.2 Volume overload
  38.3 Other complications

09HLTH09A08-007-C: APHERESIS

39 Technology of apheresis and various machines

40 Haemapheresis (platelets, granulocytes, plasma)
- 40.1 Donor selection
- 40.2 Procedure
- 40.3 Complications

41 Therapeutic apheresis
- 41.1 Indications, procedure & complications
- 41.2 Plasma exchange, Red cell Exchange
- 41.3 Newer methods of Immunoadsorption

09HLTH09A08-008-C: AUTOLOGOUS TRANSFUSION

42 Basic principles, indications, contra-indications.
- 42.1 Pre-deposit
- 42.2 Haemodilution
- 42.3 Intra-operative blood salvage including equipment
- 42.4 Directed donation

09HLTH09A08-009-C: ANTINATAL & NEONATAL TRANSFUSION PRACTICE

43 Pathophysiology, diagnosis & management
- 43.1 Rh incompatibility
- 43.2 ABO & other blood group incompatibility

44 Exchange transfusion
- 44.1 Indications, methodology & complications
- 44.2 Intrauterine transfusion

45 Neonatal transfusion practice

09HLTH09A08-010-C: IMMUNOHEMATOLOGY

46 Classification, diagnosis and management
- 46.1 Immune haemolytic anaemia
- 46.2 Immune thrombocytopenia
- 46.3 Immune neutropenia

47 Immunohaematological problems in multi-transfused patients

09HLTH09A08-011-C: HEMOTHERAPY

48 Pathology, diagnosis and management of anaemia
- 48.1 Anaemia
- 48.2 Iron deficiency anaemia
- 48.3 Megaloblastic anaemia
- 48.4 Aplastic anaemia
- 48.5 Haemolytic anaemia including fragmentation syndrome
- 48.6 Anaemia of chronic diseases – liver disease, uremia, thyroid disease etc.

49 Haemoglobinopathies
- 49.1 Thalassaemia
- 49.2 Sickle cell anaemia
- 49.3 Other haemoglobinopathies

50 Pathophysiology, diagnosis and management of haemostatic disorders
- 50.1 Haemophilia
- 50.2 Von willebrands disease
- 50.3 Platelet disorders
- 50.4 Qualitative disorders
- 50.5 Quantitative disorders
- 50.6 DIC

51 Pathophysiology, diagnosis and transfusion support in acute blood loss
- 51.1 Shock
- 51.2 Massive transfusion

52 Transfusion support in cardiac surgery

53 Classification & transfusion support in Oncology
- 53.1 Leukaemia
- 53.2 Lymphoma
- 53.3 Marrow failure

09HLTH09A08-012-C: TRANSPLANTATION

54 Transfusion support in transplantation

55 Peripheral blood stem cell transplantation
- 55.1 Harvesting
- 55.2 Cryopreservation
- 55.3 CD34 counting

56 Bone Marrow Transplantation
- 56.1 Processing
- 56.2 Harvesting
- 56.3 Immunohaematological problems in ABO mismatched BMT

57 Transfusion support in specialized conditions
- 57.1 Renal transplantation
- 57.2 Liver transplantation
- 57.3 Umbilical cord blood transplantation
  - 58.3.1 Collection
  - 58.3.2 Processing
  - 58.3.3 HLA typing & cross matching
- 57.4 Irradiation of blood products
- 57.5 Indications, dosage, adverse effects
- 57.6 Tissue banking

09HLTH09A08-013-C: BLOOD SUBSTITUTE & HEMOPOIETIC AGENTS

58 Crystalloids & colloids

59 Oxygen carrying compounds

60 Haemopoietic growth factors

61 Albumin

09HLTH09A08-014-C: MEDICOLEGAL CONSIDERATIONS IN TRANSFUSIUON

62 Ethical & legal considerations pertaining to transfusion practice

63 Identification of blood stains

64 Paternity testing

65 Donor notification and counseling

66 Look back programme

67 Drugs & Cosmetics Act

68 Clinical, Legal and Ethical considerations in Organ Transplantation

09HLTH09A08-015-C: TOTAL QUALITY MANAGEMENT

69 Development of Standard Operating Procedures (SOP) manual

70 Quality control
- 70.1 Reagents
- 70.2 Instruments
- 70.3 Personnel
- 70.4 Blood & Components

71 Quality Assurance
- 71.1 Internal quality control
- 71.2 External quality control

72 Medical audit

73 Hospital transfusion committee

74 Good manufacturing practice

75 Turnaround time

76 ISO : 9000, Accreditation

09HLTH09A08-016-C: ORGANISATION & MANAGEMENT OF TRANSFUSION SERVICES

77 Organization & function of blood services & hospital transfusion practice
- 77.1 Donor recruitment & motivation
- 77.2 Operation of blood mobile units
- 77.3 Development of transfusion services
- 77.4 Inventory control
- 77.5 Development of forms, labels, records etc.
- 77.6 Reports & Returns

78 National Blood Transfusion Policy

09HLTH09A08-017-C: BLOOD SAFETY

79 Sterilization

80 Disposal of bio-hazardous material

09HLTH09A08-018-C: MODERN BIOLOGICAL TECHNIQUES

81 Principles, methods, relevance in transfusion medicine
- 81.1 Western blot
- 81.2 Polymerase chain reaction
  - 82.2.1 SSCP
  - 82.2.2 SSOP
- 81.3 Dot blot hybridization

09HLTH09A08-019-C: AUTOMATION & COMPUTERIZATION

82 Automated blood grouping & processing
83 Instrumentation & use of bar codes
84 Use of computers in blood banking including implementation of blood banking software

09HLTH09A08-020-C: RECENT ADVANCES IN IMMUNOHAEMATOLOGY & BLOOD TRANSFUSION

BACK TO MAIN

होमी भाभा राष्ट्रीय संस्थान
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SYLLABUS

OF

MD ANAESTHESIOLOGY

(PROGRAM CODE – HLTH09A02)

SYLLABUS OF MD - HBNI

ANAESTHESIOLOGY — M D

The course content should include a fund of acquired information and the strategy evolved for acquiring the information. Most useful information should be included taking into account the limits of the time available. The contents should ensure that the candidate acquires basic skills and attitudes in the subject. It should discipline the thinking habit for problem solving and discovery of new knowledge in the field.

To this Extent the Course Content should Include Certain Facts

a) A thorough knowledge of the pharmacokinetics and pharmacodynamics of anaesthetic drugs and adjuncts.

b) Knowledge of cardiovascular, respiratory neurological, hepatobiliary, renal and endocrine homeostasis and related drugs as relevant to patients undergoing anaesthesia.

c) Relevant anatomy, physiology and biochemistry.

d) A basic idea of the relevant physical principles involved in the construction and functioning of equipment used in anaesthesia and monitoring.

e) Knowledge to attain expertise of the commonly used techniques in general, regional and local anaesthesia.

f) A clear-cut concept of unconsciousness and its implications.

g) Relevant knowledge about chronic intractable pain and its management.

h) Relevant knowledge to manage patients in intensive therapy unit.

i) Relevant knowledge of medical Statistics

j) Knowledge & Expertise in Cardiopulmonary resuscitation.

The Course content should also include ways and means of stimulating the thought processes of the candidate and ensure that the candidate can critically acquire new information from books, journals, lectures, seminars and discussions. It should include ways and means of developing reflective thinking and problem solving by critically analysing events during anaesthesia. Interpretation of these data and logical reasoning should lead to application of facts and principles in practice.

It is needless to emphasise that the course content should ensure that the candidate acquires the necessary aptitude and motor skills to become a competent anaesthesiologist, learn the art of teaching students,nurses and paramedical staff and carry out a simple research project.

1st Year Theory

Should cover the following:

a) Anatomy – Diaphragm, larynx and upper and lower airway, learn relevant, anatomy for regional anaesthesia and venous cannulations. Some Anatomical areas of interest to the anaesthetist are Orbit of the Eye, Base of skull, Vertebral Column, spinal cord, and meninges, axilla, 1st rib, Intercostal space.

b) Principles of physics and use of equipment in anaesthesia

   i) Anaesthesia machine - checking the machine and assembly of necessary items.

   ii) Airway equipment including Tracheostomy / Equipments for airway management - mask, LMA, fibreoptic laryngoscopes; other devices like Combi tube etc.

   iii) Breathing systems continuous flow systems, draw over system - Assembly and checking.

   iv) Monitoring in Anaesthesia with concepts of minimal monitoring.

   v) Safety in Anaesthesia Equipments.

   vi) Medical gases - storage and central pipeline system.

c) Physiology

   i) Theories of mechanism of production of Anaesthesia.

   Respiratory, cardiovascular, hepatobiliary, renal and endocrine system. Pregnancy, Blood Groups, Muscle & N M Junction, ECG, Regulation of temperature & Metabolism, Stress response cerebral blood flow and ICP.

d) Pharmacology

   i) General pharmacological principles.

   ii) Concepts of pharmacokinetics and pharmacodynamics.

   Uptake and distribution of inhaled anaesthesia agents.

   Drug interaction in Anaesthesiology.

   Drugs used in Anaesthesia, Drugs used for treatment of diseases and interaction of these .

e) Theoretical background of the commonly used anaesthetic techniques of general and regional anaesthesia viz.

   i) GA - Intravenous, Inhalational, Endotracheal etc. using spontaneous and controlled mode of ventilation.

   ii) RA - Spinal, epidural and local.

f) Biochemistry relevant to fluid balance & Blood Transfusions, Artificial Blood, & Perioperative fluid therapy.

   Acid base homeostasis in health and diseases.

g) Documentation and medico-legal aspects of anaesthesia.

   Stress the importance of accurate documentation.

h) Theoretical background on disorders of:
   i) Cardiovascular system.
   ii) Respiratory system
   iii) Hepatobiliary system.
   iv) Urinary system.
   v) Endocrine system. Pregnancy.

i) Cardiopulmonary Resuscitation: Theories of cardiac pump. thoracic pump
   Thoracic pump and defibrillation.
   Resuscitation of a patient with overdose of drug/poisons. Management of unconscious patients. Resuscitation of a severely injured patient.

j) Neonatal resuscitation.

k) Introduction to Research methodology. Random clinical trials etc. Basics of biostatistics.

l) Preoperative assessments and medication - general principals.

m) Introduction to anatomical. physiological. pharmacological and biochemical aspects of pain and pain management.

n) Introduction to artificial ventilation.

o) Oxygen therapy

p) Introduction to the operation theatre. recovery rooms (concepts of PACU). ICU.

q) Recovery from anaesthesia.

r) Shock - pathophysiology. clinical diagnosis and management.

s) Pulmonary function tests - principles and applications.

t) Effect of positioning.

2nd Year Theory

a) Relevant anatomy o f each system

b) Physics of equipment used in anaesthesia
   Medical gases - gas plant. central pipeline Scavenging system.
      Reducing valves
      Anaesthesia machine. Humidifiers
      Flow meters
      Vaporizers - Characteristics and functional specifications.
   Breathing systems - Assembly. functional analysis. flow. Minimum monitoring standards requirements. APL and flow directional valves.

c) Sterlization of equipment.

d) Computers. Utility. computer assisted learning and data storage. Computerised anaesthesia records.

e) Pharmacology of drugs used in cardiovascular. respiratory endocrine. renal diseases and CNS disorders.

f) Acid-base and electrolyte balance and.

g) Interpretation of blood gases and other relevant biochemical values. various function tests and basics of measurement techniques. ECG

Paediatrics – Prematurity. Physiology.anatomy of neonate NS adult

h) Principles of monitoring equipment used for assessment of

  i) Cardiac function viz. Rhythm. pulse. venous and arterial pressures. cardiac output.

  ii) Temperature

  iii) Respiratory function viz., Rate volumes. compliance. resistance. blood gases.

  iv) Intracranial pressure. depth of anaesthesia and

  v) Neuromuscular block.

i) Working principles of ventilators.

j) Special anaesthetic techniques as relevant to outpatient anaesthesia, hypotensive anaesthesia, anaesthesia in abnormal environments and calamitous situations.

k) Anaesthetic management in special situations - Emergency. ENT. Ophthalmology. Obstetrics. Obstetric analgesia. Plastic. Dental. Radio-diagnosis and Radiotherapeutic procedures and patients with systemic diseases.

l) Medical statistics relevant to data collection. analysis. comparison and estimation of significance.

m) Journal clubs.

SECOND YEAR

1. Principles of paediatric anaesthesia. management of neonatal surgical emergencies. RA in infants.
2. Associated medical disorders in surgical patients - anaesthesia implications and management.
3. Basics of orthopaedic anaesthesia.
4. Day care anaesthesia.
5. Rural anaesthesia - anaesthesia for camp surgery.
6. Anaesthesia for otorhinolaryngology with special emphasis on difficult airway management.
7. Blood and blood component therapy. Anaesthetic implications in coagulation disorders.
8. Monitored anaesthesia care.
9. Anaesthetic implication in Diabetic mellitus, thyroid and parathyroid disorders, phaeochromocytoma, cushings disease etc.
10. Management of acid-base disorders
11. Principles of geriatric anaesthesia
12. Anaesthesia outside the OR and in special situation

Principle of management in Trauma. disorders and mass casualties

3rd Year Theory

a) Anaesthesia for patients with severe cardiac, respiratory, renal and hepatobiliary disorders posted for unrelated surgery.

b) Management of patients in shock, renal failure, critically ill and/or on ventilator.

c) Chronic pain therapy and therapeutic nerve blocks.

d) Selection, purchase, maintenance and sterilization of anaesthesia and related equipment.

1. Principles of anaesthetic management of neuro/ cardiac/ thoracic / vascular/ Transplantation/ burn and plastic surgery.
2. Principles of neonatal ventilation and critical care.
3. Principles of human resources and material management.
4. General principles of medical audit
5. Principles of one lung anaesthesia

ATTITUDE DEVELOPMENT

The student should develop attitudes that lead to:

1. Life long learning and updating
2. Sympathetic Communication with relatives
3. Sympathetic Communication with patients
4. Appropriate communication with colleagues to function in a group in OR/ICU
5. Become a teacher for Technicians, Nurses, and paramedical staff. And teach undergraduates.
6. Ability to discuss. Participate in case discussion and scientific presentations

Ability to function as a leader in the Operating room

SKILL DEVELOPMENT

Trainee

Requirement of Practical Training by Junior Resident

It is felt that at the end of a 3-year training course a candidate should have the knowledge and ability to:

1. Plan and conduct anaesthesia, recovery, and postoperative pain relief for elective and emergency surgery related to all surgical specialties.
2. Carry out basic life support (BLS) and advanced life support (ALS) and train medical and paramedical staff in BLS and ALS.
3. Manage unconscious patients : Airway management and long term management of unconscious patient.
4. Manage patients admitted to an intensive care unit.
5. Manage patients suffering from chronic intractable pain.
6. Organize the Hospital environment to manage mass casualty situation
7. Critically review and acquire relevant knowledge from the journals about the new development in the speciality.
8. Should be able to participate in anesthesia audit.

Major stress will be on practical training. The Goals of postings both the general goals and of specific sub speciality postings will be fulfilled by rotating the junior resident in various operating theatres.

Intensive Care, Pain Clinic, Emergency Room (Casualty) Out Patient Department and Peripheral anaesthesia Facilities. The recommended period of stay in each area is as follows:

Speciality	*Months*
General Surgery	4
Urology	1
Eye	2
ENT	2
Dental	1
Orthopedics Trauma	3
Gynecology	2
Obstetrics	2
Pediatrics	2
Burns Plastic	1
CTVS	2
Neurosurgery	2
ICU	3
Pain	2
Recovery	1
Organ Transplant	1
Peripheral Theatre (Radiology, Radiotherapy ECT Cardiac Cath.)	1
Elective	1

The student will be instructed in preoperative preparation of the patients and discussion of the intraoperative problems of cases being conducted on the day. During these postings the students will initially observe and then perform various procedures and conduct the anesthetic procedure as listed. Each procedure observed and performed will be listed in the logbook. Which will be signed by attending faculty.

The trainee will undergo a graded training in the following manner:
1st year trainee
Orientation: ~~At the beginning of 3 Years each~~ student should be given an orientation to the hospital operation theatre and subject of anaesthesia. The candidate shall be assigned thesis guides so as to help them prepare protocols.

Introductory lectures should be aimed to familiarize the student with the a) basic anaesthesia delivery equipment and Monitors and important principles of physics that govern the functions of these equipments. b) Intravenous Anaesthetic drugs and Inhalation agents. c) Patient evaluation, interpretation of laboratory investigation as applied to the care of the patients planning and conduct of general anaesthesia, and postoperative care. The faculty should do the teaching. Students should be taught basic and advanced cardiac life support. The student should be familiarized about the principle of the sterilization and universal precautions. They should be able to ask for consultation when necessary.

The students are encouraged and taught to search literature to be able to write a thesis protocol.

1st Year Objectives

The first year resident should be taught expertise in the management of ASA I and II cases. To start with they will observe and slowly become independent in giving general anaesthesia and spinal anaesthesia to ASA I & II cases for minor and major surgery, under graded supervision. They should be posted to the following specialties ~~doing~~ during the first year, gynecology, General Surgery, Orthopedic, ENT, Recovery Room, Urology.

2nd Year Objectives

The student should be taught to give general anaesthesia, regional anesthesia to ASA I, II, III & IV under supervision they should be able to give extradural block (EDB), Spinal Block, and Peripheral Nerve Blocks under supervision. Should learn pediatric and trauma life supports and maintain skills for basic and advanced cardiac life support.

It is advised that they may be posted in the following specialties Obstetrics, Dental Surgery, Eye, ICU, Pain Clinic and Peripheral Theatres.

The student should be able to ~~be able to~~ analyze data and write a thesis. Should be able to present scientific data.

3rd Year Objectives

The student should be able to plan and administer anaesthesia to all patients under graded supervision including patients for cardiac, Neurosurgery, Pediatric surgery and for all major surgery. The aim at the end is to be competent and independent soon after the third year of ~~junior~~ residency in providing anaesthesia to elective and emergency cases. The junior resident should be able to manage critically ill patient treat intractable pain. They should also know how to organize mass casualty. The curriculum should be able to provide 1 month of elective posting.

Minimum Procedures/Cases to entered in the log book.

Regional

SAB	=	30 SAB
EDB	=	30 including continuous EDB
Caudal	=	10
Sciatic/Femoral	=	5 + 5
Bier Block	=	5
Ankle Block	=	5
Stellate Ganglion	=	3 (observe)
Brachial Plexus	=	5 observe 10 do
Sympathetic Block	=	5 (Observe)
Trigger Point injection	=	5
Other peripheral N. Block	=	10
Ophthalmic Blocks	=	5 (observe)
Field Block	=	5

Anaesthesia for:

Open Heart	=	3 – 5 observe
Closed Heart	=	5 observe
Craniotomy	=	5 observe
Spinal Surgery	=	5 observe
Joint Replacement	=	5 observe
Anesthesia for organ transplant	=	5 observe (desirable)

Procedures

Internal Jugular Cannulation	=	5 + 5 do/observe
External Jugular Cannulation	=	5
Subclavian Vein Cannulation	=	5 + 5 do/observe
Peripheral Central Line	=	15 – ?X
Arterial Line Cannulation	=	10

Conduct of Cases

ASA I	=	100
ASA II	=	50
ASA III	=	30
ASA IV	=	10
Labour Analgesia	=	5
Organ Transplant	=	5 observe – ?

DETAILED CURRICULUM FOR POSTINGS

I. GENERAL GOALS OF ALL POSTINGS

II. Objectives:

A. Learn to perform preoperative evaluation

1. Learn to collect and synthesize preoperative data and to develop a rational strategy for the perioperative care of the patient. Outpatients: Develop skills in obtaining medical information from sources outside our institution, that is, other hospital and private physicians.
2. Learn a thorough and systematic approach to preoperative evaluation of patients with systemic diseases. Perform preoperative medical evaluations of patients undergoing many different types of operations, both of inpatients and outpatients but especially elderly patients with complex medical illnesses such as alcoholism, chronic obstructive pulmonary diseases, congestive heart failure, coronary artery disease, hepatic failure, hypertension, myocardial infarction, renal failure, and stroke etc.
3. Learn to prioritize problems and to present cases clearly and systematically to attending consultants.
4. Develop working relationships with consultants in other specialities to assist in preoperative evaluation.

Learn to get a good consultation.

5. Learn to interact with preopertive patients and develop effective counseling techniques for different anesthetic techniques and perioperative procedures. Learn to assess and explain risk of procedure and take informed consent.

B. Learn anesthetic techniques and skills and understant operate different equipment used by anaesthetist, develop optimum plans depending on patients condition Know the special considerations and techniques required to anesthetize patient in locations inside and outside of the operating room, for example, the Cardiac Catheteriza-tion Laboratory, Electroconvulsive Therapy, Genitourinary Clinic, Magnetic Resonance Imager, Radiology & Radiotherapy.

1. Perform the anesthesia machine check and prepare basic equipment necessary for all anesthetic cases.
2. Prepare drug table: select appropriate drugs for a case and develop a good system for arranging the drug and work tables.
3. Place standard monitors, for example, electrocardiogram, noninvasive blood pressure device, precordial stethoscope, neuromusclar blockade monitor, pulse oximeter, and capnograph.
4. Learn proper techniques of preoxygenation.
5. Learn how to induce anesthesia, both routine induction and rapid sequence induction, and the pertinent mechanical skills and choice of drugs
6. Perform airway management by knowing various procedures and equipment:

   They should know how to use/do

   i) Direct laryngscopy using curve and straight blade
   ii) Laryngeal mask airway

   They should be familiar with

   a. Fiberoptic techniques
   b. Light wand techniques
   c. Blind techniques
   d. Combitube
7. Failed Intubation or difficult airway algorithms
   a. All techniques for endotracheal intubation
   b. Additional techniques such as retrograde wire intubation and surgical cricothyroidotomy both of which will be learned on a mannequin.
8. Awake intubation
   a. Topical/Local anaesthesia for airway
   b. Airway nerve block, for example, superior laryngeal nerve and glossopharyngeal nerve block
9. Learn anesthetic maintenance: appropriate choice and use of anesthetic drugs and adjuvant drugs such as muscle relaxants and how to monitor their effects
   a. Assessment of Anesthetic depth.
   b. Assessment of volume status

c. Replacement of intraoperative fluid losses

d. Appropriate use of blood and blood products

e. Effect of different types of surgical procedures on anesthetic management, for example, effects of aortic cross-clamping

f. Appropriate use of intraoperative laboratory tests blood gas coagulation tests etc.

10. Become skilled in catheterizing or cannulating the following vessels for sampling blood, measuring concentrations or pressures, or administering drugs of fluids:
    a. Veins: all ages and all sizes
    b. Arteries: radial and other sites
    c. Central vessels: internal jugular, subclavian, and "long-arm" routes

11. Become skilled in using and interpeting the following routine noninvasive and invasive monitors intraoperatively and others:
    a. Electrocardiogram with ST-segment analysis
    b. Noninvasive blood pressure
    c. Capnograph: values and changes in values and waveform.
    d. Pulse oximetry: values and changes in values
    e. Neuromuscular blockade monitor
    f. Invasive arterial pressure: waveform and changes in the waveform
    g. Central venous pressure: values and waveform
    h. Pulmonary artery pressure: Values and waveforms, pulmonary capillary wedge tracing
        i. Cardiac output
        ii. Mixed venous oxygen saturation
        iii. Evoked potential
        iv. transesophageal echocardiography: basic understanding

12. Become skilled in techniques for regional anesthesia
    a. Brachial plexus blockade: interscalene, supraclavicular, axillary techniques with and without nerve stimulator for localization
    b. Spinal anesthesia (including continuous spinal where appropriate)
    c. Epidural anesthesia: lumbar, caudal, and thoracic.
    d. Lower extremity blockade: femoral, sciatic, and lateral femoral cutaneous nerves
    e. Upper extremity blockade: ulnar, median, and radial nerves
    f. Bier block
    g. Cervical plexus block

13. Become skilled in discontinuing anesthesia and monitoring emergence from anaesthesia
    a. Reversal of neuromuscular blockade

b. Determination of appropriate time for extubation

c. Monitoring of airway function during and after emergence

14. Become familiar with/skilled in perioperative pain management

a. Postoperative epidural infusion (opiates, local anesthetics)

b. Patient-controlled analgesia

c. Adjunctive nerve blockade

15. Become skilled in use of techniques for conscious sedation and monitored anaesthesia care

a. Selection of patients for conscious sedation

b. Selection of drugs for use in conscious sedation

c. Monitoring techniques helpful in controlling depth of sedation

d. Recognition of when conscious sedation has become unconscious sedation

16. Know how to successfully resuscitate, and develop skill of Basic Life support and Advance Cardiac Life support.

17. Work with other members of the OR team, including surgeons and nurses, to optimally care for surgical patients, especially develop communications skill.

09HLTH09AQ2-001-C ANAESTHESIA OUT SIDE OPERATING ROOM

1. Radiology and interventional neuroradiology: Know special anaesthetic considerations in these settings:

a. Dye allergies

b. Embolization

c. Examination for magnetic resonance imaging (MRI)

i. Monitoring

ii. Equipment options in the MRI suite

iii. General anesthetic/sedation techniques

2. Electroconvulsive shock therapy (ECT)

a. Preoperative

b. Anesthetic techniques and drug effects on seizure duration

c. Hemodynamic responses and appropriate treatment

3. Cardiac catheterization

a. Preoperative evaluation of children

b. Anesthetic consideration

i. Children

ii. Electrophysiologic tests/radiofrequency ablation Cardioversion

4. UROLOGY SERVICE (This service may be in OPD or OT)

Become skilled in anesthetic techniques applicable to the Genitourinary Clinic

a. Transurethral resection of the prostate: recognize and treat hyponatermia; know different anesthetic options and advantages and disadvantages of each

b. Irrigation fluid options: know advantages and disadvantages of each

c. Anesthetic techniques for extracorporeal shock wave lithotropsy

d. Anesthetic considerations for percutaneous placement of nephrostomy

III. Evaluation to Determine Goal Achievment

a. The resident will be evaluated every 3 months end posting by all attending consultants who worked with them.The attending physicians complete a Departmental Resident Evaluation Form, which is reviewed by the Clinical Competence Committee. informs them of any problems identified. and serious problems will be discussed with them immediately after they occur.

b. Residents will complete a log book. After each posting it will be checked and signed by the faculty concerned.

Trauma & Resuscitation

All residents must achieve basic and advanced cardiac life support, advanced trauma life support, and pediatric life support training. They should start with the training of Airway breathing circulation (ABC) training and master the skills repeatedly and then procedure to advanced life support.

I. GOALS OF TRAUMA/TRAUMATISED PATIENT AND DISASTER MAAGEMENT

a. Acquire Improve ability to evaluate & triage the patient and formulate anesthetic plans, especially in the trauma patient.

b. Acquire ability to administer operative anesthesia safely and rapidly.

c. Acquire ability to identify, prevent and care for postoperative complications.

A. Manage anesthesia for severely traumatized patients by doing the following as rapidly as possible:

1. Evaluation/documentation
2. Placement of intravascular catheters
3. Airway intubation
4. Choose among anesthetic options and induce and maintain anesthesia safely

09HLTH09A02-OD2EC POST ANESTHESIA CARE UNIT (PACU)

1. Goals

Understand the importance, purpose, and components of the anesthesia record and the report from the anaesthetizing anesthesiologist.

Use information about the patient that is received and observed on admission to the PACU and during care there for the following purposes:

1. To create a care plan
2. To score the patient's condition according to the Aldrete system
3. To assess the patient's recovery and condition for a safe discharge or transfer

Observe, recognize, and learn to treat the most commonly occurring problems likely to arise in the Postaanesthesia Care Unit (PACU). Understand the parameters patients must meet for safe discharge from the PACU to the following:

1. home
2. inpatient ward
3. intensive care unit

Detection of Hypoxemia and Oxygen therapy should be learned in this posting Should be recognize.

1. Airway integrity and compromise.
2. Arrhythmia
3. Hypertension
4. Hypotension
5. Pain prevention and relief.
6. Nausea and vomiting
7. Decreased urine output
8. Emergence delirium
9. Delayed emergence from anesthesia
10. Shivering
11. Post obstructive pulmonary oedema

III. Evaluation to Determine Goal Achievement (End posting summative)

09HLTH09A02-003-C

INTENSIVE CARE UNIT

I. Goals

Understand the spectrum of critical illnesses requiring admission to ICU recognize the critically ill patient who needs intensive postoperative care from the patient who does not require such care.

PRINCIPLES OF MANAGING A CRITICALLY ILL MEDICAL PATIENT

Cardiovascular

Recognition and acute management of Shock (all forms) Cardiac arrythmiasCardiogenic pulmonary edema Acute cardiomyopathies Hypertensive emergencies,myocardial infarction.

Respiratory

Recognition and acute management of Acute and chronic respiratory failure Status asthmaticus Smoke inhalation and airway burns Upper airway obstruction, including foreign bodies and infection Near drowning Adult respiratory distress syndrome. Use of Pulmonary function tests including bedside spirometer.

Renal

Recognition and acute management of Fluid and electrolyte disturbances.

Should be able to prescribe fluids in Renal failureAcid-basis disorders. Should be able to prescribe drugs based on Principles of Drug dosing in renal failure Should know when to use Dialysis/hemofiltration.

Central Nervous System

Recognition and Acute management of Coma. Drug overdose know Glasgow Coma Scale Metabolic and Endocrine.emergencies like Diabetic ketoacidosis Hypoadrenal crisis. pheochromocytoma.

Infectious disease

Recognition and acute management of hospital acquired and opportunistic infections. including acquired immunodeficiency syndrome. Should know how to protect against cross infection Infection risks to healthcare workers.

Hematologic disorders

Recognition and acute management of Defects in hemostasis Hemolytic disorders should be able to prescribe component therapy based on the results of Coagulation profile.

Thrombotic disorders sould be able to diagnose Deep Vein thrombosis and know Principles of Anticoagulation and fibrinolytic therapy.

Know the indications of Plasmapheresis for acute disorders. including neurologic and hematologic. diseases.

Gastrointestinal disorders

Sould be able to recognize and manage Gastrointestinal bleeding hepatic failure should be able to prescribe prophylaxis against stress ulcer bleeding.

A. Should be able to do the following (ideally) at the end of the posting:
   1. Radial arterial catheters and other sites as necessary
   2. Central venous catheters
      a. Subclavian route
      b. Internal or external jugular route
   3. Pulmonary artery (PA) catheters (Observe only)

B. Understand and interpret the following PA catheter variables. initiate appropriate therapy in response to changes in them:
   1. PA waveform
      a. Normal
      b. Pathologic
      c. PA wedge
   2. Mixed venous oxygen saturation
   3. Right ventricular ejection fraction
   4. Thermodilution cardiac output
      a. Technological basis for cardiac output measurements
      b. Factors producing errors in cardiac output measurements

C. Manage cardiovascular instability
   1. Know different fluid therapy options and when to use them
   2. Know the different inotropic drugs and when to use them
   3. Know how to use invasive monitoring devices to guide therapeutic use of fluids and inotropic drugs

D. Manage respiratory failure and postoperative pulmonary complications
   1. Know how to use arterial blood gas and ventilatory variables to evaluate postoperative patients with respiratory failure
   2. Understand the operation of mechanical ventilators including different ventilatory modalities and how each is best used for management of respiratory failure and noninvasive) including modes complications and modes of weaning

      Principles & application of Oxygen therapy.

E. Pathophysiology and Clinical manifestation of septicemia and its treatment
   1. Recognize sepsis in the postoperative patient including all the typical hemodynamic findings
   2. Know the appropriate tests to diagnose sepsis. including diagnostic tests
   3. Use various monitoring devices to assist in managing sepsis: specifically understand the optimization of oxygen delivery to tissues in the septic patient and the appropriate management of fluids and vasopressors to accomplish these goals.
   4. Know the different classes of antibiotics and antifungal agents and their use in treating sepsis

F. Deliver appropriate nutritional support
   1. Learn about the use of enteral nutrition in the patient who cannot tolerate input per os
   2. Learn about the use of parenteral nutrition in the critically ill surgical patient
   3. Interact with nutrition support services in planning nutrition for the critically ill patient

G. Provide effective pain management and sedation postoperatively
   1. Learn the appropriate use of pain management modalities in the ICU including:
      a. Patient-controlled analgesia
      b. Epidural and subarachnoid narcotics
   2. Learn the use of sedative/hypnotic drugs in the ICU for:
      a. For Patient on Ventilator

Principles of Transplantation

Care of Immunosuppression Infections in the immunocompromised patient Should know Organ rejection.

Monitoring and Biostatistics

Should be able to use Prognostic indices such as acute physiology and chronic health evaluation. therapeutic intervention scoring system and know the concept of audit

Ethical and legal aspects of critical care

Know the legal importance of documentation of recordkeeping + communication

Should be able to take informed consents, not resuscitate orders: (DNR) withdrawing of therapy

Psychosocial Issues

Should be able to communicate with distressed relatives

Should be able to give the correct picture of a critical patient, but with compassion in view of critical nature of the illness

Should be able to Transport a critically ill patient/ resuscitate patient with acute traumatic injury

PEDIATRIC TRAINING

Sould be able to

Recognize and manage cardiovascular and respiratory failure in a critically ill child

Evaluate manage the critically ill neonate /infant / child

Prescribe appropriate dose of all drugs and fluid and electrolytes in a child

Core procedural skills for residents. In addition to practical training in the following procedural skills, the resident must have an understanding of the indications, contraindications, complications & pitfalls of these interventions. Due to the variability of individual training programs, practical experience may be limited for some procedures

Cardioversion

Pulmonary artery catheterization

Trancutaneous pacing

Draining of tension Pneumothorax

Insertion of chest drain

Conventional and Percutaneous Tracheostomies

09HLTH09A02-004-C CARDIOVASCULAR ANESTHESIA

I. Goals

A. Understand cardiac physiology Develop knowledge of cardiovascular anesthesia (anesthesia for the patient with cardiovascular disease). Choose appropriate anesthetic techniques for patients with different types of cardiovascular disease and the skills for lifelong continuing education

B. Develop technical and monitoring skills necessary for cardiovascular anesthesia

C. Administer anesthesia for a wide variety of cardiothoracic Cases and develop interest in further learning

D. Perform a thorough preoperative assessment of the patient undergoing cardiovascular surgery

E. Know intraoperative anesthetic management for the patient undergoing cardiopulmonary bypass. Know how cardiopulmonary bypass is instituted and discontinued Understand cardiopulmonary bypass and discuss the mechanical aspects of it as follows:

1. Different types of pumps - pulsatile and nonpulsatile
2. Physiology of hypothermia and cardiac and cerebral protection
3. Effects of bypass on volumes of distribution and clearance of anesthetic drugs and anesthetic maintenance, including amnesia

D. Know how and why to use of inotropic support, vasodilators, and antiarrhythmic drugs that may be necessary before but are especially necessary after cardiopulmonary bypass

E. Develop and understanding of the major issues involved in the perioperative care of the child with congenital heart disease

B. Insert vascular catheters or cannulas for adult and pediatric patients and obtain measurements from them as follows:

1. Arteries

Internal jugular vein and the subclavian vein

Pulmonary artery (Swan-Ganz) catheters and initiate appropriate therapy in response to changes in the following pulmonary artery (PA) variables:

a. Waveform

b. Normal tracing

c. Pathologic tracing

c. Pulmonary artery wedge tracings

2. Mixed venous oxygen saturation

3. Theromodilution cardiac output

observe/know about a Transesophageal echocardiograpy (TEE) probe and interpret TEE images

F. Manage care during cardiac surgery as follows:

1. Blood replalcement

2. Monitoring the effect of heparin

3. Postcardio:ulmonary bypass coagulopathy

Rationale for various therapies such as aprotinin designed to prevent

Coagulopathy

G. Know following procedures and anesthetic implications:

1. Aortic repairs

2. Congenital repairs - pediatric

3. Coronary artery bypass grafting and valves - adults

4. Electrophysiology

5. Thoracic surgery

6. Transplantation - heart and lungs

H. Work as a team member with fellow anesthesiologists, surgeons, perfusionists, and nurses

I. Maintain good clinical judgment under stress and act quickly and accurately in diagnosis, interpretation, and treatment of intraoperative problems

Evaluation to Determine Goal Achievement.

09HLTH09A02-005-C

NEUROANESTHESIA

I. Goals

A. Administer anesthesia safely to patients with neurologic disease who are undergoing neurologic or non-neurologic surgery, diagnostic procedures requiring anesthesia, or nonsurgical interventions requiring anesthesia.

B. Understand the basic concepts of central nervous system (CNS) physiology as they relate to neuroanesthesia, specifically, mastery of autoregulation of blood flow, blood flow response to CO2, blood flow response to cerebral oxygen ($CMRO_2$) and glucose (CMRglu) metabolic rates, and cerebrospinal fluid physiology.

C. Know the effect(s) of commonly used anesthetic agents and adjuvant agents, for example antihypertensives, on cerebral physiology.

D. Understand the anesthetic implications of the most common neurosurgical procedures, that is, what is likely to happen during neurosurgery that will affect anesthetic management.

E. Understand the basic concepts behind electrophysiologic monitoring of the brain and spinal cord.

F. Understand how concurrent medical illnesses affect anesthesia during neurologic surgery.

II. Objectives

A. Review the medical history and physical examination of patients; assess their major neurosurgical problem. Evaluate the patients Glasgow Coma Scale as well as other medical problems that may affect anesthetic care; and know what information about nervous system function and pathology as important to the anesthesiologist.

1. Recognize both the adult and pediatric patient with poor elastance of increased intracranial pressure (ICP).
2. Evaluate the patient with subarachnoid hemorrhage and intracranial aneurysm by means of the Hunt-Hess and Fischer gradings systems; recognize preoperative vasospasm; and anticipate which patients are likely to require special techniques such as barbiturate protection, hypotension, induced hypertension, or temporary vessel occlusion.
3. Differentiate between radiculopathy and myelopathy and understand the anesthetic implications of each, that is, which patients require awake intubation and positioning.
4. Know the basic differences between the following types of brain, spinal cord, and metastatic tumors of the CNS and their association with edema and intraoperative blood loss. Know the anesthetic implications of:

   a. Acoustic neuroma, Ependymoma, Gliomas, Meningioma, Pituitary tumours

   Understand the following different types of spinal operations as well as their anesthetic implications:

      a. Anterior cervican discectomy and fusions, anterior cervial corpectomies, posterior cervical fusions, laminectomies, and foramenotomy, Laminectomies for excision of spinal cord tumors, both intrameullary and extramedullar, Lumbar laminectomies, microdiscectomies, corpectomies, and fusions with instrumentatio, Thoracic laminectomies and discectomies.

6. Anticipate premedication for and anesthetic considerations during electrocorticography
7. Anticipate airway and sedation requirements for stereotactic neurosurgical procedures conducted with either general anesthesia or monitored anesthesia care

Perform the following specific procedures and monitoring techniques necessary to care for the neurosurgical patient.

1. Choose appropriate premedication and agents for anesthetic induction and maintenance based on a knowledge of their effects on cerebral physiology and on neuropathology
2. Choose and place the following monitors and monitoring devices for use during spinal and intracranial surgery:
   a. Arterial line, central venous (CVP) or pulmonary artery (PA) pressure catheters by all approaches, especially the basilic or cephalic veins
   b. observe/know about Precordial Doppler and interpretation of sounds
3. Perform techniques for awake intubation and positioning of the neurosurgical patient with either an unstable neck or myelopathic signs and symptoms
   a. Assess when awake intubation and positioning are needed
   b. Intubate an awake patient such that coughing or movement are minimal
   c. Master anesthesia for awake intubation, including but not limited to, superior laryngeal and glossopharyngeal nerve blocks and transtracheal injection of lidocaine
4. Detect and treat air embolism during neurosurgery:
   a. Know use of monitors to detect air embolism and what monitoring patterns are associated with air embolism.
   b. Recognize the relative risks of different procedures and positions for air embolism.
5. Know general priniciples of positioning the patient for neurologic surgery and the advantages and disadvantages of each position:
   a. Lateral
   b. Prone
   c. 3/4 prone
   d. Supine-head turned
   e. Sitting - theoretical knowledge only because this position is no longer used at our institution
6. Know anesthetic effects on the electroencephalogram (EEG) and evoked potentials and basic implications of and appropriate responses to changes in each.
7. Understand the basic indications and techniques, and, if possible, perform the following special procedures used during neuroanesthesia:
   a. Induced hypotension
   b. Induced hypertension
   c. Moderate Hypothermia

   Barbiturate cerebral protection, Cardiopulmonary bypass and circulatory arrest — theoretical knowledge only in most instances.
8. Know the differential diagnoses and treatment alternatives of intraoperative intracranial hypertension ("tight brain").
9. Reverse general anesthesia rapidly with a minimum of hemodynamic change to allow early postoperative assessment of the patient and recognize when failure to emerge from anesthesia is not likely an anesthetic effect.
10. Know the management of Head Trauma, and its anesthetic management

III. Evaluation to Determine Goal Achievement

A. Preparation for case and ability to carry out plan discussed the night before:

1. Recognition of intraoperative problems and communication with the attending; ability to appropriately respond to changing clinical situation; clinical judgment
2. Mechanical skills of placing lines and positioning the patient
3. Application of basic and clinical science knowledge and skills to the neurosurgical patient

B. The neuroanesthesia group will meet at the conclusion of each rotation and an overall performance evaluation will be made based on the above criteria ED.

09HLTH09A02-006-C PAIN MANAGEMENT

Acute postop pain management.

I. Goals

A. Differentiate among the different chronic pain states, for example, reflex sympathetic dystrophy and neuropathic or myofascial pain, and know what treatments are effective for each.

B. Know the types of drugs that relieve pain and their efficacy, indications, side effects and contraindications and use.

C. Know the laboratory tests, radiologic studies, and psychological tests used to help differentiate chronic pain syndromes.

D. Learn to perform a thorough, directed history and physical examination, which will emphasize and facilitate the diagnosis of different pain states.

E. Know the multidisciplinary approach to pain management.

F. Know when it is appropriate to refer patients to different specialists for definitive or adjunctive therapy, for example, neurosurgery, orthopedic surgery, neurology.

G. Manage acute and perioperative pain syndromes proficiently.

II. Objectives

A. Learn the anatomy of the sympathetic nervous systems, specifically, the anatomy of the epidural and subarachnoid spaces and the location of sympathetic and parasympathetic ganglia

B. Perform blocks and techniques in administering them that are commonly used to manage acute and chronic pain as follows (Please note: Some of these blocks may not be performed in a given month because of the patient population available during that month):

1. Epidural steroid injuction (all levels)
2. Long-term epidural catheterization — ?
3. Blocks Should observe and know about the following blocks:
   a. Celiac plexus
   b. Infraorbital nerve
   c. Intercostal nerve
   d. Lumbar sympathetic
   e. Stellate ganglion
   f. Facet blocks — ?

4. Complications associated with each blocks and appropriate treatment of each

C. Know the cutaneous dermatomal mappings

D. Diagnose myofascial pain syndromes and perform trigger point injections

E. Know the different modalities of physical therapy that may relieve both acute and chronic pain and learn how to obtain such therapy

F. Know the indications for stimulation techniques such as transcutaneous electrical nerve stimulation (TENS), dorsal column stimulation, and deep brain stimulation

G. Know the acute pain and cancer pain guidelines:

1. Treatments the WHO Treatment Ladder
   - a. Drugs: analgesics, opiates, sedatives, and stimulants
   - b. Nerve blocks
   - c. Neruolysis, surgical and chemical
2. Routes of administration and risk and benefits of each epidural
   - a. Intramuscular
   - b. Intrapleural
   - c. Intravenous
   - d. Oral
   - e. Patient controlled
   - f. Subcutaneous

H. Diagnose and know how to treat the following pain syndromes:

- a. Diabetic neuropathy
- b. Inflammatory states such as bursitis, carpal tunnel syndrome, skeletal pain, and tendonitis
- c. Phantom limb pain
- d. Post-herpetic neuralgia
- e. Reflex sympathetic dystrophy
- f. Trigeminal neuralgia
- g. Low back pain

III. Evaluation to Determine Goal Achievement

09HLTH09A02-007-C

PEDIATRIC

I. Goals

A. Administer anesthesia safely for routine surgical, diagnostic, and therapeutic procedures.

B. Recognize and treat postanesthesia problems

C. Recognize when you or your institution cannot provide adequate care for a particular problem

II. Objectives

A. Preoperative

Neonatal anatomy and physiology applied to conduct of anesthesia.

1. Review the chart, take an adequate history, assess the major systemic problems, identify special problems such as latex allergy or apnea related to prematurity, and develop a plan of care.
2. Recognize and cope with the emotional problems of parents and child, and attempt to alleviate them.
3. Know the priniciples of and medications used for preoperative sedation.
4. Induce anesthesia in an distraught or uncooperative child.
5. Recall and state the anatomic, physiologic, and pharmacologic differences and similarities in the major organ systems between children and adults.
6. Transport safely a sick pediatric patient to the operating room and be able to state and perform the solutions to any problems which may arise in the following areas:
   a. Heat maintenance
   b. Cardiovascular stability
   c. Ventilation
   d. Oxygenation
7. Record and estimate preoperatively blood volume, hourly fluid requirements, estimated fluid deficit, third space loss, red cell mass at the patient's hematocrit, acceptable red cell mass loss, and acceptable blood loss.

B. Intraoperative

1. Know appropriate endoracheal tube sizes - cuffed and uncuffed.
2. Induce and maintain anesthesia by inhalation, intravenous, intramuscular, and rectal routes and know the differences in effects of various anesthetics between adults and pediatric patients.
3. Administer mask or laryngeal mask airway anesthesia when appropriate.
4. Maintain the airway of an anesthetized pediatric patient and intubate the trachea without trauma in 98% of cases within 1 minute.
5. Perform awake intubation.
6. Recognize abnormal airways and maintain them during anesthesia.
7. Describe the appropriate management of laryngospasm.
8. Recognize the following signs of hypoxias: bradycardia, poor color, poor venous filling, distant heart tones, and abnormal elctrocardiogram.
9. Understand the various forms of breathing circuits used in pediatric anesthesia and them appropriately.
10. Apply consistently and interpret data from a blood pressure cuff, electrocardiogram, oximeter, capnograph or mass spectrometer, and a thermistor.
11. Know the indications of use of a heat lamp and heated humidifier when appropriate Answer questions concerning the importance of thermoneutrality in pediatric by demonstrating the use and abuse of the followi.ng. Heat lamp.b. Heat blanket. Heat humidifier. Room temperature.
13. Master the techniques of halothane and isoflurane/nitrous oxide/oxygen/muscle relaxant anesthesia.
14. Determine and discuss when deep or awake extubation is appropriate and apply the proper approach.
15. Understand and apply the basic concepts of neuromuscular blockade in children, know when anesthesia is adequately reversed, and know the differences between dose/effect in infants and children as compared to adult patients.

16. Apply the priniciples of fluid and blood replacement during anesthesia.
17. Understand the benefits and risks of regional anesthesia, including spinal anesthesia and regional analgesia for postoperative pain.

C. Postoperative

1. Transport safely and manage immediate postoperative care in the following areas: ventilation, oxygen administration, temperature control, cardiovascular monitoring, fluid balance, and pain relief.
2. Recognize postoperative croup and treat it.
3. Understand postanesthesia apnea, factors associated with it, the appropriate duration of monitoring, and treatment.

D. Special problems

1. Manage the following in pediatric patients undergoing anesthesia and surgery:
   a. Blood replacement
   b. Drug administration and anesthetic requirement (minimum anesthetic concentration)
   c. Fluid and electrolyte balance, glucose requirement, and renal maturation
   d. Hypocalcemia
   e. Hypoglycemia
   f. Metabolism
   g. Temperature control
   h. Vitamin K administration
2. Care of patients in the following special circumstances:
   a. Special problems
      i. Congenital heart disease
      ii. Epiglottitis
      iii. Malignant hyperyrexia
      iv. The child with the anatomically difficult airway (e.g. Pierre Robin syndrome)
   b. Special procedures
      i. Bronchoscopy (in particular for foreign body aspsiration)
      ii. Tonsillectomy (in particular for the rebleeding tonsil)
      iii. Computerized axial tomographic scan and magnetic resonance imaging
3. Know and experience management of a pediatric patient with a full stomach
4. Identify the following various problems in pediatric patients and handle them:
   a. Diaphragmatic hernia
   b. Omphalocele and gastroschisis
   c. Pierre-Robin syndrome
   d. Pyloric stenosis
   e. Tracheoesophageal fistula
5. Understand pediatric resucitation, drugs and doses used for it, and defibrillation

III. Evaulation to Determine Goal Achievment

09HLTH09A02-008-C OBSTETRIC

I. Goals

A. Learn how the physiology of normal pregnancy alters the response to anesthesia
B. Learn pertinent aspects of fetal and placental physiology
C. Learn what obstetricians may require from anesthesiologists
D. Learn how pregnancy creates special problems for the anesthesiologist learn the nature of high-risk obstetrics and how special medical problems alter the approach to obstetric anesthesia
E. Participate in morbidity mortality conference and ongoing research

II. Objectives

F. Learn how to evaluate the neonate and principles of neonatal resuscitation
G. Learn how drugs affect the neonate
H. Learn how to communicate effectively with obstetricians and with labor and deliver nurses.
A. Obtain pertinent information from the history and physical examination of the obstetric patient to assess major systemic problems
B. Understand obstetric physiology and pharmacology as follows:
   1. Alteration of maternal physiology during pregnancy
   2. Effects fo anesthesia, both general and regional, on human uteroplacental blood flow and of adjunctive medications such as vasopressors and vasodilators on uterine blood flow
   3. Perinatal pharmacology and placental transfer of drugs
   4. Effects of epidural and systemic medications on labor and delivery
   5. Learn all anesthetic techniques suitable for managing normal labor pain including:
      a. Epidural local anesthesia
      b. Epidural opiate anesthesia
      c. Inhalation analgesia
      d. Intravenous analgesia
C. Understand epidural and spinal analgesia and anesthesia as follows:
   1. Anatomy and physiology of the epidural space and spine
   2. Techniques of needle placement including midline and paramedian approaches
   3. Pharmacology of local anesthetics
   4. Complications and side effects
D. Know common problems encountered in continuous epidural infusion and how to prevent and treat them
E. Know how to use of intraspinal opiates in obstetrics:
   1. Physiology and pharmacology

2. Benefits for labor, deliver and postoperative pain
3. Side effects

F. Understand the advantages of regional and general anesthesia for cesarean section

G. Know the risk factors, prevention, and treatment of maternal aspiration

H. Evaluate difficult airways and know how to prevent the problems associated with them and to manage failed intubation

I. Be familiar with recent advances in obstetric anesthesia
1. The effect of epidural anesthesia on labor and deliver
2. Drug interaction
3. The epidural test dose
4. Anesthesia for pre-term delivery

J. Recognize high-risk factors in obstetric patients and how they affect anesthetic management as follows:
1. Morbid obesity and anesthesia: Problems and management
2. Preeclampsia: Basic considerations and controversy in management
3. Neurologic disease and pregnancy

K. Understand anesthetic choices for the pregnant patient with heart disease

L. Identify and manage common medical emergencies in the post-parturient

M. Know how the late 20th century social problems affect anesthetic care, such as perinatal human immunodeficiency virus infection and maternal substance abuse

N. Manage maternal anesthesia and the stressed fetus

O. Know current fetal monitoring techniques and how to interpret the information they provide

III. Evaluation to Determine Goal Achievement

09HLTH09A02-009-C

REGIONAL ANESTHESIA

I. GOALS

A. To teach anesthesia residents the art and sciences of regional anesthesia understand the anatomy, pathophysiology, and appropriate management of complications and side effects of regional anesthetic techniques. - the test doses; total spinal, subdural blocks - assessment and treatment; Risks of spinal, epidural hematoma and abscess - assessment and treatment; Postdural puncture headache - assessment and treatment; Pneumothorax- assessment and treatment; Physiologic side effects: sympathectomy, phrenic nerve block, intercostal nerve block - assessment and treatment; Peripheral nerve injury - assessment and follow up.

B. To understand general priniciples of local anesthetic pharmacology, including the pharmacodynamics and pharmacokinetics of various local anesthetics. This includes onset duration, motor/sensory differentiation, and toxicity profile of various local anesthetics and allergy its treatment:

C. To understand the principles and indications for various local anesthetic adjuvants including:

Epinephrine. phenylephrine. narcotics. sodium bicarbonate. carbonation. hyaluronidase. alpha agonists. anticholinesterases.

D. To be familar with the relevant anatomy for regional techniques. including: Spinal canal and its contents. neural plexuses of the limbs. major autonomic ganglia.

E. Be familiar with the physiologic changes associated with spinal and epidural anesthesia.

F. Understand the indications for and the contraindications to regional anesthetic techniques including central neuraxis blocks. peripheral nerve blocks. sympathetic nerve blocks.

B. COGNITIVE SKILLS

At the compleltion of this rotation residents should be able to demonstrate the following skills.

1. Rational selection of regional anesthesia technique and choice of local anesthetic for particular patient encounters.
2. Ability to assess adequacy of regional anesthesia before the start of surgery. and demonstrate appropriate plans for supplementation of inadequate blocks.
3. Provide effective anxiolysis and sedation of patients by both pharmacologic and interpersonal techniques.
4. Select appropriate monitors for specific patient encounters. and document performance of regional anesthetic adequately.

III. EVALUATION TO DETERMINE GOAL ACHIEVEMENT

SKILLS SHEET FOR RESIDENTS ON THE REGIONAL ANESTHESIA ROTATION

Demonstrate ability to perform/familiarity with the following regional anesthesia techniques:

- Brachial plexus blockade
- sciatic nerve block
- femoral nerve block. o or 3-in-1 block
- Caudal block – adult and peadiatric
- ankle block
- epidural block/Catheter
- spinal subarachnoid block
- Biers block
- others

OBJECTIVES OF DENTAL ANESTHESIA

Understand the principles of conscious sedation

Principles of anesthesia in a dental Chair

Local Blocks For Dental Surgery

OBJECTIVES OF TRANSPLANT ANESTHESIA

Know the basic Principles of anesthetizing An immunocompromised Patient Principles of anesthetising patient with end stage renal/liver disease Warm/Cold ischemic Time

OBJECTIVES FOR OPHTHALMOLOGY POSTING

1. Give anesthesia for intra and extraocular surgery
2. To anesthetize premature babies for ROP surgery.
3. To give Monitored Anesthesia Care to learn to sedate patients for MAC
4. To give Ophthalmic nerve blocks.

OBJECTIVES FOR ENT POSTING

1. To give topical anesthesia for awake intubation.(nasal and oral)
2. To give local block for Tonsillectomy
3. Local anesthesia for tracheostomy..
4. Local block for thyroid surgery TO give anesthesia for MLS
5. To give anesthesia for Laser surgery of airway.
   To give anesthesia for vascular malformations /tumours of noses

APPENDIX — I

Text books:

1. Miller RD. ed. Anesthesia. 5th ed.
2. Wylie Churchill Davidson
3. Nunn and Utting
4. Stoelting RK. Miller RD. eds. Basics of Anesthesia

APPENDIX (CARDIAC)

Text books:

1. JA Kaplan: Cardiac Anesthesia J Benum of: Anesthesia for Thoracic Ssurgery
   C Lake: Pediatric Cardiac Anesthesia

APPENDIX (NEURO ANAESTHESIA)

Text books include:

1. Cucchiara and Michenfelder: Clinical Neuroanesthesia. Churchill-Livingstone
2. Cottrell and Smith: Anesthesia and Neurosurgery. 3rd ed. CV Mosbyd
3. Millelr: Aanesthesia. 4th ed. Churchill-Livingstone: chapters 21. 38. and 56
4. Kirby and Gravenstein: Clinical Anesthesia Practice. WB Saunders: chapters 22. 4. and 73
5. Russell and Rodichok: Primer of Intraoperative Neurophysiologic Monitoring. Butterworth and Heinemann

APPENDIX (PEADIATRIC ANAESTHESIA)

Text books:

1. Gregory GA: Pediatric Anesthesia, 2nd ed
2. Steward D: Handbook of Pediatric Anesthesia, MD

APPENDIX (ICU)

1. ICU Book Paul Marino
2. Critical Care by Joseph Civetta, Robert W Taylor and Robert Kirby publisher Lippincott

APPENDIX (PAIN)

1. Bonica: The Management of Pain
2. Cousins and Bridenbaugh: Neural Blockade in Pain Management
3. Raj: Practical Management of Pain

ASSESSMENT METHODS

Assessment is a vital part of any course and it is element where there is frequently considerable doubt. There are 2 major components:

A) Formative Assessment: Ongoing evaluation during the course – During each posting/ Module/ End Unit

B) Summative Assessment: Final assessment after 3 years and/at the end of each semester Assessment

FORMATIVE ASSESSMENT/(Ongoing Evaluation)

Formative assessment will be conducted during each posting/module/unit. This will include the following:

TECHNICAL SKILLS COMPETENCY EVALUATIONS:

Methods to be used

1) Performing anaesthetic management on real patients (check lists of each skill and competency including log book evaluation)
2) Simulators
3) Objective Structured Clinical Examination (OSCE)

This evaluation will be done either in the OT or ICU or PAC or Postoperative wards.

PROBLEM SOLVING CASES:

Method to be used

1) Case presentations (evaluation by Peers)
2) Simulated case cards

3) OT discussions
4) OSCE

ORAL SKILLS – Attitudinal Development:

Method to be used
1) Ability to present seminars, discussion in class room (evaluation by Peers)
2) Talking to patients in pre-anaesthesia rounds
3) Operation theatre Management

CARDIOPULMONARY RESUSCITATION:

Method to be used
1) Mannequins demonstration
2) Check lists for evaluation
3) OSCE

C P R evaluation will be repeated at the end of each semester

SUMMATIVE ASSESSMENT (FINAL ASSESSMENT) and End Semester assessment

1) THEORY (Subject contents already outlined in curriculum)

Should consist of

a) Structured Essay Questions (SEQs) .
b) Short Answer questions (SAQs) minimum of 10 SAQs will be Mandatory (in all four papers taken together)
c) Problem Solving Questions ,
d) Multiple choice Questions (MCQs) MCQs of different types Shoule be included atleast in one of the 4 papers. The use of MCQs is recommended for formative/end semester evaluation.

Final Theory papers: 4 Papers

		Marks
Paper I	Basic Sciences as applied to Anaesthesiology, including ethics, statistics. Quality assurance, medicolegal Aspects.	100
Paper 2	Anaesthesia in relation Associated Systemic	100
Paper 3	Anaesthesia in relation to subspecialities such As cardiac, neuro, obstetrics and pediatrics etc.	100
Paper 4	Intensive care Medicine, Pain Medicine and Recent advances in Anaesthesiology	100

2) PRACTICAL

4 components: Marks

The practical examination should be structured and objective as possible

	1 long case	40 min	100
A) Clinical Cases			
	2 Short cases	15 min each	40 each

Structured Assessment (Long Case)

1.	Oral skills/presentation	10
2.	Diagnosis/investigations	10
3.	Preanaesthetic Preparation	20
4.	Anaesthetic management	40
5.	Post operative complications & management	20
B)	**OSCE:** At least 10 OSCE stations with checklists For objective assessment marks	20

C) VIVA-VOCE (Structured)

		TOTAL MARKS: 200
1.	Problem solving situations	40
2.	Drugs/Anaesthetic	40
3.	Equipments for Anaesthesia/In. Care	40
4.	Investigations}ECG/Xrays/MRI Endoscopy etc.	40
D) 1.	**CPR** Assessment on Mannequins	40

	Total Marks
Theory (Papers 1-4)	400
Practical (Cases, OSCE, Viva Voce)	400
Grand Total	**800**

The candidate will be required to secure minimum 50% marks in theory and 50% marks in clinicals and viva-voce separately, which is mandatory for passing the whole examination. Candidate failing in theory will not qualify to take practical examinations. There should be enough gap between theory and practical Exam. As recommended by MCI rules.

Final Assessment Marks Weightage

30% : Internal (Formative) Assessment & Thesis

70% : Summative Assessment

The committee recommends that three external and three internal examiners should conduct the clinical examination. A maximum of 4 candidates should be examined per day and if there are more than 4 candidates the examination should be conducted on 2 consecutive days.

THESIS

Objectives

1. The student would be able to demonstrate capability in research by planning and conducting systematic scientific inquiry & data analysis and deriving conclusion.
2. Communicate scientific information for health planning.

Guide for thesis

1. Chief guide will be from the department of Anaesthesiology
2. Co-guide(s) will be from the department or from other disciplines related to the thesis.

Submission of thesis protocol

It should be submitted at the end of six months after admission in the course.

1. Protocol in essence should consist of:
   a. Introduction and objectives of the research project.
   b. Brief review of literature.
   c. Suggested materials and methods, and (scheme of work)
   d. Statistician should be consulted at the time of selection of groups, number of cases and method of study. He should also be consulted during the study.
   e. Bibliography
2. The protocol must be presented in the department of Anaesthesiology before being forwarded to the Research Committee of the Institute.
3. Protocol will be approved by the research committee appointed by the Dean/Principal to scrutinise the thesis protocol in references to its feasibility, statistical validity, ethical aspects, etc.

Submission of thesis

1. The thesis shall relate to the candidate own work on a specific research problem or a series of clinical case studies in accordance with the approved plan.
2. The thesis shall be written in English, printed or typed on white bond paper 22 × 28 cms with a margin of 3.5 cm, bearing the matter on one side of paper only and bound with cloth/rexine, with the title, author's name and the name of the College printed on the front cover.
3. The thesis shall contain: Introduction, review of literature, material and methods, observations, discussions, conclusion and summary and reference as per index medicus.

Each candidate shall submit to the Dean four copies of thesis, through their respective Heads of the Departments, not later than six months prior to the date of commencement of theory examination in the subject.

Evaluation of thesis

1. The thesis shall be referred by the University evaluation to the Examiners appointed by the University. The examiners will report independently to the Controller of Examinations and recommend whether the thesis is-

a) approved

b) returned for improvements as suggested or

c) rejected

2. The thesis shall be deemed to have been accepted when it has been approved by atleast two external examiners and if the thesis is rejected by one of the external examiners it shall be referred to another external examiner (other than the one appointed for initial evaluation) whose judgement shall be final for purposes of acceptance or otherwise of the thesis.

3. Where improvements have been suggested by two or more of the examiners, the candidate shall be required to re-submit the thesis, after making the requisite improvements, for evaluation.

4. When a thesis is rejected by the examiners, it shall be returned to the candidate who shall have to write it again. The second thesis, as and when submitted shall be treated as a fresh thesis and processed.

5. Acceptance of thesis submitted by the candidate shall be a pre-condition for his/her admission to the written, oral and practical/clinical part of the examination.

   Provided that under special circumstances if the report from one or more examiners is not received by the time, the Post-graduate examination is due, the candidate may be permitted provisionally to sit for the examination but the result be kept with held till the receipt of the report subject to the condition that if the thesis is rejected then the candidate in addition to writing a fresh thesis, shall have to appear in the entire examination again.

6. A candidate whose thesis stands approved by the examiners but fails in the examination, shall not be required to submit a fresh one if he/she appears in the examination in the same branch on a subsequent occasion.

TMC

MEDICAL ONCOLOGY — D M

(Program Code: HLTH10A01)

INTRODUCTION

The practice of oncology is in a period of significant change. There is an expansion of new information regarding the molecular and cellular biology, immunology and biochemistry of cancer and a steady increase in our ability to more effectively diagnose and treat human malignancies. 'Medical Oncology' as a specialty has assumed immense importance. Institute Rotary Cancer Hospital, All India Institute of Medical Science is one of the few centers in India that provides the prestigious postgraduate super specialty course-DM Medical Oncology. It is important that the candidates interested in pursuing their career in medical oncology, besides a good clinical acumen, possess a sound understanding of the related basic sciences. They should be able to comprehend the essentials of molecular biology, genetics, signal transduction and immunology and translate the knowledge into clinical practice.

GOAL OF THE PROGRAM

To ensure adequate supply of medical oncology experts who assume leadership role in their fields.

AIMS OF THE PROGRAM

To produce a medical oncologist who:

1. Is capable of providing an excellent patient care
2. Possesses adequate knowledge base (both basic and applied) to effectively interact with medical colleagues in a wide range of disciplines.
3. Is a good researcher
4. Is a competent teacher

OBJECTIVES AND GUIDELINES TO THE CONDUCT OF PROGRAM

It is a 3-year course that imparts intense training to DM candidates into the field of medical oncology and related subjects with adequate exposure to clinical and laboratory based activities.

CLINICAL TRAINING

The objectives of the clinical training are:

1. To develop clinical judgment and technical skills in diagnosis and the total management of patients with neoplastic diseases, with various modalities of treatment individually or in combination

2. To make the student expert in handling all kinds of medical emergencies arising either due to cancer spread or problems related to therapy. The latter include: a) infections secondary to severe neutropenia, leading to respiratory distress/failure, renal insufficiency, hepatic insufficiency, and neurological disturbance, b) hemorrhagic complications, c) electrolyte disturbance, d) other toxicities.

3. To impart full knowledge concerning cancer chemotherapy, hormone therapy, biologics, gene therapy, immune therapy; their mechanism of action, side effects, mode of administration, inter-relation with other drugs and their therapeutic effects.

4. To make the candidate familiar with all the modern diagnosis aids including ultrasound, CT scan, NMR, MRI, PET scans, mammography, endoscopy, and radinuclide scans.

5. To make the candidate conversant with the indications and application of blood component therapy, newer antibiotics, newer antifungal and antiviral agents and other supportive measures.

6. To make the candidate fully conversant with and trained in various aspects of high dose chemotherapy and stem cell transplantation (both allogeneic and autologous) including schedule of treatment, indication for the use of growth factors, GVHD prophylaxis and management of various complications including acute and chronic GVHD.

7. To provide an insight into clinical trials (design, data collection, analysis and interpretation of related statistics), cancer epidemiology, preventive and community oncology.

8. To make the candidate understand the psychology of his patients, which is often disturbed with the knowledge that he or she has a cancer. The candidate will be made to learn to understand and tackle these psychological issues with compassion and gentle behaviour.

9. To teach the candidate about effective communication skills and how to impart bad news to the patients.

10. To make them expert in managing the terminally ill patients. They would be given knowledge regarding pain management and other palliative care measures.

GUIDELINES

The candidate works in the department of medical oncology as following

INDOORS POSTING

This may vary from **8 to 12 months**

The candidate is allotted certain beds and he is required to work up patients admitted on those beds. He plans out a diagnostic work up and treatment plan, discusses it with the concerned consultants, presents it on the grand rounds and assumes complete responsibility of the patients during their hospital stay. He should work in harmony with the ward nurses.

OUT PATIENT DEPARTMENT (OPD) POSTING

Duration is **16 months**. The candidate is posted to **chemotherapy evaluation clinics** and various **specialty clinics** including *breast cancer, gastrointestinal, urology, lymphoma-leukemia, pain evaluation, bone and soft tissue, pediatric tumors, head and neck, gynecology oncology, pulmonary oncology.*

The candidates posted to these clinics work under the supervision of consultants. They are expected to see new as well as follow-up patients so as to plan out the management and assess the therapeutic responses of a particular patient.

DAY CARE AND OPD PROCEDURES (MINOR OT) POSTING

Duration is 4 months. During this posting a candidate is expected to learn skills

- In introducing per cutaneous subclavian, internal jugular, and femoral vein catheters
- Familiarity with different venous access devices likes Hickman catheter, subcutaneous port etc.
- Institution of chemotherapy and supervision of side effects
- Procedures like bone marrow biopsy, liver biopsy, trucut biopsy, lumbar puncture, intrathecal chemotherapy and aspiration of fluids.

BMT UNIT POSTING

Duration is **2 months**. The candidate works under the supervision of concerned consultants and assumes responsibility of managing the patients undergoing high dose chemotherapy.

ELECTIVE POSTING

It is for **6 weeks**. The candidate selects the area of his or her interest, it may be training within the institute or at other specialized centers within or out side India. The candidate is required to seek acceptance from the concerned departments/centers where he wishes to work and also permission from the Chief IRCH.

ANCILLARY POSTING

It will be for 3 months as follows:

- Surgical oncology (3 weeks)
- Radiation oncology (3 weeks)
- Laboratory (4 weeks)
- Rotation to blood bank and nuclear medicine department (1 week each)
- Radiodiagnosis (2 weeks)

LABORATORY TRAINING

The candidate, apart from understanding the value of laboratory tests in a given malignancy must possess the basic knowledge of interpreting the laboratory data and correlating it with clinical data. For this purpose, candidate is posted in various laboratories through laboratory posting or dissertation topic.

- The candidate are posted to various laboratories, some o which are attached to medical oncology itself, such as cytogenetics laboratory, in-vitro tissue culture laboratory. In addition, candidate is posted in immunology, microbiology, HLA and pathology laboratory.
- These postings enable the candidate to understand histopathology, immunopathology, histochemsitry, cytopathology, genetics of tumors, their functional properties and modes of spread etc. He is also made familiar with the various types of stem cell mobilization, harvesting, and cryopreservation techniques.
- The candidate is required to learn the basic techniques of tissue culture, cytogenetics, staining and study of peripheral/bone marrow smears, operation of blood cell counter and cell separator machine.

RESEARCH TRAINING

The candidate is introduced to the field of research in medical oncology; both at clinical and laboratory level.

DISSERTATION

The candidate is required to work on **2 projects clinical** and **laboratory based**. The research proposals are to be submitted within 6 months of joining the course and completed report 6 months before the final exam. Every 6 months the candidate should present the progress report on the thesis work.

The candidate can either design a prospective study or do retrospective analysis related to his thesis work. The candidate should see to it that the study is published in a national or international journal.

Besides the dissertation work, the candidate is encouraged to work on and publish case series and case reports in peer reviewed journals and send papers for presentation to national and international conferences. He is also be encouraged to design new clinical as well as laboratory based protocols, to write research proposals for granting of funds and to establish new laboratory techniques.

TRAINING ORIENTED TOWARDS MAKING THE CANDIDATE AN EXPERT TEACHER

Academic schedule

Integrated teaching program to expose the candidate to various fields of oncology are provided by regular clinico-pathologic conferences, seminars, case discussion sessions, and radiology conferences. Following academic activities are planned through out the year except during summer and winter vacations. The candidate will be encouraged to actively participate in these meetings, carefully listen to the topics, ask questions, critically analyze and give his/her comments and suggestions.

Monday: Teaching program, 8-30 to 9-30AM. Faculty from IRCH and from other departments at AIIMS discusses topics related to basic and clinical oncology, biostatistics, making an effective presentation etc.

Tumor Board, 4-30 to 5-30 PM. By rotation senior resident working with each of the faculty members brings some interesting/difficult case/es for discussion. After taking into consideration view points of various members, a consensus is reached as to the best treatment plan for the patient.

Tuesday: Radioconference, 8-30 to 9-30 AM. The radiographs, CT/MRI/bone scans and GI series of patients seen in the OPD and wards are discussed with the radiologist. If present, serial films are discussed. This helps in diagnosis, staging, prognosis and response evaluation. It is preferable that the senior resident reads the films and then asks for the expert opinion.

Oncopath Conference, 12 noon to 1 PM. The senior residents provide the clinical history of the cases and the histopathology slides are discussed with the expert pathologists.

Wednesday: Journal club/mortality meeting, 8-30 to 9-30 AM. Alternatively journal club and mortality meeting are planned. In the journal club, the senior resident reviews relevant studies published in the latest journals, presents them and critically analyze the design of the study, the results, drawbacks and feasibility of carrying out the study in our set up. In the morality meeting, the treatment course and probable cause of death of the patients expired recently in the IRCH ward is discussed. The senior resident also discusses a related topic in detail.

Thursday: Seminar, 8-30 to 9-30 AM. Candidate presents a given topic and discusses it. He should be able to review the topic critically and make independent observations.

Friday: 8-30 to 9-30 AM. During this session, the candidates present their research proposals and update on their projects. Also case discussions are held, whereby the candidate presents the case history, examination and management plan of the patient.

CONDITIONS FOR CERTIFICATION

The candidate will be guided and judged as regards his/her abilities to provide competent care to his patients through various means like ward rounds, discussions held in OPD/clinics and weekly academic activities. Internal assessment through internal examination held in March and September every year will be done and this record will be made available at the time of final examination.

EXAMINATION

The examination will be conducted in there parts.

1. *Theory paper*

Paper I

Basic science in oncology: Radiation physics, Tumor biology, Biochemistry, Biometry, Immunology and Pharmacology.

Paper II

General oncology, Tumor pathology, Staging, Diagnosis, Radiology, Nuclear medicine.

Paper III

Medical Oncology including chemotherapy, epidemiology, rehabilitation, terminal care, clinical trials and prevention.

2. *Clinical and practical*

Long case I

Short cases 4

Spotters 4

3. *Viva-voce*

Grand viva, histopathology, hematology slides, CT scans and X rays.

BOARD OF EXAMINATION

Two internal and two external examiners

Assessment of Candidate

1. Assessment of the three parts of the examination shall be done jointly by the members of the respective board of examiners.
2. Assessment of theory papers will be done individually by each examiner. The average of marks will be taken into consideration
3. A candidate will be declared to have qualified for the DM degree in medical oncology if the candidate has satisfied the members of the respective boards of examiners individually and collectively that he/she had an adequate knowledge in all aspects of the three parts of examination. The candidate is required to score at least 50% of marks in theory separately and 50% of marks in clinical and viva-voce examination taken together.
4. A candidate whose thesis/research work has not been approved or who is unsuccessful in any part of the examination will be followed up as per institute rules.
5. The examination is conducted generally twice a year in the months of May and December.

SYLLABUS

09HLTH10A01-001-C

Paper I (Basic Science in Oncology)

1. Cell cycle
2. Pathology, Invasion & Metasssssstasis
3. Etiology of Cancer
   a. Viral
   b. Chemotherapy
   c. Physical
   d. Hormonal
4. Epidemiology of Cancer
5. Principles of Cancer Management – Surgical Oncology, Radiation Therapy, Chemotherapy, Biologic therapy
6. Pharmacology of Cancer Chemotherapy
7. Clinical trials in cancer

8. Cancer prevention Tobacco related cancer. Diet & Risk reduction Chemopreventive Agents, Hormones
9. Caner Screening
10. Imaging Techniques of Cancer Diagnosis & Management
11. Specialized techniques of Cancer Diagnosis and Management
12. Vascular Access and Specialised Technique of drug delivery

09HLTH10A01-002-C

Paper – II Clinical Oncology (Medical)

1. Cancer of Head and Neck
2. Cancer of Lung and Mediastinun
3. Cancer of Gastro Intestinal Track
4. Cancer of Genito Urinary System
5. Cancer of the Breast
6. Cancer of Endocrine System
7. Sarcomas of Soft Tissues & Bone
8. Benign & Malignant Mesotheliomas
9. Cancer of skin
10. Malignant Melanoma
11. Neoplasms of CNS
12. Cancers of childhood
13. Lymphomas
14. Leukemias and other Haematological Malignancies
15. Paraneoplastic Synddromes
16. Cancers of unknown primary site
17. A.I.D.S – related malignancies
18. Oncological Emergencies
19. Treatmetn of Metastatic Cancers
20. Gynaecological Cancers
21. High Dose Chemotherapy & Transplantation

09HLTH10A01-003-C

Paper – III (Recent Advances in Oncology)

1. Essentials of Molecular Biology
2. Molecular Biology of Cancer: Onccogenes Cytogenetics
3. Bone Marrow dysfunction in cancer patient
4. Infections in cancer Patients and neutropenic patients
5. Adverse effects of treatment
6. Supportive Care and Quality of Life

7. Rehabilitation of Cancer Patient
8. Newer approaches in caner treatment
9. Newer drugs in cancer treatment

Periodicals Recommended

Book	*Editor*
1. Caner Principles and Practice of Oncology	Vincent T. Devita
2. Principles and Practice of Pediatric Oncology	Philip A. Pizzo
3. Decision Making in Oncology	Bengamin Djubegovic
4. Current Medical Diagnosis and Treatment	Lange Medical Book International edition
5. The Basic Science of Oncology	IanF. Tannock
6. Cancer Treatment	Charles M Haskel
7. Cancer Chemotherapy	Chabner
8. Principles of Internal Medicine	Harrison
9. Text Book fo Pediatrics	Nelson
10. Text Book of Oncology	Abelloff and Armitage

Journals

1. Cancer Treatment Review
2. Journals of Pediatric Hematology/Oncology
3. Current Opinion in Oncology
4. The Indian Journal of Cancer
5. The Seminars in Oncology
6. Haematology/Oncology Clinics of North America
7. Medical and Pediatric Clinic of North America
8. Cancer
9. Current Problems in cancer
10. Journal of Clinical Oncology
11. Lancet
12. NEJM (New England Journal of Medicine)
13. Blood
14. British Journal of Hematology
15. Bone Marrow Transplantation
16. Seminars in Hematology

होमी भाभा राष्ट्रीय संस्थान

Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
PAREL, MUMBAI – 400 012

SYLLABUS
OF
DM PAEDIATRIC ONCOLOGY

(Program Code: HLTH10A02)

Curriculum & syllabus for DM in pediatric oncology

Curriculum:

Aims and Objectives:

To train a pediatrician having requisite postgraduate qualification (MD Pediatrics or its equivalent) as a specialist in Pediatric Oncology who at the completion of the program would be able to:

1. Diagnose and provide comprehensive care to children with hematological and solid malignancies
2. Is able to carry out all necessary diagnostic and therapeutic procedures as required for the care of children with hematological and solid malignancies
3. Is equipped with adequate basic and applied knowledge to deliver optimal treatment for all childhood malignant disorders
4. Counsel parents and relatives of the the patient with empathy and compassion
5. Design and execute research projects
6. Interact with medical colleagues in multiple disciplines
7. Conduct teaching sessions, bedside seminars and lectures

Eligibility:

M.D. Pediatrics or equivalent

* At present candidates with MD Pediatrics or equivalent degree are eligible for DM in Medical Oncology which is being stopped after the DM Pediatric Oncology is established .

B. Duration of the course*:*

Three years residency program (6 semesters)

C. Admission to the Course*:*

As per MCI rules

D. Proposed Training Program*:*

1. Indoor service:

a) The candidates will learn the management of various hematological and solid tumors of childhood, and their early diagnosis as well as interpretation of various tests and procedures for optimal outcome.

b) Throughout the three years of training, the candidate will maintain a weekly continuity clinic that provides the opportunity to care for patients longitudinally and to continually improve clinical skills. Candidates establish an ongoing relationship with patients and their families and, under the guidance of a faculty member in pediatric oncology, take primary responsibility for establishing chemotherapy treatment plans, participating in surgical and radiotherapy treatment decisions, and treating complications of a disease or its therapy.

c) They would perform specialized diagnostic and therapeutic procedures like bone marrow aspiration and trephine biopsy, FNAC, true cut biopsy, use and care of central venous access, lumbar puncture along with administration of intrathecal chemotherapy,pleurocentesis,pericardiocentesis,peritoniocentesis, stem cell harvest (PBSC and bone marrow) etc. wherever indicated and learn the use and maintenance of various equipment used for patient care.

2. Outdoor Service: These would be an integral part of the functioning of the Pediatric Hemato-oncology Clinic and the Pediatric solid tumor Clinic.

3. Subspeciality clinics: They will also get opportunity to be involved in the care of Pediatric Oncology patients with special needs:

a) Day Care Centre: for giving chemotherapies, blood transfusions, care of central venous lines conducting routine procedures

b) Leukemia/Lymphoma Clinic

c) Solid tumour clinic

d) Neuro-oncology Clinic

e) Bone-soft tissue tumor clinic

f) After completion of therapy (ACT) clinic: for long term follow up of patients completed chemotherapy

g) Palliative care clinic

Research

The candidate would be introduced to research methodologies and would be expected to complete an independent research project under the supervision and guidance of the faculty to be submitted as a dissertation.

Teaching Programme*:*

1. In addition to the daily instructions that candidates receive from faculty on the inpatient services, and mini-rotations, there will be daily clinical/ academic activities designed to enhance the candidate's learning experience for which they will maintain a Logbook, to be submitted at the time of final examination.

2. The candidate would participate in all teaching activities both intradepartmental as well as interdepartmental. The academic activities should include :

a) Morning in-patient rounds

b) Case presentations

c) Ward grand rounds

d) Mutidisciplinary joint meeting/round with pathologist/ haemato-pathologist ;radiolologist; radiotherapist; pediatric/ neuro/ortho surgeons

e) Seminars & Journal Clubs

Clinico-pathological conferences

f) Mortality meetings

g) Autopsy conferences

A minimum of one hour a day should be devoted for academic activity .

Syllabus:

<u>09HLTH10A02-001-C</u> General principles of pediatric oncology

- Epidemiology of Childhood Cancer
- Childhood Cancer and Heredity
- Molecular and Genetic Basis of Childhood Cancer
- Biology of Childhood Cancer
- Tumor Immunology and Pediatric Cancer
- Pathology and Molecular Diagnosis of Pediatric Malignancies
- Imaging Studies in the Diagnosis and Management of Pediatric Malignancies
- Principles of Chemotherapy
- Principles of Surgery
- Principles of Radiation Oncology
- Principles of supportive care & oncologic emergencies
- Infants and Adolescents with Cancer: Special Considerations
- Cancer Clinical Trials: Design, Conduct, Analysis, and Reporting
- Good clinical practice
- Cell and Gene Therapies – Role in pediatric oncology
- Evolving Targeted Therapies and biotherapeutics

<u>09HLTH10A02-002-C</u> Hemato-oncology: [Acute lymphoblastic leukemia;Acute Myelogenous Leukemia;Chronic Leukemias of Childhood; Myelo-proliferative and Myelodysplastic Disorders;Hodgkin lymphoma; Non-Hodgkin Lymphomas ;Lymphoproliferative Disorders and Malignancies Related to Immunodeficiencies; Histiocytoses]

- Diagnosis including morphology, cytochemistry, immuno-phenotyping & cytogenetics & participation in clinicao pathological meetings
- Inpatient and outpatient care
- Management of emergencies and treatment related complications
- Risk stratification & appropriate treatment planning
- Treatment as per clinical protocol

- Response evaluation
- Follow up guidelines
- Late effects
- Diagnosis & treatment option for relapse
- Data collection

09HLTH10A02-003-C Extra cranial solid tumour: [Retinoblastoma;Tumors of the Liver; Renal Tumors; Neuroblastoma; Rhabdomyosarcoma and soft tissue sarcomas;Ewing Family of Tumors; Osteosarcoma; Germ Cell Tumors; Endocrine Tumors &Rare Cancers of Childhood]

- Inpatient and outpatient care in conjunction with Pediatric Surgical Oncologist/Pediatric Surgeon, orthopedic Surgeon, Radiotherapist[preferably dedicated to pediatrics]Radiologist & Pathologist/Molecular Pathologist and participation in tumor boards.
- Management of emergencies and treatment related complications
- Staging, Risk stratification & appropriate treatment planning
- Treatment as per clinical protocol
- Response evaluation
- Follow up guidelines
- Late effects & Rehabilitation
- Diagnosis & treatment option for relapse
- Data collection

09HLTH10A02-004-C CNS tumours

- Inpatient and outpatient care in conjunction with Neurosurgeon, Radiotherapist[preferably dedicated to Neuro-oncology] Radiologist & Pathologist/Molecular Pathologist and participation in tumor boards.
- Management of emergencies and treatment related complications
- Staging,Risk stratification & appropriate treatment planning
- Treatment as per clinical protocol
- Response evaluation
- Follow up guidelines
- Late effects & Rehabilitation
- Diagnosis & treatment option for relapse

- Data collection

<u>09HLTH10A02-005-C</u> Haematopoietic stem cell transplant [HSCT]

- Indications for HSCT
- Tissue typing
- Principles of
  - Donor selection
  - Donor counseling
  - Conditioning regimens/stem sell manipulation/ immuno-suppression
  - Transplant immunology
- Graft versus host disease
- Other complications
- Supportive care
- Long term follow up and late effects

<u>09HLTH10A02-006-C</u> Laboratory training

- Interpretation of peripheral blood and bone marrow aspiration smears.
- Basic knowledge of bone marrow biopsy and solid tumour histopathology.
- CSF cytology
- Cytochemistry/Immunohistochemistry
- Flow cytometry & immunophenotyping
- Cytogenetics/Molecular diagnosis
- Coagulation
- Blood Transfusion & Component therapy
- Principles of infection control [microbiology]

<u>09HLTH10A02-007-C</u> Generic training in practical skills

- Optimal use of diagnostic services
- Ensuring good clinical practice
- Recognition of a critically ill child and the need for high dependency care/ICU
- Central venous access and care

- Chemotherapy drug handling, administration & management of acute side effects including intrathecal & intrcavitory chemotherapy.
- Care of infants and adolescents
- Late effects monitoring & survivorship issues
- Pain evaluation & management
- Palliative care
- Counsellling of patients and parents
- Organization & managerial skills
- Leadership of multidisciplinary team

09HLTH10A02-008-C Other issues

- Educational Issues for Children with Cancer
- Financial Issues in Pediatric Cancer
- Pediatric Cancer: Advocacy, Insurance, Education, and Employment
- Complementary and Alternative Medical Therapies in Pediatric Oncology
- Pediatric Oncology in Countries with Limited Resources
- Preventing Cancer in Adulthood: Advice for the Pediatrician
- Resources for Children with Cancer, Their Families, and Physicians
- Role of Telemedicine in Pediatric Cancer Care

09HLTH10A02-001-RA Research Activities:

In addition to prospectively following their cases for 3 years, the candidate would be encouraged to undertake independent research projects and also actively associate with the ongoing research activities. He/she would be expected to publish the results of his/her research in journals of repute.

It is expected that the candidate would have at least 1 publication at the end of 3 years in a reputed journal.

E. Assessment and Evaluation:

1. **Internal assessment**: This will be done at the end of each year and will include theory, practical and evaluation of skills. The results of internal assessment will be given due weightage in the final examination.

2. **Evaluation at the end of the course**:

a) Final theory papers: At the end of three years, theory examinations would be held like all other DM courses.

*(1) **PAPER I**: Basic and Applied Sciences as related to Pediatric Oncology*

*(2) **PAPER II**: Principles and practice of Clinical Pediatric Oncology part 1*

*(3) **PAPER III:** Principles and practice of Clinical Pediatric Oncology part 2*

*(4) **PAPER IV**: Recent advances as related to Pediatric Oncology*

b) **Practical examination**: This will include clinical cases, Pediatric Oncology ward round and viva voce. Viva voce shall include skiagrams, spots, clinical problems, investigative data, procedures etc. the candidate is also required to submit his/her Logbook, Thesis and Research works.

3. **Examiners**: There will be four examiners with two internal and two externals. For qualifications and experience of the examiners, the same rules will apply as for the examiners of any other DM courses of the Institute.

F. Course Faculty:

- **Director TMC** Dr.R.A.Badwe
- **Director Academics** Dr.K.S.Sharma
- **Core Faculty**:
- Dr.P.A.Kurkure, Prof & HOD Pediatric Oncology
- Dr.B.Arora, Associate Prof, Dept of Pediatric Oncology
- Dr.T.Vora, Assistant Prof, Dept of Pediatric Oncology
- Dr.G.Chinnaswamy, Assistant Prof,Dept of Pediatric Oncology

1. **Intra-Departmental Faculty**: Faculty of the Dept of Medical Oncology.

2. **Inter-Departmental**: Faculty of department of Hematopathology, Molecular cytogenetics, Histopathology, and Transfusion Medicine and of the Bone Marrow Transplant Unit will be involved. Related Departments of Radiodiagnosis, Pediatric Radiation Oncology, Nuclear Medicine, Pediatric Oncosurgery, Orthopedic Oncology, Neurosurgery, Head & Neck oncology will provide all necessary help for the teaching and training of the candidates undergoing the course.

3. **Extra-Institutional**: Proposed (pending MOU) for training in

   benign hematology

   Division of Pediatric Hematology

   Bai Jerbai Wadia Hospital for Children

Role of other Departments:

Bone Marrow Transplant Unit: For training of the candidate in the preparation of the patient for the procedure, methodology of the procedure, care of such patients and management of the complication which may arise during the procedure and long term follow up of such patients.

Transfusion Medicine: For training of the candidate in various aspects of blood component therapy, their storage and usage, aphaeresis and stem call separation for bone marrow transplantation.

Hematopathology: For training of the candidate in the laboratory aspects of Pediatric hematology and oncology like routine hematological investigations, interpretation and reporting of bone marrow aspirate and biopsy, flowcytometry, cytogenetics, chromosomal analysis, Hb electrophoresis, factor assay, hemolytic anemia and bleeding disorder work-up, FISH etc.

Cytopathology: For training of the candidate in the routine cytological investigations related to hematology and oncology, interpretation and reporting of FNAC, Immunocytochemistry etc.

Immunopathology: For training of the candidate in the routine immunological investigations related to Paediatric hematology and oncology, interpretation and reporting of HLA, Immunocytochemistry, PCR, chromosomal culture etc.

Histopathology: For training of the candidate in the routine histopathological investigations related to Paediatric hematology and oncology.

Microbiology: For training in relevance to Paediatric hematology and oncology.

Radiodiagnosis: For training of the candidate in interpretation of various radiologic diagnostic procedures in relevance to Paediatric hematology and oncology like X-rays, USG, CT scan, MRI, interventional radiology etc. Radiation Oncology: For training of the candidate in role of radiotherapy in childhood malignancies.

Nuclear Medicine: For training of the candidate in role of nuclear medicine in childhood malignancies, e.g. Bone scan, Gallium scan, MIBG, PET-CT scan.

Paediatric Surgery: For familiarizing the candidate with the surgical procedures in relevance to Paediatric hematology and oncology and placement of central venous catheters.

Orthopedic Oncology: For familiarizing the candidate with the orthopedic aspects in relevance to Paediatric oncology, e.g. Ewing's sarcoma, osteo-sarcoma, LCH, amputation, limb sparing surgeries, etc.

Radiation Oncology: For familiarizing the candidate with the principles & practice of radiotherapy procedures in relevance to pediatric oncology.

Proposed Time Schedule

The rotations are divided as follows:

S. No.	Rotation	Duration
1.	Clinical Hematology-Oncology 1. Hemato-oncology 2. Solid tumors	24 months 12 months 12 months
2.	Bone Marrow Transplantation	4 months
3.	Laboratory Hematology-Oncology*	4 months
4 5.	Research & Elective** Exam preparation leave	3 months 1 month

*Rotations in Transfusion Medicine, Hematopathology, Molecular cytogenetics, Cytopathology, Histopathology, Immunopathology.

**Rotations of 2-3 wks in various specialties associated with Pediatric hematology and oncology such as radiation oncology, Pediatric Oncosurgery, bioimaging, catheter clinic, Radiodiagnosis etc.

The first semester of the program is an intensive clinical experience designed to allow the candidate to develop cognitive and psychomotor skills in diagnosis and management of pediatric hematology-oncology problems. During the second and third semesters, the candidate will pursue independent clinical and laboratory based research. In addition, the candidate will take courses in biostatistics and clinical trials design offered by faculty. In the last semester, the candidate would enhance the skills related to allied specialties such as BMT, Laboratory oncology, radiation oncology, imaging & bio-imaging and molecular diagnostics.

The candidates will participate in the night and weekend call schedule as per roster in Dept of Pediatric Oncology throughout the three years of training program.

BACK TO MAIN

HOMI BHABA NATIONAL INSTITUTE

DEPARTMENT OF DIGESTIVE DISEASES AND CLINICAL NUTRITION

Speciality Training Curriculum

For

DIGESTIVE DISEASES

Luminal Gastroenterology, Hepatology, Biliary and Pancreatic Diseases, Gastrointestinal Oncology, Liver transplant, Endoscopy, Clinical Nutrition

SYLLABUS
OF
D.M. in GASTROENTEROLOGY
Under TMC
(Program code: HLTH10A03)

INDEX

I. INTRODUCTION

Gastroenterology is one of the major specialties of internal medicine. The specialty has grown incredibly fast over the past 30 years.

Several factors that have led to the substantial growth of gastroenterology as a specialty include, the increasing application of endoscopic and radiological intervention to replace surgery, specialized non-surgical therapies for in-operable bowel cancers and liver diseases, development of liver transplant and the need to liaison with surgeons, radiologists, nurse specialists, nutritionists, pathologists and oncologist for successful treatment of such patients. In addition a number of subspecialties of gastroenterology are now evolving such as pediatric gastroenterology, hepatology, liver transplantation and digestive oncology.

Diagnosis in gastroenterology requires a combination of the use of fundamental clinical skills along with very complex investigational approaches both radiological and endoscopic, thereby making it challenging branch to practice. While most gastroenterologists provide a broad, comprehensive service, there is a perceived need for some clinicians in the speciality to deliver a high quality service in very specific areas.

This curriculum has been drawn to meet the above challenges and is focused towards all round development of basic skills and competencies in gastroenterology.

The purpose of this curriculum is to define the process of training and the competencies required for safe and successful specialist practice in digestive disorders at basic level at also prepare trainees for sub-specialities if they wish to pursue it in future.

II. KEY FEATURES OF CURRICULUM

1. **Enhanced disease-specific training:** Focused training blocks in specific disease areas, such as motility and functional disorders, advanced inflammatory bowel training, digestive oncology, advanced endoscopy, pediatric gastroenterology (if available) and transplant hepatology will be made available during and the basic three year course.

2. **Endoscopy Training:** Competency based endoscopy training includes in depth training in diagnostic and basic therapeutic endoscopy skills and patient care along with and setting up and management of endoscopy suite and broad training with future prospect of a career in advanced endoscopy based on aptitude and skills. Technical and cognitive milestones will be periodically assessed using standard assessment parameters.

3. **Ancillary skill training:** Practical skills required to optimize patient care including basic and advanced clinical nutrition, stoma care and venous insertion device care. A basic course in research methodology and epidemiology (public health) is also provided to cover up for lack of training opportunity during undergraduate and broad speciality training.

III. TRAINING EXPOSURE:

The program consists of four main pathways of learning: clinical activities, procedural training, didactic learning and research experience. Trainees and faculty are expected to follow and complete the curriculum set for a particular year of training (as per the year-wise syllabus described) within this framework in order to ensure completion of training.

1. Academic Exposure:

A. Specialty out-patient clinics, indoor care and ward rounds, MDT meetings, grand rounds and mortality meetings: trainees are expected to attend and contribute towards the same. After initial induction, trainees will review patients in outpatient clinics and in-patients under direct supervision of training faculty. The degree of responsibility taken by the trainee will increase as competency increases.

B. Formal Didactic Teaching: Case presentations (mini-CEX and CBD can be used to assess skills during this session), seminars, journal clubs, landmark studies, evidence based management, Health Technology Assessments.

C. Training in endoscopy and other Procedures: The trainee will maintain a written log of each procedure performed. A six monthly appraisal will be conducted by the trainers for endoscopy training. .

D. Rotations in all sub-specialties in digestive diseases: A system of Inter-Hospital Rotation will be used to provide basic training in sub-specialty areas such as hepatology and transplant and motility disorders. This will be facilitated by the inter-institutional MOU.

E. Clinical research training, audits and research projects:: A dedicated block for clinical research methodology course in included in the first year curriculum to develop understanding of project design, protocol development, basics of biostatistics, manuscript writing, grant writing and bioethics of research. This is has been incorporated in the curriculum to fulfill the deficiency in training at undergraduate and broad specialty levels of training. Second and third year residents will engage in either clinical or laboratory related research project that will result in the preparation of at least one abstract for national meeting and preparation of a manuscript to be submitted for publication. In addition, trainees will participate in audits which contribute to patient care. Thesis will be completed and submitted to the university at end of 3 year training. Information generated during the research years will be presented at academic and national meetings. Dissertation will be done by the trainees.

F. Attendance at society and other educational Meetings: Each 2nd and 3rd year fellow will need to attend and do presentation at a minimum of one conference annually. The conference can be a national or local society meeting. In addition, the fellow may also attend conferences in which they are presenting research work or any other relevant educational courses approved by the program/institute faculty.

2. **Mentorship and Career Development:** Periodic meetings will be organized with national faculty members of training units in the city (country if feasible) in order to guide fellows and improve on their training and help them plan future career goals and job opportunities. This will be conducted under the auspices of the Bombay Gastroenterology Research Society. In addition to this guidance faculty can provide input in up-gradation of training infrastructure for basic training and also for development of specific sub-specialty training units in HBNI and in the country.

3. **Competency development and evaluation:** A detailed competency development guide for both generic competencies and core competencies is being drawn up. Periodical assessment and annual appraisals will be done both by trainers (and later a system set up for assessment of program and trainer by trainees as well). More details of the format has been described in the section on "Trainee Competency Development" .

4. **Curriculum monitoring:** A progress (review of successful application and appraisal) of the curriculum and training and any special needs will be periodically sent to BOS, HBNI for review.

IV. ORIENTATION/INDUCTION PROGRAMME FOR NEW TRAINEES

A half day orientation will be held by the department within the first two to six weeks of joining:

1. The orientation will familiarize the trainee with activities of the department and those of allied departments.
2. Orientation topics include but are not limited to:
   a. Overview of program
   b. Introductions of select faculty and fellows.
   c. Tour of key clinical and research areas.
   d. Review of clinical rotation schedules: Intra-department, inter-department and inter-hospital exchange program.
   e. Financial and leave allowance information.
   f. Appraisal process and schedule.
   g. Academic Meeting and national Conference information.
   h. Distribution of keys, phone, pagers.
   i. Instructions for attendance and accommodation facilities.
   j. Special topics: Clinical Ethics, DNR and autopsy policies.

All the above is described in the Residents Manual (under preparation).

V. OVERVIEW OF PROGRAM: SUBJECTS INCLUDED IN 3 YEAR FOUNDATION COURSE:

1. Main Subjects:

09HLTH10A03-001-C	Luminal Gastroenterology
09HLTH10A03-002-C	Hepatology
09HLTH10A03-003-C	Biliary and Pancreatic diseases
09HLTH10A03-004-C	Basic Endoscopy

2. Sub-specialty: Basic training to prepare to future sub-specialty tracks

09HLTH10A03-001-SS	Liver transplant
09HLTH10A03-002-SS	Gastrointestinal Oncology
09HLTH10A03-003-SS	Pediatric and Geriatric Gastroenterology
09HLTH10A03-004-SS	Advanced Endoscopy

3. Ancillary Courses: (Compulsory)

09HLTH10A03-001-A GI and liver pathology

09HLTH10A03-002-A GI imaging

09HLTH10A03-003-A Clinical Nutrition

09HLTH10A03-004-A Allied Clinical Experience: Catheter care, stoma care, consequences of abdominal surgery, management of end-stage digestive diseases.

09HLTH10A03-005-A Clinical Research Methodology

09HLTH10A03-006-A Epidemiology and Public health related to digestive diseases

09HLTH10A03-007-A Basic Sciences: Genetics, Molecular biology

VI. SUBJECT: YEARWISE DISTRIBUTION OF TEACHING PROGRAM.

SUBJECTS	I YR RESIDENT	II YR RESIDENT	III YR RESIDENT
Basics Gastroenterology	Anatomy, Physiology Approach to GI symptoms and symptom complexes	_	_
Luminal Gastroenterology	Part I: Foregut diseases Esophagus, Stomach Functional and Motility disorders of entire GIT	Part II: Mid and Hindgut diseases Small Bowel Large Bowel	-
Motility Procedure training	Part I: level I and II	-	-
Hepatobiliary and Pancreatic diseases	-	Part - I Hepatology General Topics Basic sciences	Part- II Biliary, Pancreatic diseases Liver transplant rotation
Pediatric Gastroenterology	Part – I: Luminal GI (UGIT and LGIT)	-	Part - II Specific HPB disease and pediatric transplant related issues
GI Oncology	Part – I: Basic Approach Part – II: Foregut tumors & GI Lymphomas	Part – III: Lower GI tumors Part – IV: Liver Cancer	Part - V BP cancers, Retroperitoneal tumors, GIST
Clinical Nutrition	Part – I Basic	Part – II Advanced	-
Applied (related) Pharmacology	I	II	III
Clinical Research Methods, Bio-Statistics and Epidemiology	I-II	III	-
Endoscopy	I: Basic Skills UGI, LGI, PEG, Hemostasis, Enteral feeds	II: Intermediate skills: colonoscopy, dilatation, Assist in luminal stenting, DBE, ERCP, EUS	III: Higher skills Luminal stenting EUS- indications and basic interpretation ERCP hands on for those pursue HBP fellowships
Day to Day: Clinical Care and Community outreach	Diagnostic Tests Radiology IV access, enteral access, stoma care, palliative care, familial diseases	GI Consults – hepatobiliary	-
Research	Dissertation planning Small projects/Audits	-	Dissertation submission

VII. CLINICAL ROTATIONS

Clinical Training	**Length (months)**		
	Ist Yr	**IInd Yr**	**IIIrd Yr**
Luminal GI: in – patients Luminal GI: OPD clinics	4	3*	4
HPB: OPD clinics HPB: in – patients	4	3*	4
Liver transplant*	0	0	2*
GI oncology including EUS observation*	0	3*	0
Pediatric Gastroenterology*	0	2	0
Nutrition*	1	0	0
Catheter Clinic*	0.5*	0	0
Stoma Clinic*	0.5*	0	0
Radiology	1	0	0
Motility Clinic and pH Monitoring*	0.5#	0.5#	0
Epidemiology intensive Block	0	0.5	0
Palliative Care	0.5	0	0
Clinical Research Methodology$	2 days	2 days	0
Sedation (anesthesia posting)	0.5	0	0
Vacation	0.5	0	1- study leave

***: Specialty Rotations**

#: Can be clubbed into continuous 1 month training

$: weekend intensives

VIII. TEACHING STRATEGY:

TEACHING STRATEGY: First year: Part- I – Basic Sciences and Allied Clinical Training.

Theory	Practical
Basics in GE	
Applied and Integrated Anatomy	Analysis of symptoms and symptom complexes
Applied and Integrated Physiology	
Applied Pharmacology: Drug in IBD, IBS, chemotherapy of foregut malignancy, enteral and parenteral formulae	
Basic Investigation in GE	
pH monitoring, H Pylori tests Malabsorption Tests Normal Pathology of Digestive tract Molecular Pathology and applied techniques	Clinical case studies, practicals for sampling errrors and interpretation of results. Demonstration and recognize normal histology, abnormal GI and liver pathology, aspiration cytology
Basic Sciences: Gastrointestinal Cellular and Molecular Physiology	
General concepts: Molecular biology/ Techniques/ Testing, Genetics, Cell biology, Pharmacology and cellular signaling, Host environment interaction, Immunology, Genetics,	Molecular Techniques/Testing: HTA
Imaging of the GI Tract	
Barium studies, Enteroclysis USG, CTscan, MRI, Bioimaging (PET, SPECT) Virtual imaging Specific aspects related to the diseases of GI tract	Orientation and image interpretation during the radiology posting HTA

TEACHING STRATEGY: First year: Part- I – Basic Sciences and Allied Clinical Training contd.

Allied Clinical Training: Stoma care, Catheter Care, End-stage Care	
1. Enterostomies- complications, diet, home care and counseling 2. IV Access Catheter insertions and care 3. Enteral access devices, counseling and care 4. Palliative care- palliation of GI symptoms in end stage digestive diseases and GI cancers, familiarity with, and at least limited experience with stenting, pain control, hospice and home care in advanced and terminally ill patient 5. GI and related interventions: obtaining consent, benefits and risks of procedures, post procedure care, treating complications, delayed sequele of therapy	Procedures: paracentesis, pleural tappings, liver biopsy, FNAC of cervical nodes and superficial lumps, bone marrow exam. Each procedure must be prepared for discussion by the trainee In addition, practical sessions and clinical exposure obtained during dedicated rotation Assessment of this must be included in the appraisal
Basic in Biostatistics and Clinical Research Methodology	
Sampling: concept of population and sample and need for statistics, random sampling, standard error, confidence intervals Properties of “Normal and Gaussian Distribution” Curve Types of Data: Paired unpaired; categorical continuous; numerical data (discrete & continuous), bar charts, histograms Comparing mean and median: χ student “t” test etc. Measurement and tests of association between variables: correlation and regression scatter plots, sensitivity and specificity, positive and negative predictive value	Assessment of quality of a clinical trial- exercises Guidelines for authorship and disclosures

TEACHING STRATEGY: First Year: PART II: DIGESTIVE DISEASES

<table>
<tr><th>Theory</th><th>Practical</th></tr>
<tr><td colspan="2">Luminal Gastroenterology, Public Health related disorders, Women's Digestive Health</td></tr>
<tr><td>Functional, and Motility Disorders and
Foregut diseases
GI inflammation, enteric and infectious
Diseases a. adult and Pediatric, HIV,
Iflammatory Bowel Disease (IBD) - it
includes immunology, microbiology, and
molecular biology aspects of these diseases.
b. Develop skills for long term care of these
patients, especially IBD patients
Public health aspects of Infectious and
diarrhoeal, diseases in India
"Tropical digestive diseases"
Specific issues in women's digestive health:
in general and related to Pregnancy and
childbearing</td><td>Motility clinic practical experience is given in table
<table>
<tr><td>Esophageal motility</td><td>50</td></tr>
<tr><td>24pH probe and monitoring</td><td>25</td></tr>
<tr><td>Gastric secretory studies</td><td>10</td></tr>
<tr><td>Gastric / small bowel motility</td><td>25</td></tr>
<tr><td>Gastric emptying</td><td>25</td></tr>
<tr><td>Colonic motility studies</td><td>20</td></tr>
<tr><td>Anorectal motility studies</td><td>30</td></tr>
<tr><td>Anal sphincter biofeedback</td><td>10</td></tr>
<tr><td>Colonic transit study</td><td>20</td></tr>
</table></td></tr>
<tr><td colspan="2">Basics of Oncology Care</td></tr>
<tr><td>Principles of staging of cancers
Assessment, Investigations (tumor markers,
imaging, metastatic workup, nodal stations),
Joint clinic forum (outline of Rx plans),
symptom control, reviews and treatment
checks, follow up
Principles of adjuvant, neo-adjuvant and
palliative therapy and Multimodality therapy
Sequele of chemotherapy, radiation, surgery
Counseling: informing diagnosis, treatment
plan,
Rehabilitation- fertility, organ removal
Cancer survivorship</td><td></td></tr>
</table>

TEACHING STRATEGY: First Year: PART II: DIGESTIVE DISEASES

GI Oncology Part I	
Early GI cancers : Recognition, Polyps, pre-neoplastic lesions Polypectomy, screening and surveillance Differentiating benign from malignant strictures Surveillance for IBD Familial GI cancer syndromes and related genetic/molecular testing Upper GI Cancers: Esophagus, Stomach, NHL Pathology, tumor staging, familial cancers, prognostic factors, management, surgery, drug therapy (cytotoxic chemotherapy and targeted therapy), palliative therapy, prevention and public health issues, early diagnosis and referral	Landmark articles Protocol discussion EBM
Geriatric Gastroenterology	
Normal function, drug metabolism/elimination, nutrition, specific GI conditions in the elderly	
Pediatric Gastroenterology - Part I	
General concepts and the unique aspects of pediatric GE luminal pediatric GE, Foregut diseases	Case presentations

TEACHING STRATEGY: First year: PART III: PREPARATION FOR RESEARCH

Concept sheet: Fellows are required to propose a hypothesis-based research project in the area of basic science or patient-oriented outcomes research, in the form of a 2-3 page concept sheet before the final quarter of their first year of training. This concept sheet will be submitted to the IRB for approval and includes:

1. Title of the proposal
2. Mentor: a faculty member (Principal Investigator)
3. Hypothesis to be tested and specific research plan (specific aims), including outcome parameters, sample size and statistical plan, and / or laboratory assay endpoints as appropriate.
4. References.
5. Significance to Gastroenterology
6. Relevant background information, intellectual and physical resources available locally.
7. Timeline for completion of the project.
8. Source of proposed funding for this project: training grant or other.
9. Additional training or coursework to be taken (if any) and its relevance.
10. Brief statement about career goals: "Where do you see yourself in 5 years?"
11. Brief statement regarding your commitments to other academic activities including scientific projects, chapters and reviews, etc.

TEACHING STRATEGY: Second Year: Part I – basic Sciences and Allied Clinical Training.

Theory	Practical
Basics in GE	
Applied and Integrated Anatomy – liver, portal circulation, abdominal vascular anatomy, bile duct, pancreas mid and hindgut, Anorectum	Analysis of symptoms and symptom complexes
Applied and Integrated Physiology – liver, biliary, pancreas	
Applied Pharmacology: Drug in liver, biliary and pancreatic diseases, PHT, foregut oncology, GI emergencies	
Basic Investigation in GE	
Normal Pathology of Liver, Bile ducts and pancreas Molecular Pathology and applied techniques	Normal and abnormal liver, bile ducts and pancreatic pathology Foregut tumor pathology including molecular path
Basic Sciences: Gastrointestinal Cellular and Molecular Physiology	
Specific molecular and genetic tests used in digestive diseases	Demonstrate Molecular Techniques/Tests. HTA
Imaging of the GI Tract	
Angiography: CT, MRI, DSA Assessment of Liver volume Detailed evaluation of Intra and extra hepatic BD Detailed pancreatic anatomy and its relation Pelvic MRI	Orientation and image interpretation during the radiology posting Use 3-D Anatomy Modules HTA

TEACHING STRATEGY: Second Year: Part I – basic Sciences and Allied Clinical Training contd.

Allied Clinical Training: Digestive Tract Surgery – Bowel, Liver, Portal HTN, Emergency Mx	
1.Digestive Surgery: Bowel and Liver resection Basic knowledge of surgical anatomy, especially relationships of ductile, vascular and luminal structures Endoscopic vs. interventional radiology vs. surgical procedure and when to pursue which one Indications and contraindications for surgery, bowel and liver resection Post-op care of patients after major and minor procedure Recovery and rehabilitation after major abdominal surgery Morbidity and management of post resection nutritional deficiencies and bowel disturbances Long –term rehabilitation after organ removal Pre-anesthesia Risk evaluation: Anesthesia, analgesia, sedation – in deranged liver Profiles 2.Emergencies in GE and Hepatology	Each topic must be prepared for discussion by the trainee In addition, practical sessions and clinical exposure obtained during dedicated rotation Assessment of this must be included in the appraisal

TEACHING STRATEGY: Second Year: Part I – basic Sciences and Allied Clinical Training contd.

Basic in Epidemiology, Public Health and Database Management	
Principles of statistical inference: hypothesis testing, sample size, Type I and II errors, interpretation of p-values, statistical and clinical significance. Survival analysis in cancer: types of time-to-event data, Kaplan Meier and Acturial Survival curves Comparing groups: log-rank test, use of Cox's proportional hazards regression model, hazard ratio, and their interpretation Clinical Trial Methodology: Phase I-IV trials, randomization and stratification methods, problem of non-randomized studies and historical controls, blinding/masking, design of clinical trials, content of trial protocol, ethics and informed consent, sample size calculation, interim analysis Measures of Response; Tumor regression, morbidity, local-regional recurrence, distant mets, death, quality of Life, intention to treat analysis Epidemiology: retrospective 9 case- control studies, prospective cohort studies, Odds ratio and relative risk, mortality rates, cancer registration and follow –up, trends in cancer incidence Multivariate analysis, Meta-analysis and Systematic Reviews.	Acturial Survival curves for a given data set Estimating sample size for a given type I and II error Information management: retrieving data from the internet, Medline, PubMed, Cochrane Data base searches Medical Writing: research articles for scientific journals Research Proposal: Designing a research study and protocol writing Designing and writing protocols for phase I, II and III studies Multivariate analysis Meta-analysis and Systematic Reviews Relational Databases and use of MS Access

TEACHING STRATEGY: Second Year: PART II: DIGESTIVE DISEASES

<table>
<tr><th>Theory</th><th>Practical</th></tr>
<tr><td colspan="2">Luminal Gastroenterology</td></tr>
<tr><td>Diseases of mid and hind gut
Anorectal disorders – adults and children</td><td>Motility clinic practical experience is given in table.
<table>
<tr><td>Esophageal motility</td><td>50</td></tr>
<tr><td>24pH probe and monitoring</td><td>25</td></tr>
<tr><td>Gastric secretory studies</td><td>10</td></tr>
<tr><td>Gastric / small bowel motility</td><td>25</td></tr>
<tr><td>Gastric emptying</td><td>25</td></tr>
<tr><td>Colonic motility studies</td><td>20</td></tr>
<tr><td>Anorectal motility studies</td><td>30</td></tr>
<tr><td>Anal sphincter biofeedback</td><td>10</td></tr>
<tr><td>Colonic transit study</td><td>20</td></tr>
</table>
Clinical and procedure practice to continue in 2nd Yr</td></tr>
<tr><td colspan="2">Hepatology</td></tr>
<tr><td>Viral Hepatitis
Drug induced LD
CLD, Cirrhosis
Portal circulation and portal HTN</td><td></td></tr>
<tr><td colspan="2">GI Oncology Part II</td></tr>
<tr><td>1. Risk evaluation, screening and surveillance in GI cancers
2. Mid and Hind gut cancers: small bowel, colon rectum and Liver cancers and heaptoblastoma:
Pathology, tumor staging, familial cancers, prognostic factors, management, surgery, drug therapy (cytotoxic chemotherapy and targeted therapy), palliative therapy, prevention and public health issues</td><td>Landmark articles
Protocol discussion
EBM</td></tr>
<tr><td colspan="2">Pediatric Gastroenterology - Part II</td></tr>
<tr><td>1. Luminal pediatric GE of mid and hind gut
2. Pediatric liver, Biliary and Pancreatic diseases</td><td>Case presentations</td></tr>
</table>

TEACHING STRATEGY: Third Year: Part I – basic Sciences and Allied Clinical Training

Theory	Practical
Basics in GE	
Applied and Integrated Anatomy – liver, portal circulation, abdominal vascular anatomy, bile duct, pancreas mid and hindgut, Anorectum	Analysis of symptoms and symptom complexes
Applied and Integrated Physiology – liver	
Applied Pharmacology: Drug in liver diseases, PHT, foregut oncology, GI emergencies	
Basic Investigation in GE	
Pathology Tumors: bile duct, pancreas, GIST, Retroperitoneal tumors	Tumor pathology including molecular path
Imaging of the GI Tract	
Applied Radiology: related to therapy planning CT, MRI, DSA, angiograms Assessment of Liver volume	Orientation and image interpretation during the radiology posting
Allied Clinical Training: Digestive Tract Surgery – Bowel, Liver, Portal HTN, Emergency Mx	
Digestive Surgery: Bowel and Liver resection	Long Case presentations based on theory knowledge learnt in first and second year Assessment of this must be included in the appraisal
Dissertation and Research Project Evaluation	

TEACHING STRATEGY: Third Year: PART II: DIGESTIVE DISEASES

Theory	Practical
Luminal Gastroenterology	
Diseases of bile ducts and pancreas- adults and children	
Hepatology	
Viral Hepatitis Drug induced LD CLD, Cirrhosis Portal circulation and portal HTN	
GI Oncology Part II	
1. Risk evaluation, screening and surveillance in GI cancers 2. Mid and Hind gut cancers: small bowel, colon rectum and Liver cancers and heaptoblastoma: Pathology, tumor staging, familial cancers, prognostic factors, management, surgery, drug therapy (cytotoxic chemotherapy and targeted therapy), palliative therapy, prevention and public health issues	Landmark articles Protocol discussion EBM
Miscellaneous	
Investigational techniques in clinical and laboratory HTA and outcome measures Economics in Gastroenetorology and GI endoscopy Setting up of GI Endoscopy, Liver Transplant and GI oncology and Nutrition therapy units	

IX. ENDOSCOPY SYLLABUS: Diagnostic and basic therapeutic endoscopy training

Educational Goals

- Learn the proper indications, contraindications, special needs, and procedural preparations for diagnostic and therapeutic gastroenterology procedures.
- Understand the role of endoscopic management in a multidisciplinary approach to various patient disorders and problems
- Practice detailed informed consent and informed refusal: Learn to interact effectively with patients and families to communicate the purpose of procedures and their results, and complications of procedures if necessary.
- Understand the system under which outpatient and inpatient endoscopic procedures are provided and collaborate with other team members in helping patients effectively negotiate the system.
- Learn management of an endoscopy unit: set-up of endoscopy suite, its management issues, learn the role and function of other members of the endoscopic procedure team and to interact effectively with other members of the endoscopy suite team in order to optimize patient care and co-ordinate working.
- Learn how to safely administer conscious sedation to provide for patient comfort during procedures, and when general anesthesia is appropriately indicated.
- Learn appropriate endoscopic surveillance regimens for various forms of upper and lower endoscopic pathology.
- Correlate visual and pathologic findings at endoscopy with clinical conditions.
- Identify areas of personal deficiency in skill and knowledge in the performance of endoscopic and other core procedures. In gastroenterology and hepatology and develop and implement strategies for correcting these deficiencies.
- Learn to identify procedure complications and formulate strategies for avoiding those complications.
- Learn to formulate comprehensive, clear and concise procedure reports to referring physicians and image capture.
- Identify and understand risk management issues in the performance of endoscopic procedures.

- **Achieve technical competence in the performance of Gastroenterology core diagnostic and basic therapeutic procedures - should be able to perform:**

1. **By completion of first year:**
    a. Diagnostic Esophago-Gastro-Duodenoscopy to the second portion of the duodenum
    b. Diagnostic Colonoscopy to the cecum with limited assistance.

2. **By completion of second year:**
    a. Complete competency-level performance of the following basic gastroenterology procedures as per the curriculum
    b. Master all Year I upper endoscopic skill requirements. Additionally, begin to develop competency in performing therapeutic maneuvers: banding and sclerosing of varices, and sclerotherapy and thermal coagulotion of bleeding vessels, luminal dilatation, enteral access (NGT, NJT)
    c. Master all Year I colonoscopic skill requirements. Additionally, perform endoscopic maneuvers, including snare polypectomy and begin to develop competency in control of GI bleeding: sclerotherapy and thermal coagulotion of bleeding vessels.

3. **By completion of Third year:**
    a. Attain trainer level proficiency in the following gastroenterology procedures pertinent to his/her career choices:
    b. Upper Endoscopy: master all Year II endoscopic skill requirements. Additionally, be able to pass a side viewing scope to identify the papilla or lesions difficult to observe with forward viewing scope and perform advanced maneuvers, such as placing clips on bleeding vessels or argon plasma laser coagulation.
    c. Colonoscopy: Master all Year II colonoscopic skill requirements. Additionally, be able to independently intubate the terminal ileum and begin to develop independent mastery of more advanced maneuvers, e.g., removal of large or complex polyps by saline assisted polypectomy or piecemeal resection and control of bleeding using clips or argon plasma laser coagulation.
    d. Learn the unique functions of the procedure assistant especially ERCP and therapeutic EUS.
    e. Expand clinically applicable knowledge base of biliary/pancreatic disorders, including patient's tolerance of ERCP in their management.

f. Expand clinically applicable knowledge for endoscopic ultrasound with respect to indication and application of the procedure for maximal impact on patient care.

Basic endoscopy training year wise schedule:

First Year Basic Skills	Second Year Intermediate Skills	Third Year Introduction to Advanced Skills	Objective performance criteria after prescribed numbers performed
General Aspects			
1. Obtaining consent for different endoscopy procedures 2. Infection control, universal precaution, cleaning and disinfection of endoscopes, reuse of accessories 3. Image capture, reporting of endoscopy procedures, endoscopy database 4. Preparation for UGI, LGI endoscopy, ERCP 5. Pre and Post Procedure care	1. Sedation and Monitoring 2. Quality Assurance in endoscopy	1. Setting up an endoscopy unit 2. Cost- evaluation in endoscopy	Appraisal evaluation
Procedures to be Perfomed			
1. UGI endoscopy examination 2. Sigmoidoscopy 3. Simple therapeutic procedures- enteric access - NGT insertion and luminal dilation 4. Hemostasis	1. Diagnostic Colonoscopy 2. Polypectomy 3. Esopahgeal Bougie Dilation 4. Enteral Access: NJT 5. Variceal therapy 6. PEG	Sideviewing scopy Chromoscopy NBI, FICE, AFI Luminal stents Pyloric and colonic dilation 1. Capsule endoscopy and its interpretation 2. EUS indications and image interpretation, applications(optional) 3. ERCP if likely to pursue second tier in hepatology	1. Intubations of different areas 2. Recognition of normal / abnormal 3. Appropriate knowledge and treatment of findings See details for endoscopy appraisal Appraisal to be taken for procedures observed

Basic endoscopy training year wise schedule:

<table>
<tr><th colspan="4">Procedures to be Observed/Assisted</th></tr>
<tr><th>First Year
Basic Skills</th><th>Second Year
Intermediate Skills</th><th>Third Year
Introduction to Advanced Skills</th><th>Objective performance criteria after prescribed numbers performed</th></tr>
<tr><td>1. Observation of colonoscopy and management of loop reduction
2. Theory pertaining to and practical assistance for higher procedures: PEG, APC, luminal stenting, hot biopsy polypectomies
3. Diagnosis of early cancers: NBI (if available and feasible) and chromoendoscopy</td><td>ERCP
EUS
Enteroscopy
Capsule Endoscopy
NBI</td><td>ERCP: applications, complications, post-procedure management, discharge, re-interventions, interpretation of ERCP images.

EUS observation and image interpretation, learning indications and applications

Animal Model training: ERCP, EUS, EMR, ESD Enteroscopy</td><td>Appraisal to be done for procedures observed

Conduct teaching program of Nurses and Technicians</td></tr>
</table>

MINIMUM NUMBER OF ENDOSCOPY PROCEDURES PERFORMED INDEPENDENTLY TO BE ELLIGIBLE FOR COMPETENCY EVALUATION

NO	Procedures	ACGME Procedure Requirement	Proposed at HBNI
1.	Esophagogastroduodenoscopy	130	200
2.	Flexible Sigmoidoscopy	25	025
3.	Colonoscopy	140	150
4.	Colonoscopy with Polypectomy	30	015
5.	Esophageal Dilation	20	025
6.	Wire Guided Enteral Access- NGT, NJT	-	NGT- 10, NJT- 10
7.	Variceal Hemostasis	20 cases, including 5 active bleeders	25 cases including 5 active bleeders
8.	Nonvariceal Hemostasis (upper & lower)	25 cases, including 10 active bleeders	025 cases including 010 active bleeders
9.	Side-viewing endoscopy and biopsy		010
10.	Other Diagnostic & Therapeutic Procedures Utilizing Enteral Intubation (Enteroscopy, Ileoscopy)	10	010
11.	Video-capsule endoscopy	10	010
12.	Luminal Stenting	-	005
13.	Percutaneous Endoscopic Gastrostomy	20	025
14.	Conscious Sedation	-	50
15.	ERCP Basic: observe and assist Advanced: Hands on training		Level 1: basic: 100 Level 2 Advanced : 150
16.	EUS Basic: observation Advanced: hands on training*	-	Level I: Minimum Mediastinal: 20 HPB: 20 Level 2 advanced training - 200
17.	Percutaneous Liver Biopsy	20	015
18.	PICC insertion		010
19.	Foreign body removal		005
20.	GI manometry and pH probe studies		010

NOTE:

The number of procedures given here, indicates the number to be performed before undertaking an assessment or appraisal. ACGME (The American Council for Graduate Medical Education) requires fellows to complete the specified number of procedures during the three training years. If there is no number provided in the following chart, this indicates that the ACGME does not require a specific number of these procedures. D.N. B has similar specification, although numbers may vary. The Society of GI Endoscopy of India and Indian Society of Gastroenterology do not have any guidelines for the same.

Proficiency is defined as understanding the clinical indications and contraindications, proper sedation techniques and intra-procedural monitoring, physical performance of the procedure, interpretation of abnormal and normal findings and proper post-procedural monitoring.

Fellows are required to maintain a written log of each procedure performed, the date, patient identification, findings and comments and to submit procedure log forms to trainer.

Program directors/ Head of Departments will sign the procedure log. The endoscopy procedure log is given in log book format section. During each of these procedure log submissions, fellows are required to submit in the following format.

- All procedures submitted since the start of their fellowship with a numerical total of each type of procedure.
- All procedures submitted since the last procedure log submission, assessment and appraisal.
- Improvement in specific areas after last appraisal.

X. PROFESIONAL COMPETENCY DEVELOPMENT AND ASSESSEMENT PARAMETERS:

A detailed guide of competency development both generic and core competencies is under preparation and will be submitted for review to the BOS, HBNI. Comptencies include both generic and core competencies as briefly outlined below:

1. **Development of Generic Competencies:** 'Generic competencies' are the knowledge, skills, attitudes and behaviors (KSA) required by physicians in all medical specialties to practice effectively. Generic competencies are therefore based on *Good Clinical Practice.* All trainees will be assessed for these periodically. These are described in the table on page no 30. These include:
   - A. **Mandatory (Level 1) Competencies:** *Good Clinical Practice* that a trainee **must** have achieved by the end of this training and is mandate for his graduation.
   - B. **Desirable (Level 2) Competencies:** In addition, it is highly desirable that Specialist trainees demonstrate acquisition of further competencies termed in the domains of Good Clinical Practice. This will help trainees to grow develop from being 'competent' to becoming an 'experts.

2. **Core Competencies in Gastroenterology: related to the speciality as proposed in the teaching strategy.**

Generic Competency to be achieved during training:

Focus Areas	**Level 1** **Mandatory CT Competency areas**	**Level 2** **Desirable CT Competency areas**
1. Good Clinical Care	1.1 History Taking	-
	1.2 Physical Examination	-
	1.3 Medical Record Keeping and Information Management Skills	-
	1.4 Diagnosis, Clinical Reasoning and Decision Making Skills	-
	1.5 Therapeutics and safe prescribing	-
	1.6 Time Management and Organizational skills	-
	1.7. Patient Centric service and Patient Education	-
	1.8 Patient Safety Concerns	-
	1.9 Infection Control	-
		1.10 Quality Improvement and Health Promotion
	1.11. Medical Ethics: Valid Consent	1.12. Medical Ethics and Legal Framework for Practice
		1.13. Managing Long Term Conditions & Promoting Patient Self- Care
2. Maintaining Good Clinical Practice	2.1. Medical Knowledge, evidence and guidelines	2.2. Clinical Audits
3. Communication Skills	3.1 Communication with Patients within a Consultation	3.2 Breaking Bad News 3.3 Complaints and Medical Error
4. Multidisciplinary Team Work	Working with Colleagues	-
5. Teaching and Training	Basic Teaching and Training skills	-
6. Professionalism	Professional Behavior	-
7. Research Ethics	Basic Ethics of Clinical Research	-

XI. TRAINEE ASSESSMENT METHODS:

Both generic and core competencies described will be assessed using an integrated package of "Workplace-based assessments" and examination of knowledge and clinical skills. The formal workplace-based assessment tools will include mini-CEX (mini- Clinical Examination) case based discussions (CBD) for clinical work, objective structure clinical examination (OSCE) for theoretical knowledge and DOPS (Direct Observation of Procedural Skills) for endoscopy and other procedures.

1. **Mini-Clinical Evaluation Exercice (Mini-CEX):** A method of assessment of skills essential for the provision of a good standard of clinical care. It will be done during monthly case presentations. A minimum of * (6 internal and 2 external) mini-CEX are recommended per year of training.

2. **Case Based Discussion (CBD):**
   - This method is designed to assess clinical judgment, decision-making and the application of medical knowledge in relation to patient care in cases for which the trainee has been directly responsible. CBD is conducted during routine case discussions during the OP clinics and ward rounds.
   - The method is particularly designed to test higher order thinking and synthesis as how trainees compile, prioritize and apply knowledge.
   - By using clinical cases that offer a challenge to the trainee, rather than routine cases, the trainee is able to explain the complexities involved and the reasoning behind choices they made. It also enables the discussion of the ethical and legal framework of practice.
   - It uses patient records as the basis for dialogue, for systematic assessment and structured feedback.
   - As the actual record is the focus for the discussion, the assessor can also evaluate the quality of record keeping and the presentation of cases. Most assessments take no longer than 15-20 minutes.
   - A minimum of 4 CBD will be conducted per year by internal faculty.

3. **Direct Observation of Procedural Skills (DOPS):**
    - This is used to assess the trainees' technical, operative and professional skills in a range of basic diagnostic and interventional procedures, or parts of procedures, during routine practice and will facilitate developmental feedback.
    - A minimum of 4 DOPS (2 internal and 2 external) can be conducted per year of training.

XII. TRAINEE APPRAISAL

1. Log Book
2. Endoscopy DOPS evaluation format
3. Annual Appraisal review format

1. **LOG BOOK: Enlists:** details of case presentations during evaluations, seminars, journal clubs, meetings and conference attendances. A log of endoscopy procedures done and assisted will be maintained separately as described below.

2. **ENDOSCOPY PROCEDURE EVALUATION**

Method: Direct Observation of Fellow by Supervising Training Faculty

The trainees performance will be evaluated Twice per year (November/December and May/June). Proficiency and competence in technique is based upon the observations from close supervision of the faculty in Endoscopy.

Year I, II and III trainees will receive a focused direct observation evaluation of procedural competency. This evaluation will be performed on one diagnostic and one therapeutic upper endoscopy and one diagnostic and one therapeutic colonoscopy twice per year. The evaluator will be the in-house consultant and may include one other external faculty. The evaluation will take place as part of the routine endoscopy procedures scheduled.

Given that competency develops over the three fellowship years, and certain aspects of procedural skills are learned with time, the task being evaluated is done according to the level of training expectation for each year. Related to the colonoscopy procedure, for example, insertion of scope into rectum should be achieved by all three years, whereas intubation of terminal ileum is expected only of Year III trainee.

At the completion of the evaluation, the faculty will provide written and verbal feedback. For any areas "not competent," the attending will discuss area(s) requiring remediation with the fellow and will repeat the evaluation at a later date after additional training has occurred (no more than eight weeks from original evaluation). If the fellow remains “not competent” in a certain area, further remediation and training will be provided by the program.

Year III trainee are only required evaluation once (July/August). If deficiencies are identified at that time, additional training will be administered by the program, and re-evaluation will occur in November/December.

Certification of procedural competence requires maintenance of a procedural log book. Log Book provides record of patient name, file numbers, diagnoses, procedure done, duration of procedure and sedation used, complications and recommendations for management based on the findings.

ENDOSCOPY PROCEDURE GENERAL EVALUATION FORM AND CHECKLIST

PART A

Trainee Name:	**Year #:**
HBNI Registration Number	
Procedure No:	**Date:**
No of Previous Procedures performed by trainee:	
Difficulty of Procedure: High Average Low	

Assessor Details
Number of Previous DOPS observed by assessor with any trainee:
Time taken for observation (minutes):
Time taken for Feed Back (minutes):
Evaluating Faculty - I: Internal
A. Assessors Name: **B. Assessors Signature:** **C. Assessors Registration Number:**
Evaluating Faculty – II: External
A. Assessors Name: **B. Assessors Signature:** **C. Assessors Registration Number:**

2. ENDOSCOPY PROCEDURE GENERAL EVALUATION FORM AND CHECKLIST

PART B1

Procedure Activity	Competency Skills – see guide below					
	1	2	3	4	5	6
Demonstrates understanding of indications, relevant anatomy , techniques of the procedure						
Obtains informed consent: Consents the patient for the procedure appropriately, explaining risks, benefits and alternatives of procedure (Years I, II & III)						
Demonstrates appropriate preparation for pre-procedure						
Understands the safe and proper administration of sedation (Years I, II & III) and has developed technical ability for administration and monitoring						
Aseptic technique						
Communication skills: Appropriate communication and orders given to nursing and technical staff (Year I, II & III)						
Seeks help when appropriate						
Generation of procedure report with appropriate recommendations (Year I, II & III)						
Post procedure management: Post-procedure review of findings and plan with patient and family/friend (Year I, II & III)						
Demontrates patient related professionalism						
Appropriate recognition of abnormal findings and action taken based on finding (Year II & III)						
When indicated, proper biopsy technique (Year II & III)						
Master scoping and patient manipulations to the degree that patient comfort is acceptable at						

the level of a beginning independent gastroenterologist (Year II & III)						
When indicated, proper snare polypectomy, dilation, NGT placement, EST, EVL, PEG, (Year III)						

Areas of Strength:

Areas of needing further development:

UPPER GI ENDOSCOPY EVALUATION FORM AND CHECKLIST

PART B2

Procedure Activity	Competent	Not Competent	Not Applicable
Successful and safe intubation of the esophagus (Year I, II & III)			
Evaluation of esophagus and recognition of GE junction (Year I, II & III)			
Evaluation of stomach to the pylorus (Year I, II & III)			
Evaluation of duodenum to second portion (Year I, II & III)			
Appropriate retrieval of scope (Year I, II & III)			
Retroflexion of scope in stomach (Year II & III)			
Intubation of pylorus (Year II & III)			

Areas of Strength:

Areas of Development

COLONOSCOPY EVALUATION FORM AND CHECKLIST

PART B3

Procedure Activity	Competent	Not Competent	Not Applicable
Digital rectal exam and insertion of scope into rectum (Year I, II & III)			
Passage of scope to the splenic flexure (Year I, II & III)			
Appropriate retrieval of scope and inspection of colon (Year I, II & III)			
Passage of scope to the hepatic flexure (Year II & III)			
Passage of scope to the cecum (Year II & III)			
Appropriate maneuvers utilized to reach cecum, (i.e., pressure on abdomen, rolling patient, etc.) (Year II & III)			
Retroflexion of scope in rectum (Year II & III)			
Passage of scope to the ileum (Year III)			

Areas of Strength:

Areas of Development

3. ANNUAL/ SIX MONTHLY PERFORMANCE APPRAISAL FORM: # YEAR:

Training started on: ……………….Period from…………..……to ………………

Rotational Postings in the past one year:

No	ATTRIBUTES	SCORE/REMARK
1	**Generic Competencies**	
2	**Specialty (core) competencies**	
3	**Other Procedure Skills**	
4	**Endoscopy DOPS**	
5	**Meeting Presentations**	
6	**Audits and Research**	
7	**Dissertation Progress**	

Final Score:

Remarks of Guide/Assessor/

	Name	Signature	Date
Trainee	…………………………..	…………………	…….....
Trainer/Research Guide	…………………………..	………………….	…….....
H.O.D	………………………….. …	……………………	…….....

XIII. TRAINEE FEEDBACK OF PROGRAM:

The key clinical faculty of the department will review the educational effectiveness of the training program at least once in six months. Annually, a more formal review of the training program, its goals, effectiveness in achieving past objectives, and curriculum will be reviewed by the department and report will be sent to HBNI. The third year fellows and senior trainees will participate in this process. The fellows will submit a written evaluation of the program to the division chief and program faculty.

Fellows Feedback:

1. Have you received a written curriculum guide?
2. Do you feel that your professional environment promotes your education?
3. Do you feel the program prepared you sufficiently for your chosen and/or current career path - through consultative experience, clinic experience, endoscopic experience, didactic and other conference attendance - with a breadth and depth of exposure to the patient disorders, clinical problems, and technical and other skills as outlined in the curriculum?
4. Do you feel that you are progressing satisfactorily to achieving competence in the core technical procedures? Are there specific core procedures that you can identify for which you feel the need for extra attention?
4. Do you feel that the program responds flexibly to the needs and interests of the individual trainee?
5. Is the program leadership accessible to discuss your concerns?
6. Do you feel that the program is concerned about your overall practice development?
7. Has the program encouraged and supported your participation in special meetings, travel, courses, etc which are of education benefit to you?
8. Have you been provided a semi-annual review of your evaluations?
9. Have you had the chance to review and provide feedback about your faculty?
10. What issues do you identify that require serious attention in the training program?
11. Do you have any other specific recommendations to help improve the training program?

XIV. LOG BOOK PAGES: attached as appendix 1

होमी भाभा राष्ट्रीय संस्थान
Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
PAREL, MUMBAI – 400 012

SYLLABUS

OF

DM CRITICAL CARE

(Program Code: HLTH10A04)

CURICULLAM OF DM (CRITICAL CARE)

The candidate must gain experience in the diagnosis and treatment of adult patients with acute, serious, and life-threatening medical and surgical diseases.

The present document defines the core curriculum of cognitive knowledge and procedural skills that a specialist in Critical Care Medicine is expected to be equipped with to effectively approach the complex problems encountered in the critically ill patient.

The content of this three-year training in critical care medicine deals with the learning objectives of the course focusing on acquisition of skills, knowledge, behaviour and attitude pertaining to following core domains. The list enclosed here is not comprehensive and can be modified time to time

(A) General curriculum

- Diagnosis : Assessment, Investigation, Monitoring and Data Interpretation
- Practical Procedures
- Comfort, Pain-Relief and Recovery
- Basics of Pediatric Critical Care
- Physics & Clinical Measurement
- Research Methods
- Applied Anatomy
- Applied Physiology & Biochemistry
- Applied Pharmacology

(B) Advanced curriculum

- Resuscitation and Initial Management of the Acutely Ill Patients
- Disease Management
- Therapeutic Interventions/Organ System Support in Single or multiple organ failure
- Inter and Intra hospital Transport of critically ill
- Peri-operative Care

(C) Professional qualities curriculum

- Patient Safety and Health Systems Management
- Professionalism and Ethics
- End of Life Care

Eligibility and Admission

The person applying for the DM course must be a postgraduate possessing MD/MS in Anaesthesiology, Internal Medicine, Respiratory Medicine, Pediatric and Emergency Medicine from a university recognized by the Medical Council of India. Admission would be made through a national competitive entrance examination.

Clinical Training Programme

In order to foster the growth of Critical Care Medicine, wherever stand-alone department of Critical Care Medicine do not exist, for the first ten years MCI should accept departments of Anaesthesiology, Internal

Medicine, Respiratory Medicine and Emergency Medicine as parent departments recognized to start DM in Critical Care Medicine.

The department should have been running general purpose adult intensive care (minimum 08 beds) for medical and surgical patients for at least two years before applying for DM in CCM. It should not be mandatory for the parent department (responsible for DM in CCM) to have (or manage) super-specialty postoperative intensive care for liver transplant, cardiac surgery or neurosurgery. However the students would be rotated through these intra-departmental ICUs if they exist in the institution.

The training programme for DM in Critical Care Medicine should be of 3 years (36 months) duration. The resident doctors would be spending their time in the following clinical disciplines:

A. Three month rotation in core discipline i.e. Intensive Care Units, High Dependency Units and Outreach Services of the Department of Critical Care Medicine.

B. Three month rotation in Anaesthesiology, Trauma and Emergency Care and Intensive Care Units of other disciplines like Cardiovascular and Thoracic surgery and Neurosurgery etc.

C. Three month rotation in clinical specialties like Cardiology, Nephrology, Neurology, Medical Gastroenterology, Endocrinology, Medical Oncology and Immunology etc.

D. Three month rotation in non-clinical specialties like Microbiology, Transfusion Medicine, Radiology and Nuclear Medicine etc.

E. Three month rotation of choice to cover any deficiency in pre-designed rotations.

Year	Semester	For candidates with MD in Anaesthesiology and Emergency Medicine	For candidates with MD in Internal Medicine	For candidates with MD in Pulmonary Medicine/ Tuberculosis and Chest Diseases	For candidates with MD in Pediatrics
1st	1st 2nd 3rd 4th	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 1B, ½ C, ½D
2nd	1st 2nd 3rd 4th	3 ½ A, ½ D	4A	4A	3A, 1B
3rd	1st 2nd 3rd 4th	2 ½ A, 1E, ½ C	2A, 1B, 1E	2A, 1B, 1E	2A, 1B, 1E

Educational Programme

Weekly Teaching Schedule

Days	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**

8-9 am OR 2.30 – 3.30 pm	Clinical case/ Case study	Lecture/ Audit	Institutional Clinico-Pathological Conference	CGR/ Radiology Conference	Journal Club/ Mortality meet	Joint Academic Meet/Seminar/ Progress in Research work

- DM Program Moderator : Faculty ‘A’
- DM Program Coordinator: Faculty ‘B’
- Mortality Meets Coordinator: Faculty ‘C’
- Radiology Conference Coordinator: Faculty ‘D’
- DM Dissertation: 2 dissertation to be presented : HOD and one faculty by rotation
    - Submission of protocols: within 6 months of joining DM course
    - Submission of final dissertation: at the end of 2 and half years.

Evaluation and Mode of Examination

DM candidates should at least have two manuscripts as first author likely to be accepted for publication. Examination will be held at the end of having completed three years of supervised training and having submitted two dissertations. The work could be either clinical, laboratory or combined. Three papers each of 3 hours duration and 100 mark each. (total 300 marks) would be given . They would include either 10 short questions or 2 long and 6 short questions. In addition, a candidate will have to appear in practical and clinical examination of 350 marks, candidate will have to pass both in theory and practical examination as given below for the DM degree.

Theory Examination:
Paper I (100 marks) : Basic and applied Critical Care
Paper II (100 marks) : Paper on clinical Critical Care
Paper III (100 marks): Advances in Critical Care

Practical and Clinical examination:
Two long cases (100 marks)
Two short cases (50 marks)
Case Exercises (50 marks)
Skills (ICU procedures) (50 marks)
Spots-Data analysis (50 marks)
Viva Voce (50 marks)

Evaluation and Mode of Examination

Domain	**Course Description**	**Credits for Theory Exam.**			**Credits for Practical Exam.**			**Credits for Research**
		Basic	**Clinical**	**Recent**	**Clinical**	**Practical**	**Viva-voce**	
CCM 1	Resuscitation and Initial Management of the Acutely Ill Patients							
CCM 2	Diagnosis : Assessment, Investigation, Monitoring and Data Interpretation							
CCM 3	Disease Management							
CCM 4	Therapeutic interventions/organ							

	system support in single or multiple organ failure							
CCM 5	Practical procedures							
CCM 6	Peri-operative care							
CCM 7	Comfort and Recovery							
CCM 8	End of life care							
CCM 9	Pediatric Care							
CCM 10	Transport							
CCM 11	Patient safety and health systems management							
CCM 12	Professionalism							
CCM 13	Physics & Clinical Measurement Mathematical Concepts							
CCM 14	Research Methods							
CCM 15	Applied Anatomy							
CCM 16	Physiology & Biochemistry							
CCM 17	Pharmacology							

The List of Course Contents

1. Resuscitation and Initial Management of the Acutely Ill Patients
   Adopts a structured and timely approach to the recognition, assessment and stabilization of the acutely ill patient with disordered physiology

Manages cardiopulmonary resuscitation
Manages the patient post-resuscitation
Triages and prioritises patients appropriately, including timely admission to ICU
Assesses and provides initial management of the trauma patient
Assesses and provides initial management of the patient with burns
Describes the management of mass casualties

2. Diagnosis : Assessment, Investigation, Monitoring and Data Interpretation

Obtains a history and performs an accurate clinical examination
Undertakes timely and appropriate investigations
Describes indications for echocardiography (transthoracic/transoesophageal)
Performs electrocardiography (ECG/EKG) and interprets the results
Obtains appropriate microbiological samples and interprets results
Obtains and interprets and results from blood gas samples
Interprets chest x-rays
Liaises with radiologists to organize and interpret clinical imaging
Monitors and responds to trends in physiological variables
Integrates clinical findings with laboratory investigations to form a differential diagnosis

3. Disease Management

Acute disease
Manages the care of the critically ill patient with specific acute medical conditions
Chronic Disease
Identifies the implications of chronic and co morbid disease in the acutely ill patient
Organ System Failure
Recognises and manages the patient with circulatory failure
Recognises and manages the patient with, or at risk of, acute renal failure
Recognises and manages the patient with, or at risk of, acute liver failure
Recognises and manages the patient with neurological impairment
Recognises and manages the patient with acute gastrointestinal failure
Recognises and manages the patient with acute lung injury syndromes (ALI/ARDS)
Recognises and manages the septic patient
Recognises and manages the patient following intoxication with drugs or environmental toxins
Recognises life-threatening maternal peri-partum complications and manages care under supervision

4. Therapeutic Interventions/Organ System Support in Single or Multiple Organ Failure

Prescribes drugs and therapies safely
Manages antimicrobial drug therapy
Administers blood and blood products safely
Uses fluids and vasoactive/inotropic drugs to support eh circulation
Describes the use of mechanical assist devices to support the circulation
Initiates, manages and weans patients from invasive and non-invasive ventilatory support
Initiates, manages and weans patients from renal replacement therapy
Recognises and manages electrolyte, glucose and acid-base disturbances
Co-ordinates and provides nutritional assessment and support

5. Practical Procedures

Respiratory system
Administers oxygen using a variety of administration devices
Performs fibreoptic laryngoscopy under supervision
Performs emergency airway management

Performs difficult and failed airway management according to local protocols
Performs endotracheal suction
Performs fibreoptic bronchoscopy and BAL in the intubated patient under supervision
Performs percutaneous tracheostomy under supervision
Performs thoracocentesis via a chest drain

Cardiovascular system

Performs peripheral venous catheterization
Performs arterial catheterization
Describes a method for surgical isolation of vein/artery
Describes ultrasound techniques for vascular localization
Performs ventral venous catheterization
Performs defibrillation and cardioversion
Performs cardiac pacing (transvenous or transthoracic)
Describes how to perform pericardiocentesis
Demonstrates a method for measuring cardiac output and derived haemodynamic variable

Central Nervous System

Performs lumbar puncture (intradural/spinal) under supervision
Manages the administration of analgesia via an epidural catheter

Gastrointestinal System

Performs nasogastric tube placement
Performs abdominal paracentesis
Describes sengstaken tube (or equivalent) placement
Describes indications for, and safe conduct of gastroscopy

Genitourinary System

Performs urinary catheterization

6. Peri-operative Care

Manages the pre and post-operative care of the high risk surgical patient
Manages the care of the patient following cardiac surgery under supervision
Manages the care of the patient following craniotomy under supervision
Manages the care of the patient following solid organ transplantation under supervision
Manages the pre and post-operative care of the trauma patient under supervision

7. Comfort, Pain-Relief and Recovery

Identifies and attempts to minimize the physical and psychosocial consequences of critical illness for patients and families
Manages the assessment, prevention and treatment of pain and delirium
Manages the administration of analgesia via an epidural catheter
Manages sedation and neuromuscular blockade
Communicates the continuing care requirements of patients at ICU discharge to health care professionals, patients and relatives
Manages the safe and timely discharge of patients from the ICU

8. End of Life Care

Manages the process of withholding or withdrawing treatment with the multidisciplinary team
Discusses end of life care with patients and their families/surrogates
Manages palliative care of the critically ill patient
Performs brain-stem death testing
Manages the physiological support of the organ donor

9. Paediatric Care

Describes the recognition of the acutely ill child and initial management of paediatric emergencies
Describes national legislation and guidelines relating to child protection and their relevance to critical care

10. Transport

Undertakes transport of the mechanically ventilated critically ill patient outside the ICU
Describes the special considerations required during patient transport by air.

11. Patient Safety and Health Systems Management
Leads a daily multidisciplinary ward round
Complies with local infection control measures
Identifies environmental hazards and promotes safety for patients & staff
Identifies and minimizes risk of critical incidents and adverse events, including complications of critical illness
Organises a case conference
Critically appraises and applies guidelines, protocols and care bundles
Describes commonly used scoring systems for assessment of severity of illness, case mix and workload
Demonstrates an understanding of the managerial & administrative responsibilities of the ICM specialist

12. Professionalism
Communication skills
Communicates effectively with patients and relatives
Communicates effectively with members of the health care team
Maintains accurate and legible records/documentation
Provides explanations and teaches multidisciplinary members of critical care team
Professional relationships with patients and relatives
Involves patients (or their surrogates if applicable) in decisions about care and treatment
Demonstrates respect of cultural and religious beliefs and an awareness of their impact on decision making
Respects privacy, dignity, confidentiality and legal constraints on the use of patient data
Professional relationships with members of the health care team
Collaborates and consults; promotes team working
Ensures continuity of care through effective hand-over of clinical information
Supports clinical staff outside the ICU to enable the delivery of effective care
Appropriately supervises and delegates to others, the delivery of patient care
Self governance
Takes responsibility for safe patient care
Formulates clinical decisions with respect for ethical and legal principles
Seeks learning opportunities and integrates new knowledge into clinical practice
Participates in multidisciplinary teaching
Participates in research or audit under supervision
Participates in the team approach with respect for team members

13. Physics & Clinical Measurement
Mathematical Concepts:
13.1 Relationships and graphs
13.2 Concepts of exponential functions and logarithms: wash-in and washout
13.3 Basic measurement concepts: linearity, drift, hysteresis, signal: noise ratio, static and dynamic response
13.4 SI units: fundamental and derived units
13.5 Other systems of units where relevant to ICM (e.g. mmHg, bar, atmospheres)
13.6 Simple mechanics: Mass, Force, Work and Power
Gases & Vapours:
13.7 Absolute and relative pressure.
13.8 The gas laws; triple point; critical temperature and pressure
13.9 Density and viscosity of gases.
13.10 Laminar and turbulent flow; Poiseuille's equation, the Bernoulli principle
13.11 Vapour pressure: saturated vapour pressure
13.12 Measurement of volume and flow in gases and liquids.
13.13 The pneumotachograph and other respirometers.
13.14 Principles of surface tension
Electricity & Magnetism:
13.15 Basic concepts of electricity and magnetism.

13.16 Capacitance, inductance and impedance
13.17 Amplifiers: bandwidth, filters
13.18 Amplification of biological potentials: ECG, EMG, EEG.
13.19 Sources of electrical interference
13.20 Processing, storage and display of physiological measurements
Bridge circuits

Electrical Safety:

13.21 Principles of cardiac pacemakers and defibrillators
13.22 Electrical hazards: causes and prevention.
13.23 Electrocution, fires and explosions.
13.24 Diathermy and its safe use
13.25 Basic principles and safety of lasers
13.26 Basic principles of ultrasound and the Doppler effect

Pressure & Flow Monitoring:

13.27 Principles of pressure transducers
13.28 Resonance and damping, frequency response
13.29 Measurement and units of pressure.
13.30 Direct and indirect methods of blood pressure measurement; arterial curve analysis
13.31 Principles of pulmonary artery and wedge pressure measurement
13.32 Cardiac output: Fick principle, thermodilution

Clinical Measurement:

13.33 Measurement of gas and vapour concentrations, (oxygen, carbon dioxide, nitrous oxide, and volatile anaesthetic agents) using infrared, paramagnetic, fuel cell, oxygen electrode and mass spectrometry methods
13.34 Measurement of H+, pH, pCO_2 , pO_2
13.35 Measurement CO_2 production/ oxygen consumption/ respiratory quotient
13.36 Colligative properties: osmometry
13.37 Simple tests of pulmonary function e.g. peak flow measurement, spirometry.
13.38 Capnography
13.39 Pulse oximetry
13.40 Measurement of neuromuscular blockade
13.41 Measurement of pain

14. Research Methods

Data Collection:

14.1 Simple aspects of study design (research question, selection of the method of investigation, population, intervention, outcome measures)
14.2 Power analysis
14.3 Defining the outcome measures and the uncertainty of measuring them
14.4 The basic concept of meta-analysis and evidence based medicine

Descriptive Statistics:

14.5 Types of data and their representation
14.6 The normal distribution as an example of parametric distribution
14.7 Indices of central tendency and variability

Deductive & Inferential Statistics:

14.8 Simple probability theory and the relation to confidence intervals
14.9 The null hypothesis.
14.10 Choice of simple statistical tests for different data types
14.11 Type I and type II errors
14.12 Inappropriate use of statistics

15. Applied Anatomy

Respiratory System:

15.1 Mouth, nose, pharynx, larynx, trachea, main bronchi, segmental bronchi, structure of bronchial tree and differences in the children's airway
15.2 Airway and respiratory tract, blood supply, innervation and lymphatic drainage

15.3 Pleura, mediastinum and its contents
15.4 Lungs, lobes, microstructure of lungs
15.5 Diaphragm, other muscles of respiration, innervation
15.6 The thoracic inlet and 1st rib
15.7 Interpretation of a chest x-ray

Cardiovascular System:

15.8 Heart, chambers, conducting system, blood and nerve supply
15.9 Congenital deviations from normal anatomy
15.10 Pericardium
15.11 Great vessels, main peripheral arteries and veins
15.12 Foetal and materno-foetal circulation

Nervous System:

15.13 Brain and its subdivisions
15.14 Spinal cord, structure of spinal cord, major ascending and descending pathways
15.15 Spinal meninges, subarachnoid and extradural space, contents of extradural space.
15.16 Cerebral blood supply
15.17 CSF and its circulation
15.18 Spinal nerves, dermatomes
15.19 Brachial plexus, nerves of arm
15.20 Intercostal nerves
15.21 Nerves of abdominal wall
15.22 Nerves of leg and foot
15.23 Autonomic nervous system
15.24 Sympathetic innervation, sympathetic chain, ganglia and plexuses
15.25 Parasympathetic innervation.
15.26 Stellate ganglion
15.27 Cranial nerves: base of skull: trigeminal ganglion
15.28 Innervation of the larynx
15.29 Eye and orbit

Vertebral Column:

15.30 Cervical, thoracic, and lumbar vertebrae
15.31 Interpretation of cervical spinal imaging in trauma
15.32 Sacrum, sacral hiatus
15.33 Ligaments of vertebral column
15.34 Surface anatomy of vertebral spaces, length of cord in child and adult

Surface Anatomy:

15.35 Structures in antecubital fossa
15.36 Structures in axilla: identifying the brachial plexus
15.37 Large veins and anterior triangle of neck
15.38 Large veins of leg and femoral triangle
15.39 Arteries of arm and leg
15.40 Landmarks for tracheostomy, cricothyrotomy
15.41 Abdominal wall (including the inguinal region): landmarks for suprapubic urinary and peritoneal lavage catheters
15.42 Landmarks for intrapleural drains and emergency pleurocentesis
15.43 Landmarks for pericardiocentesis

Abdomen:

15.44 Gross anatomy of intra-abdominal organs
15.45 Blood supply to abdominal organs and lower body

16. Physiology & Biochemistry

General:

16.1 Organisation of the human body and homeostasis
16.2 Variations with age
16.3 Function of cells; genes and their expression
16.4 Mechanisms of cellular and humoral defence

16.5 Cell membrane characteristics; receptors
16.6 Protective mechanisms of the body
16.7 Genetics & disease processes

Biochemistry:

16.8 Acid base balance and buffers Ions e.g. Na + , K+, Ca++ , Cl-, HCO3-, Mg++, PO4- Cellular and intermediary metabolism; variations between organs
16.9 Enzymes

Body Fluids:

16.10 Capillary dynamics and interstitial fluid
16.11 Oncotic pressure
16.12 Osmolarity: osmolality, partition of fluids across membranes
16.13 Lymphatic system
16.14 Special fluids: cerebrospinal, pleural, pericardial and peritoneal fluids

Haematology & Immunology:

16.15 Red blood cells: haemoglobin and its variants
16.16 Blood groups
16.17 Haemostasis and coagulation; pathological variations
16.18 White blood cells
16.19 Inflammation and its disorders
16.20 Immunity and allergy

Muscle:

16.21 Action potential generation and its transmission
16.22 Neuromuscular junction and transmission
16.23 Muscle types
16.24 Skeletal muscle contraction
16.25 Motor unit
16.26 Muscle wasting
16.27 Smooth muscle contraction: sphincters

Heart & Circulation:

16.28 Cardiac muscle contraction
16.29 The cardiac cycle: pressure and volume relationships
16.30 Rhythmicity of the heart
16.31 Regulation of cardiac function; general and cellular
16.32 Control of cardiac output (including the Starling relationship)
16.33 Fluid challenge and heart failure
16.34 Electrocardiogram and arrhythmias
16.35 Neurological and humoral control of systemic blood pressures, blood volume and blood flow (at rest and during physiological disturbances e.g. exercise, haemorrhage and Valsalva manoeuvre)
16.36 Peripheral circulation: capillaries, vascular endothelium and arteriolar smooth muscle Autoregulation and the effects of sepsis and the inflammatory response on the peripheral vasculature
16.37 Characteristics of special circulations including: pulmonary, coronary, cerebral, renal, portal and foetal

Renal Tract:

16.38 Blood flow, glomerular filtration and plasma clearance
16.39 Tubular function and urine formation
16.40 Endocrine functions of kidney
16.41 Assessment of renal function
16.42 Regulation of fluid and electrolyte balance
16.43 Regulation of acid-base balance
16.44 Micturition
16.45 Pathophysiology of acute renal failure

Respiration:

16.46 Gaseous exchange: O2 and CO2 transport, hypoxia and hyper- and hypocapnia, hyper-and hypobaric pressures
16.47 Functions of haemoglobin in oxygen carriage and acid-base equilibrium

16.48 Pulmonary ventilation: volumes, flows, dead space.
16.49 Effect of IPPV and PEEP on lungs and circulation
16.50 Mechanics of ventilation: ventilation/perfusion abnormalities
16.51 Control of breathing, acute and chronic ventilatory failure, effect of oxygen therapy
16.52 Non-respiratory functions of the lungs
16.53 Cardio-respiratory interactions in health & disease

Nervous System:

16.54 Functions of nerve cells: action potentials, conduction, synaptic mechanisms and transmitters
16.55 The brain: functional divisions
16.56 Intracranial pressure: cerebrospinal fluid, blood flow
16.57 Maintenance of posture
16.58 Autonomic nervous system: functions
16.59 Neurological reflexes Motor function: spinal and peripheral
16.60 Senses: receptors, nociception, special senses
16.61 Pain: afferent nociceptive pathways, dorsal horn, peripheral and central mechanisms, neuromodulatory systems, supraspinal mechanisms, visceral pain, neuropathic pain, influence of therapy on nociceptive mechanisms
16.62 Spinal cord: anatomy and blood supply, effects of spinal cord section

Liver:

16.63 Functional anatomy and blood supply
16.64 Metabolic functions
16.65 Tests of function

Gastrointestinal:

16.66 Gastric function; secretions, nausea and vomiting
16.67 Gut motility, sphincters and reflex control
16.68 Digestive functions and enzymes
16.69 Nutrition: calories, nutritional fuels and sources, trace elements, growth factors

Metabolism and Nutrition:

16.70 Nutrients: carbohydrates, fats, proteins, vitamins, minerals and trace elements
16.71 Metabolic pathways, energy production and enzymes; metabolic rate
16.72 Hormonal control of metabolism: regulation of plasma glucose, response to trauma
16.73 Physiological alterations in starvation, obesity, exercise and the stress response
16.74 Body temperature and its regulation

Endocrinology:

16.75 Mechanisms of hormonal control: feedback mechanisms, effect on membrane and intracellular receptors
16.76 Central neuro-endocrine interactions
16.77 Adrenocortical hormones
16.78 Adrenal medulla: adrenaline (epinephrine) and noradrenaline (norepinephrine)
16.79 Pancreas: insulin, glucagons and exocrine function
16.80 Thyroid and parathyroid hormones and calcium homeostasis

Pregnancy:

16.81 Physiological changes associated with a normal pregnancy and delivery
16.82 Materno-foetal, foetal and neonatal circulation
16.83 Functions of the placenta: placental transfer
16.84 Foetus: changes at birth

17. Pharmacology

Principles of Pharmacology:

17.1 Dynamics of drug-receptor interaction
17.2 Agonists, antagonists, partial agonists, inverse agonists
17.3 Efficacy and potency
17.4 Tolerance
17.5 Receptor function and regulation
17.6 Metabolic pathways; enzymes; drug: enzyme interactions; Michaelis-Menten

equation

17.7 Enzyme inducers and inhibitors.

17.8 Mechanisms of drug action Ion channels: types: relation to receptors.

17.9 Gating mechanisms.

17.10 Signal transduction: cell membrane/receptors/ion channels to intracellular molecular targets, second messengers

17.11 Action of gases and vapours

17.12 Osmotic effects

17.13 pH effects

17.14 Adsorption and chelation

17.15 Mechanisms of drug interactions:

17.16 Inhibition and promotion of drug uptake.

17.17 Competitive protein binding.

17.18 Receptor inter-actions.

17.19 Effects of metabolites and other degradation products.

Pharmacokinetics & Pharmacodynamics

17.20 Drug uptake from: gastrointestinal tract, lungs, nasal, transdermal, subcutaneous, IM, IV, epidural and intrathecal routes

17.21 Bioavailability

17.22 Factors determining the distribution of drugs: perfusion, molecular size, solubility, protein binding.

17.23 The influence of drug formulation on disposition

17.24 Distribution of drugs to organs and tissues:

17.25 Body compartments Influence of specialised membranes: tissue binding and solubility

17.26 Materno-foetal distribution

17.27 Distribution in CSF and extradural space

17.28 Modes of drug elimination:

17.29 Direct excretion

17.30 Metabolism in organs of excretion: phase I & II mechanisms

17.31 Renal excretion and urinary pH

17.32 Non-organ breakdown of drugs

17.33 Pharmacokinetic analysis:

17.34 Concept of a pharmacokinetic compartment

17.35 Apparent volume of distribution

17.36 Orders of kinetics

17.37 Clearance concepts applied to whole body and individual organs

17.38 Simple 1 and 2 compartmental models:

17.39 Concepts of wash-in and washout curves

17.40 Physiological models based on perfusion and partition coefficients

17.41 Effect of organ blood flow: Fick principle

17.42 Pharmacokinetic variation: influence of body size, sex, age, disease, pregnancy, anaesthesia, trauma, surgery, smoking, alcohol and other drugs

17.43 Effects of acute organ failure (liver, kidney) on drug elimination Influence of renal replacement therapies on clearance of commonly used drugs

17.44 Pharmacodynamics: concentration-effect relationships: hysteresis

17.45 Pharmacogenetics: familial variation in drug response

17.46 Adverse reactions to drugs: hypersensitivity, allergy, anaphylaxis, anaphylactoid reactions

Systemic Pharmacology

17.47 Hypnotics, sedatives and intravenous anaesthetic agents

17.48 Simple analgesics

17.49 Opioids and other analgesics; Opioid antagonists

17.50 Non-steroidal anti-inflammatory drugs

17.51 Neuromuscular blocking agents (depolarising and non-depolarising) and anti cholinesterases

17.52 Drugs acting on the autonomic nervous system (including inotropes, vasodilators, vasoconstrictors, antiarrhythmics, diuretics)

17.53 Drugs acting on the respiratory system (including respiratory stimulants and bronchodilators)
17.54 Antihypertensives
17.55 Anticonvulsants
17.56 Anti-diabetic agents
17.57 Diuretics
17.58 Antibiotics
17.59 Corticosteroids and other hormone preparations
17.60 Antacids. Drugs influencing gastric secretion and motility
17.61 Antiemetic agents
17.62 Local anaesthetic agents
17.63 Immunosuppressants
17.64 Principles of therapy based on modulation of inflammatory mediators indications, actions and limitations
17.65 Plasma volume expanders
17.66 Antihistamines
17.67 Antidepressants
17.68 Anticoagulants
17.69 Vitamins A-E, folate, B12

8. Assessment

Assessment would be comprised of (A) formative assessment during residency programme and (B) summative assessment at the completion of training.

(A) Formative Assessment during Residency Programme:

Integrated and coherent formative assessment of competence of the students during the residency programme shall be comprised of various suitable methods complemented by the provision of frequent and constructive feedback.

Feedback:

1. Feedback should be given to the trainees on regular basis.
2. The feedback should be about the overall integrated, coherent and longitudinal assessment of the trainee.
3. The feedback should be in the form of constructive suggestions for improvement in their performance.

Assessment shall be carried by supervising teachers with focus on:

1 Acquisition and application of knowledge and skills
2 Clinical reasoning and judgment in uncertain situations
3 Problem solving skills - Situation/Problem Based Learning
4 Skill development for diagnostic and therapeutic procedures
5 All above through departmental and extra department rotation

Formative assessment by suitable assessment method(s) should cover all competencies mentioned in the curriculum and include the following:

A. Cognitive Domain

Competence	Assessment Method(s)
1. Resuscitation and Initial Management of the Acutely Ill Patients	1 Case Presentation 2 Structured directed observation with check list 3 Objective Structured Clinical Examination (OSCE) including Problem solving skills – Problem situations and case scenario 4 Objective Structured Practical Examination (OSPE) 5 Porfolio a) Log Book (clinical cases)
2. Diagnosis : Assessment, Investigation, Monitoring and Data Interpretation	
3. Disease Management	
4. Therapeutic interventions/organ system support in single or multiple organ failure	
5. Peri-operative care	
6. Pediatric Care	

7. Transportation	b) Log Book (procedures) c) Log Book (extra-departmental rotation) 6 Structured essay
8. Research Methods	1. Short answer 2. Structured essay 3. Oral examination (viva-voce)
9. Physics & Clinical Measurement Mathematical Concepts	1. Short answer 2. Structured essay 3. Oral examination (viva-voce)
10. Applied Anatomy	
11. Physiology & Biochemistry	
12. Pharmacology	

B. **Psychomotor Domain**

Competence	Assessment Method(s)
1 Practical procedures	1. Structured directed observation with check list 2. Log Book (departmental procedures) 3. Log Book (extra-departmental procedures)

C, Affective Domain

Competence	Assessment Method(s)
1. Pain Relief, Comfort and Recovery 2. End of life care 3. Patient safety and health systems management 4. Ethics, Attitudes and Professionalism a. Integrity, Empathy & Patient Advocacy b. Self-Motivation & Time Management c. Appearance and Personal Hygiene d. Self-Confidence & Respect e. Communications f. Teamwork and Diplomacy g. Careful Delivery of Service	1. Case Presentation 2. Structured directed observation with check list 3. Objective Structured Clinical Examination (OSCE) including Problem solving skills – Problem situations and case scenario 4. Objective Structured Practical Examination (OSPE) 5. Structured essay 6. Incognito standardized method(s) 7. Oral examination (viva-voce)

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(B) Summative Assessment at the Completion of Training:

At the completion of training, summative assessment of competence of the students should be conducted by the examiners by methods as suggested below:

Competency	Method of Evaluation	Evaluator (s)
I. Patient Care	OSCE and OSPE Clinical evaluation exercises	Examiner(s)
II. Medical Knowledge	Key-feature and problem solving Short-answer questions Structured essays Oral examination	Examiner(s)

Composition of theory assessment:

1. Structured essay questions : 15%
2. Short answer questions : 55%
3. Problem based/ analysis/ interpretation : 30%

Composition of the Practical assessment:

1. OSPE/OSCE : 30%
2. Viva voce : : 20%
3. Cases / Exercises /Projects : 50%

Weightage of formative assessment in the final result: 40%

Final result = 40% of formative assessment + 60% of Summative assessment

होमी भाभा राष्ट्रीय संस्थान

Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL

PAREL, MUMBAI – 400 012

SYLLABUS

OF

D.M. in ONCO-PATHOLOGY

(Program Code: HLTH10A05)

Competency based Post graduate training programme for DM in Oncopathology
(Developed by MCI – Nominated Group of Experts)

1. **Preamble**

Competency based Post graduate training program for DM in Oncopathology aims to produce an Oncopathologist who after completion of training program should be able to offer adequate and timely laboratory support services in oncology diagnosis and be able to work as part of multidisciplinary team for overall management of patients with malignancies. He or she will understand all ancillary techniques used in oncology today and will be able to decide on the point of referral. He or she will also be able participatein quality management process in a histopathology laboratory.

2.Need Based assessment of Course

Cancer related morbidity and mortality forms a huge burden on the medical health care systems. Burden of oncologic diseases is increasing at an alarming rate in India. The past couple of decades have witnessed many scientific advances with an exponential expansion in our comprehension of pathobiology and tumorigenesis of malignancies leading to rapid evolution of diagnostic and treatment modalities that has led to improved outcomes. There is a huge unmet need in our country of skilled pathologists for diagnostic testing and monitoring of malignancies. Some of which are potentially curable if detected early and diagnosed accurately. The WHO classification of malignancies in new era, requires integration of clinical morphological, immunohistochemical and molecular data for diagnosis. There is currently no structured training program in India that provides training with a focus on all aspects of oncopathology. The above tests are available under one roof for training program in a handful of apex centres only whereas the requirement of these tests is in all comers of India. Every patient cannot reach these apex institutes for therapy. The oncologists treating these patients are handicapped to manage the patients without the requisite laboratory support. Lack of structured training also results in varied caliber of skilled pathologists. This leads to delay in diagnosis and management of the patients with its dire consequences. The proposed course is an attempt to bridge the gap in requirement, by training pathologists in skills related to cancer diagnosis and research.

There is a significant difference between a report signed out by a general surgical pathologist versus that signed out by a trained oncopathologist as basic training and philosophy is different. The minimal data set for histologic reporting that influences patient management based on the first surgical excision is actually generated at this first point of care. It is vital know that lack of inclusion of important criteria in a surgical pathology report to make it complete.

Over the years the Diagnostic oncopathology has grown with leaps and bounds and extended beyond morphology. The diagnostic armamentarium today includes many advanced ancillary techniques like immunohistochemistry, FISH, molecular techniques, flow cytometry etc. These tests are complex and require training of significant duration. These tests not only help in diagnosis and prognosis but also in personalization of therapy by detecting the target. The targeted therapy reduces the overall cost and toxicity of therapy and improves patient's outcome.

Current MD Pathology curriculum in majority of pathology training centres is restricted to basic and generalized pathology tests with focus on morphological training in surgical and cytological specimens. Students in MD PATHOLOGY course are mostly devoid of exposure to immunohistochemistry and/molecular tests for diagnostic work up as these centers lack facilities for such tests. This is due to requirement of high investment in infrastructure and technical expertise for establishing these tests. Recently. a number of predictive and prognostic markers in oncology are being incorporated into routine testing and are increasingly impacting treatment decision-making. These tests require close interaction between both the laboratory physician and treating physician and also understanding of therapeutic options for optimal management of the patient This is unavailable in the non-specialized training centers in India. Naturally this reflects on the training which can not be comprehensive.

Currently oncopathology is dealt by surgical pathologist and not an oncopathologist due to unavailability of formal training program. There is an evidence to show that trained oncopathologists are able to make a difference in diagnosis and overall management of malignancies world over. In fact, a dedicated oncopathology service is considered to be the back bone of cancer management as a proper and integrated diagnosis is a major determinant in outcome of the cancer patients in the era of targeted therapies. As the world of newer therapies based on molecular markers expands there will be a growing need for specialist oncopathologists in secondary and tertiary care levels of health care, in academic/government institution, large corporate hospitals, private laboratories, research laboratories and pharmaceutical companies in the next decade. There are excellent placement opportunities for trained oncopathology specialist in both private and public sector.need of centers with significant oncologic burden by providing the necessary laboratory support.

There is large pool of fresh MD pathologist who do not have any avenues for structured training for sub-specialization as the number of training posts in different fields of pathology is limited in India. This course will offer a novel avenue for further training. Young pathologists interested in cancer service or cancer research would avail of this course. After successfully completing the course, the "Oncopathology specialist' would get excellent placement opportunities in the private and public cancer centres.

-The specialists trained in DM Oncopathology will work as teachers in Medical college departments, teachingoncopathology and also sign out cancer related cases.

- The specialists trained in DM Oncopathology can also work in public or private pathology laboratories doing specialized testing for Oncopathology cases.

- The specialists trained in Oncopathology can pursue career in research in oncopathology

3. Eligibility for this Defined Course:

The trainee applying for the DM course in Oncopathology should be a postgraduate having MD degree in Pathology recognized by the Medical Council of India (MCI) or its equivalent degree recognized by Medical Council of India.

The other eligibility criteria would be as per general MCI rules/ condition. Admissions should be made through competitive examination as applicable in a particular state or medical institution and approved by the MCI.

4. Minimum Standard Requirement (Please refer PG regulation, 2000 available on MCI website)

The General minimum standard for running a postgraduate training program for DM in oncopathologyshall be as per the Post Graduate Medical Education Regulation 2000.

However on account of DM in Oncopathology being newly instituted postgraduate training program in India and resource constraints in Public – Funded Medical Institution the following relaxation would remain applicable for the initial period of about 10 years from date of approval of the course by Academic Council of MCI

Clause 11: Departmental training Facilities: There should be a department/ unit of Pathology as a stand-alone facility It should have a requisite minimum strength of full time faculty as prescribed in PG Medical Education Regulation,2000. They should have supportive department like major OT, Minor OT, ICU facility, microbiology, hematology and biochemistry laboratories.

The proposed three year degree program offers a very promising and rewarding career choice in oncopathology to post-graduates of pathology. The DM course in oncopathology should lead to a holistic growth and development of Oncopathology as a specialty in India from the academic and research point of view in addition to the basic need of offering comprehensive service.

At the end of training, the qualified resident doctor should have acquired thorough and comprehensive training in the various aspects of the specialty of Oncopathology to enable him/her to:

1. To function as a faculty/consultant in the specialty, confidently signing out report.
2. To shoulder the responsibility of an oncopathology section in a busy tertiary care hospital single handedly.
3. To understand the principle, application, interpretation and limitation of Oncopathology tests in relation to clinical problems
4. To participate actively in joint multi-disciplinary clinics making significant contribution in the patient care
5. To plan and set-up independent oncopathology service set-up catering to oncology care establishments
6. To set up, standardize and validate new test methodologies and maintain quality assurance for the same.
7. To teach, impart training and supervise students of oncopathology and junior colleagues
8. To carry out and help in conducting applied research in the field of oncopathology
9. To contribute towards growth of specialty including diagnostic, teaching and research

The curriculum, teaching and learning methodology and assessment methods shall be reassessed and reviewed every year.

Avenues available for this course

With advent in medical science, malignancies are detected early and are becoming increasingly treatable. The treatment costs are also reducing leading to more patients going in for curative intent therapy. For many cancers, specialized testing for predictive markers, for example, HER2 status, KRAS or EGFR mutation is critical for deciding choice of treatment. This has led to a pressing need for skilled pathologists trained in specialized tests essential for oncologic care. The specialists trained in DM Oncopathology will cater to the

Clause 11.1 Staff- Faculty: The minimum requirement for faculty should be 3 full time faculty members one of whom should be a Professor, one Associate Professor and one Assistant Professor. This requirement is for guidance in apex centers with extended staff managing a larger infrastructure. The minimum educational qualification for faculty is as follows.

Title	Qualification	Experience
Professor	MD in Pathology	At least 10 years Post MD experience of which 5 years at least should be as Associate Professor in a MCI recognized teaching hospital in Pathology Laboratory Minimum of 4 research publications in Indexed Journal
Associate Professor	MD in Pathology	At least 5 years Post MD experience of which 2 years at least should be as Assistant Professor in a MCI recognized leaching hospital in Pathology Laboratory Minimum of 2 research publications in Indexed Journal
Assistant Professor	MD in Pathology	At least 5 years Post MD experience of which 3 years teaching experience at MCI recognized teaching hospital in Pathology Laboratory

Clause 11.2 Minimum requirements for a Post Graduate Institution:

The department shall satisfy the minimum requirements for Post graduate training institution as per the MCI regulation.

Title	Qualification	Experience
Professor	MD in Pathology	At least 10 years Post MD experience of which 5 years at least should be as Associate Professor in a MCI recognized teaching hospital in Pathology Laboratory Minimum of 4 research publication in Indexed Journal
Associate Professor	MD in Pathology	At least 5 years Post MD experience of which 2 years at least should be as Assistant Professor in a MCI recognized teaching hospital in Pathology Laboratory Minimum of 2 research publications in Indexed Journal
Assistant Professor	MD in Pathology	At least 5 years Post MD experience of which 3 years teaching experience at MCI recognized teaching hospital in Pathology Laboratory

Clause 11.3 Bed Strength in Clinical Departments:

The department / Unit recognized for training in DM Oncopathology shall have attached training hospital with MCI recognized training for MCH in surgical oncology and / DM Medical Oncology.

Clause 11.4 Out-Patient departments:

The department / Unit recognized for training shall have minor OT for performing biopsy and OPD cubicles for fine needle aspiration procedure.

Clause 11.5 Laboratory Facilities:

The institution shall have adequate laboratory facilities for the training of the oncopathology students, and such laboratory shall provide all the facilities required for relevant investigations. These shall be regularly updated keeping in view the continuous advancement of knowledge, technology and research requirements. For training of students in non-clinical departments, proper and contemporary laboratory facilities shall be made available.

Pathology Laboratory: The laboratory should have a minimum annual work load of.

- **25000 specimens / year belonging to different systems**
- **5000 FNAC / year**
- **5000 Exfoliative cytology specimens, including Gynaec cytology / year**
- **1000 frozen sections/ year**

Haematology Laboratory: The laboratory should have a minimum work load of.

- 100 Complete blood counts/day
- 50 Peripheral Blood smears/day
- 50 Coagulation tests/day
- 1000 bone marrow aspiration smears/years
- 500 bone marrow biopsies/ years
- 100 body fluids specimens/ years

Immunohistochemistry Laboratory : Laboratory should have facility for adequate panels of immunohistochemistry for cancer diagnosis and prognostication/prediction. The laboratory should have a minimum work load of 3000 IHC tests / years

Molecular and Cytogenetics Laboratory : Laboratory should have facility for in-situ hybridization and molecular testing. There should be a minimum workload of 500 tests per year for different malignancies (solid and hematolymphoid malignancies)

Flow Cytometry Laboratory : There should be a flow cytometry laboratory processing at least 500 specimen per year for immunophenotyping.

Clause 11.5 Equipment:

The department / Unit recognized for training shall be equipped with the following Equipments.

- **Microscopes including teaching microscope**
- **Equipments for tissue processing & cutting**
- **Equipment for Immunohistochemistry**
- **Equipments for frozen section**

- **Cytocentrifuge for cytospin preparation**
- **Equipments for processing samples for molecular testing**
- **Flow cytometer**
- **Thermal cyclers and other molecular laboratory equipments including equipments for PCR, in-situ hybridization and gene sequencing**
- **Fluorescent microscopes for FISH**
- **Biosafety cabinets**

Clauses 12. Number of Post Graduate Students to be admitted.

The number of students to be admitted in case of DM Oncopathology courses shall be one student per year per MCI recognized Post Graduate teacher in department of pathology.

5. Curriculum:

The program has been designed to give the student comprehensive training in laboratory service of oncology, to enable them to follow a subsequent career pathway in either academic or oncology.

The curriculum of three years in training in DM Oncopathology includes

1. Theoretical knowledge in the subject
2. Practical and clinical skills
3. Writing Project / Research articles
4. Interpersonal relationship and communication skills.
5. Training in Research Methodology , Medical Ethics and Medico- legal aspects

09HLTH10A05-001-C: Theoretical knowledge

The course for Theoretical knowledge is under following heads normal

- Basic anatomy, embryology, physiology and immunophenotype of normal histologic tissues of different systems.
- Basic cell biology, carcinogenesis and molecular pathways.
- Proto-oncogenes and Tumor Suppressor Genes in Malignancies
- Grossing protocols of all common oncosurgical specimens and guidelines for handling all other specimens. Protocols for Obtaining tissues for ancillary methods
- Parts, working and quality assurance of important instruments like light and fluorescent microscopes, tissue processor, microtome, cryostat immunohistochemistry staining set-up (manual and automated), flow cytometer, PCR and nucleic acid sequencers.
- Types of fixatives, reagents in tissue processing, routine stains, histochemical stains and molecular techniques.
- Immunohistochemistry principle, basics, methods, [manual automated], trouble shooting and quality assurance
- Frozen section principle, technique, stains, artifacts and indication
- Principle, quality control and interpretation of data from automated counters
- Bone marrow aspiration techniques, staining, interpretation
- Flow cytometry- principles and applications
- Knowledge of evidence based guidelines and principles
- Pathogenesis and diagnostic approach and work up benign and neoplastic disease of Head and Neck, including recent advances
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Breast, including recent advances
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Gastrointestinal tract, including recent advances.

- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Lung and mediastinum, including recent advances.
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Female genital system, including recent advances.
- Pathogenesis and diagnosis approach and work up of benign and neoplastic diseases of Male genital system. Including recent advances
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Soft tissue, including recent advances
- Pathogenesis diagnostic approach and work up of benign and neoplastic diseases of Bone, including recent advance
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Hematolymphoid organs, including recent advance
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Urinary tract, including recent advances
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Endocrine organs, including recent advances
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Paediatric age group, including recent advances
- Pathogenesis and diagnostic approach and work up od benign and neoplastic diseases of Central nervous system, including recent advances
- Pathogenesis and diagnostic approach and work up of benign and neoplastic diseases of Skin, including recent advances
- WHO classification of tumours
- AJCC/TNM classification of cancer
- Bone marrow and liver transplantation
- HLA and Transplant immunology
- Research methodology
- Quality management system including quality control, quality assurance and quality indicators in laboratory medicine
- Laboratory accreditation
- Safety in laboratory practices
- Medico-legal aspects and ethical guidelines in oncopathology.

09HLTH10A05-001-P: Practical and clinical skills

The trainee should be able to do the following in cognitive and psychomotor domain.

- Grossing of all types of oncopathology tissue specimens
- Interpretation and diagnosis of routine and complex clinical problems and various tests under the domain of oncopathology
- Interpret and integrate clinical and laboratory data with reasonable accuracy
- Correlate and advise further on relevant pathology data such that various
- Staining and quality control of Hematoxylin and eosin, Papanicolaou and Giemsa stains
- Staining, standardization and quality control of Histochemical stains (including Mucicarmine, Alcian Blue, Reticulin, Periodic Acid Schiff (PAS), Pearls tain, ZielNeelson stain, Gomori's Methanamine Silver, Elastic Van Gieson, Masson Trichrome stain, PTAH, Myeloperoxidase Nonspecific Esterase, Toluidine Blue stain and Congo Red stain)
- Prepare and stain peripheral blood smear, bone marrow aspiration smear, imprint cytology and squash cytology smear
- Perform Bone marrow aspirate and biopsy
- Tissue processing techniques and quality control
- Performing Fine Needle Aspiration (FNA), and preparing smears
- Performing on-site adequacy testing for image guided biopsies
- Processing all types of cytology specimens
- Interpretation of frozen section and principles.
- Standardization and validation of newer antibodies and quality assurance in IHC lab
- Technique of staining and interpretation of immunohistochemistry
- Processing and Interpretation of flow cytometry data
- Extraction of Nucleic acids from blood, bone marrow and cytology specimens
- Extraction of nucleic acids from Formalin fixed paraffin embedded tissues
- Interpretation of RT-PCR, FISH and DNA sequencing
- Familiarity with the function, handling and routine care of equipment in the laboratory
- Teaching oncopathology to postgraduates, nurses and paramedical staff including laboratory personnel
- Supervising work of subordinate laboratory staff and colleagues
- Initiate research questions and systematically write or present a paper and publish in a journal
- Be aware of quality control and bio-safety and waste disposal issues in a laboratory
- Constantly update knowledge of recent advances in oncopathology and allied subjects

09HLTH10A05-001-R: Writing project/ Research articles

- Identification of important peer reviewed journals.
- Demonstrate ability to search literature for information
- Evaluate levels of evidence in literature
- Demonstrate ability to critically evaluate published studies
- Demonstrate ability to design, plan and do a research study/ audit as part of curriculum
- Demonstrate ability to take informed consent before procedures

09HLTH10A05-002-C: Inter-personal relationship and communication skills.

- Understanding of importance and criticality of the laboratory tests and reports
- Demonstrate objectivity in interpretation of morphology
- Understand ones limitation in interpretation of tests and knowledge and to communicate the same to colleagues
- Give importance to patient safety and safety of staff in the laboratory
- Demonstrate skills in teaching junior staff, laboratory workers and medical colleagues
- Demonstrate effective communication skills in explaining reports to patients, delay in reports and counseling them if necessary including disclosure of laboratory errors
- Demonstrate effective communication skills in interacting with clinical and multidisciplinary teams indifficult cases
- Demonstrate capability to work in a team and avoid communication breakdowns
- Understanding of managerial and administrative responsibility of laboratory.
- Demonstrate leadership skills in managing laboratory
- Ability to perform root cause analysis of critical including occurring in laboratory in technical and interpretative processes
- Understand importance of maintaining and improving quality in pre and post analytical phases

09HLTH10A05-003-C: Training in Research Methodology, Medical Ethics and Medicolegal aspects

- Training in study design, power analysis, data collection and defining outcome measures
- Training in descriptive statistics and inferential statistics
- Understanding privacy and confidentiality of patient data
- Adopting ethical practices in conducting research

1. Teaching and Learning Methodology

Teaching and Learning Methodology includes

- Lectures
- Slides Meetings by faculty including MAPCON
- Slides meeting by students
- Specialty discussion/ case reviews
- Clinicopathologic conferences
- Multidisciplinary joint meeting and Tumour boards
- Journal Clubs
- Gross /Specimen meetings
- PPT of staff presentation

The trainees shall maintain a log book of their academic activities

Training schedule over 36 months

Sr.No	Rotation to specialty/ name of service	Duration
1.	Grossing of specimens	2 months
2.	Frozen section lab	1 month
3.	Surgical Pathology, specialty-wise training	24 months
4.	Techniques in immunohistochemistry and histopathology laboratory including histochemistry	2 months
5.	Molecular pathology lab	2 months
6.	Cytology lab	1 months
7.	Hematology lab	2 months
8.	Research/Thesis	2 months

- This posting includes rotation through all sub-specialties and encompasses training in surgical pathology, FNAC, exfoliative cytology, IHC and molecular pathology reporting related to each sub-speciality

  The resident shall attend joint-clinics and academic meetings of the sub-speciality in which he/she is posted

  The resident shall complete a minimum of one Institute ethics committee (IEC)-approved project/thesis during his tenure under the guidance of his teacher

  Project/ thesis plan shall be submitted to IRB within the first 4 months of joining for approval of IEC .The resident shall be trained in Good Laboratory Practices (GLP)

2. **Assessment**

   Assessment would comprise of (I) Formative Assessment during residency program and (B) Summative Assessment at the completion of training

(I) Formative Assessment (Total score- 200 Marks): This have two parts-

A) **Appraisal** (at the end of two years) (Maximum score – 100)

The assessment shall consist of a combination of Structured MCQ and Short answers [50 marks] There shall be in addition assessments by faculty for teaching ability, interpersonal communication skills and professionalism [50 marks]

B) **Academic assessment**(over 3 years course period) **(Maximum score – 100**)

- 10 points for each publication [other than a case report] in a peer reviewed journal during the 3 years course
- 5 Points for publication of a case report in peer reviewed journal
- 5 point for each state, national conference or major hospital presentation
- 10 points for each national conference paper presentation in award session
- 10 points for each international conference presentations
- 5 Points for each Case based analysis/ interpretation for morphology and approach
- 5 points for receiving an award

There shall be regular appraisal and feedback to the teachers for the formative assessments.

Candidate with a minimum of 40% score [80 marks] in the internal assessment will be allowed to appear in the Final examination

(II) Summative Assessment shall be at the end training of 3 year and shall consist of

1. Theory evaluation
2. Practical Skill evaluation

Theory evaluation : shall consist of 4 papers of 100 marks each

Paper I – Basic Cancer Biology and laboratory techniques

PaperII – Systemic Oncopathology I (Breast, Hematolymphoid, Bone and Soft tissues, neurooncopathology,Paediatric oncopathology and endocrine pathology)

Paper III – Systemic Oncopathology II (Head Neck, gastrointestinal, thoracic, Urologic, male genital and female genital tract)

Paper IV – Recent advances in Oncopathology and molecular pathology

Practical Skill Evaluation: Shall consist of following components (600 Marks):

1. Histopathology slides (250 Marks)
2. Cytology and haematology slides (150 Marks)
3. Clinicopathological exercises (25 Marks)
4. Spots (25 Marks)
5. Gross (25 Marks)
6. Lab techniques (25Marks)
7. Evaluation of Thesis/Project: (50 Marks)
8. Viva Voce (50 Marks)

The Final Assessment shall have a component from Formative assessment [200 marks] and Component from Summative Assessment [1000 marks] with total marks pf 1200.

Minimum 600 marks [with individual passing in theory and practical] need to be obtained for successfully passing the examination.

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D.M.
INTERVENTIONAL RADIOLOGY
Under TMC
(Program code: HLTH10A06)

Curriculum for DM (Interventional Radiology)

Preamble:

The DM (Interventional Radiology henceforth referred to as IR) program is designed to provide the students with an organized, comprehensive and supervised education in the principles and practice of body, chest, musculoskeletal and cardiovascular radiology and the interventional techniques in the use of image-guided techniques in the above body systems. The course will also include in-depth training in the physical aspects of imaging, hazards of radiation and measures of protection.

Essential Requirements:

MD or DNB in Radiodiagnosis from an institution/university recognized by the Medical Council of India.

Upper Age limit: 35 years with relaxations as per the Govt. of India rules

Selection Methodology:

By a selection process, including an entrance examination pertaining to the systems listed above; and an interview/practical examination for assessment of past performance, curricular ability to imbibe training, and case presentation for assessing the examinee's communication skills and targeted problem-solving approach.

***Course Duration*: 3 years**

Scope of Services

The DM (IR) Program provides didactic and clinical experiences covering the full-spectrum of body, chest, musculoskeletal and cardiovascular radiology and the interventional techniques in the use of image-guided techniques in the above body systems. The course will also include in-depth training in the physical aspects of imaging, hazards of radiation and measures of protection. Both diagnostic and interventional vascular & non-vascular procedures will be included in the training program. The candidates will be required to obtain an in depth knowledge of imaging of vascular as well as non-vascular diseases with computed tomography, magnetic resonance imaging, conventional radiological techniques and Color Doppler Ultrasound, vascular procedures including diagnostic arteriography, vascular recanalization techniques by angioplasty/ stenting or clot lysis, embolization, endovascular stent grafts, embolotherapy, transcatheter infusion therapy, IVC filters, radiofrequency ablation, percutaneous procedures for osseous & soft tissue pathologies and venous access.

Objectives:

The main objective of the course is to rationalize the DM (IR) candidate's clinical acumen and analytical abilities so as to make him capable of taking appropriate decisions with regards to the execution of all interventional therapeutic and diagnostic procedures. This includes performance and interpretation of imaging procedures relating to the vascular (venous and arterial) systems of the body, as well as invasive (interventional) procedures for vascular & non-vascular disorders exclusive of the neurologic system (brain and spinal cord). The opportunity and skills to become a provider of top quality patient care, be a knowledgeable and inspiring teacher, and to perform clinical and experimental research in the field of vascular and interventional radiology will also be provided.

Upon completion of his training, the DM (IR) candidate should be able to:

1. Become familiar with the signs and symptoms of vascular & non-vascular disorders amenable to diagnosis and/or treatment by percutaneous methods guided by radiologic imaging.
2. Gain experience in interpreting non-invasive evaluations of vascular diseases of the arterial and venous systems.
3. Become familiar with the medical and surgical therapeutic alternatives of these disorders.
4. Become familiar with the indications and contraindications for vascular and non-vascular interventional radiologic procedures.
5. Gain experience in performing preprocedural clinical evaluation of patients and providing post procedural follow-up care
6. Perform and interpret invasive vascular interventional techniques including endovascular recanalization, reconstruction and embolization.
7. Gain exposure to new and evolving interventional techniques & technology such as Radiofrequency ablative therapy and tumor chemo & particulate embolization.
8. Become familiar with the signs and symptoms of cardiac, body, chest, musculoskeletal and peripheral system disorders that would help him to perform and interpret non-invasive investigations tailored to the clinical question.
9. Obtain an in-depth training in the physical aspects of imaging, hazards of radiation and measures of protection.

The candidate will be encouraged to inculcate relevant knowledge in anatomy, pathology, biochemistry and physiology of vascular & non-vascular diseases, imbibe patient management skills through direct patient care, and update his skills and knowledge through attending academic conferences, CMEs and hands-on workshops.

Research

Candidates will be required to participate in at least 2 research projects during the course. Clinical and experimental research oriented to understand, analyze and improve upon the existing knowledge of vascular and interventional radiological procedures should be the primary objective of this exercise. The candidate will also be introduced to the ethical and moral aspects of human and animal research through the exercise. He/she should make all efforts to publish the outcome of the projects in peer-reviewed journals, with at least one project being published. A dedicated research time will be provided in the curriculum. The candidate will be encouraged to become well versed in the techniques of research methodology by participating in the statistics courses organized at the institution.

Teaching

The candidate will be encouraged to develop his teaching skills by undertaking didactic lectures and practical demonstrations for the undergraduate and postgraduate students at the institute. The candidate will also get the opportunity to present Journal Club (one per week), case review (one per week), and academic seminar (one in 2 weeks) to peer groups. He will also get to participate regularly in the clinico-radiological conferences and multi-specialty conferences during his/her training period.

Educational Curriculum

The training program is designed to provide the candidate a closely supervised and comprehensive exposure of the clinical and radiological aspects of vascular and non-vascular diseases, through practical experience and supervised training. All aspects of image acquisition, physical aspects of the equipments and hazards of radiation & measures of protection will be taught.

The training in interventional vascular & non-vascular techniques will be provided in the angiography/fluoroscopy suites. The curriculum also includes rotations through the non-invasive imaging services to gain experience with performance and interpretation of imaging of different body parts (CT, MRI and Doppler) techniques. Special emphasis will be laid on recent advances in imaging and image-guided interventional techniques.

1st Year:

09HLTH10A06-001-C **Basics of Clinical aspects:**

- Clinical and Laboratory Considerations
    - Symptomatology and staging of vascular disease
    - Laboratory data (including non-imaging aspects of noninvasive vascular testing; for example, ankle-brachial indices for lower extremity arterial disease, impedance plethysmography for lower extremity venous disease)
- Epidemiology of vascular & non-vascular diseases
- Natural history of vascular disorders
- Vascular anatomy: arterial and venous
    - Embryology
    - Normal anatomy
    - Variant anatomy
    - Anatomy of collateral pathways
- Vascular physiology, pathology and pathophysiology: arterial system
    - Normal histology/physiology/morphology
    - Hemodynamics: normal and abnormal flow
    - Vasoactive extrinsic/pharmacologic agents
    - Disorders related to pharmacologic/extrinsic agent exposure
- Atherosclerosis
- Medial sclerosis
- Pathophysiology of arterial ischemia
- Aneurysms
- Thromboembolic disorders
- Dissection
- Congenital vascular disorders
    - Vascular malformations
    - Other congenital disorders (eg. popliteal artery entrapment)
- Arterial effects of adjacent tissues/disorders
- Arterial infection
- Vascular alterations in neoplasia: vascular supply of neoplasms, primary vascular neoplasms, vascular invasion by neoplasms
- Vascular alterations in inflammatory diseases
- Systemic vascular disorders
    - Primary systemic vascular disorders: vasculitides and others
    - Altered vascular pathology in systemic disease states
- Vascular trauma: injuries and vascular response to injury
    - Mechanical injury: acute and chronic
    - Thermal injury
- Arterial endothelium
- Alterations in coagulation status

    - Hypercoagulable states
    - Impaired coagulation
- Post-operative or post-interventional disorders
    - Synthetic and endogenous grafts
    - Myointimal hyperplasia
- Other/unclassified
- Vascular physiology, pathology and pathophysiology: venous/pulmonary arterial system
    - Normal histology/physiology/morphology
    - Hemodynamics: normal and abnormal flow
    - Vasoactive extrinsic/pharmacologic agents
        - Normal response
        - Disorders related to pharmacologic/extrinsic agent exposure
    - Thromboembolic disorders: acute and chronic
    - Venous aneurysms
    - Venous effects of adjacent tissues/disorders
    - Congenital vascular disorders
        - Vascular malformations
        - Other congenital disorders
    - Venous infection
    - Vascular alterations in neoplasia: vascular drainage of neoplasms, primary vascular neoplasms, vascular invasion by neoplasms
    - Vascular alterations in inflammatory diseases
    - Systemic vascular disorders
        - Primary systemic vascular disorders
    - Altered vascular pathology in systemic disease states
    - Vascular trauma: injuries and vascular response to injury
        - Mechanical injury—acute and chronic
        - Thermal injury
    - Venous endothelium
    - Alterations in coagulation status
        - Hypercoagulable states
        - Impaired coagulation
    - Post-operative or post-interventional disorders
        - Synthetic and endogenous grafts
        - Intimal hyperplasia
    - Other/unclassified
- Cardiac anatomy, physiology, pathology and pathophysiology

    - Normal anatomy of the pericardium and myocardium
    - Normal coronary anatomy
    - Cardiac metabolism and function
    - Cardiac hemodynamics

- Pulmonary arteries and veins
    - Pulmonary artery hemodynamics (as related to pulmonary angiography)
    - Pulmonary thromboembolic disease
    - Pulmonary arteriovenous malformations
    - Pulmonary venous disorders
- Cardiac disorders
    - Congenital heart diseases
    - Acquired heart diseases : ischemic heart diseases
    - Acquired heart diseases : valvular, endocardial, myocardial, and pericardial
    - Post-operative and post-interventional disorders including synthetic and endogenous valve prosthesis, pericardial and synthetic baffles, PTFE and endogenous shunt materials, bypass grafts, intimal hyperplasia in coronary stents

<u>09HLTH10A06-002-C</u> Basics of interventional vascular/non-vascular catheterization laboratory

- Workplace considerations
    - The vascular/interventional radiology suite
        - Equipment
        - Fluoroscopy
        - Standard angiography
        - Digital angiography
        - Image processing and recording
        - Other equipment (e.g. interventional ultrasound units)
        - Layout
    - Noninvasive vascular laboratories
        - Equipment – Color Doppler, CT and MRI
        - Management
        - Occupational Safety Issues
    - Radiation safety and hygiene
    - Infection control
    - Others
- Patient Considerations

- Pre-procedural assessment and care
- Intraprocedural monitoring
- Post-procedural follow up and care
- General pharmacologic considerations
    - Analgesia/anesthesia
    - Conscious sedation
    - Antibiotic therapy
    - Anticoagulation
    - Other

- Personnel Considerations
- The vascular/interventional radiology "team": role and relationship of nurses, technologists, trainees, other physicians

2nd Year:

09HLTH10A06-003-C **Imaging of the vascular & non-vascular system: general principles**

- Plain film
- Angiography: arteriography and venography
    - Standard angiography
    - Digital subtraction angiography
    - Contrast agents
        - Iodinated agents
        - Carbon dioxide
    - Vascular catheterization
        - Equipment: needles, guide wires, catheters, etc.
        - Vascular access
        - Selective and subselective catheterization
    - Risks and complications
        - Contrast reactions, iodinated agents
            - Anaphylactoid reactions
            - Classification
            - Prevention
                - Ionic vs. nonionic agents
                - Premedication

        - Treatment
    - Dose dependent reactions
        - Classification
            - Acute and chronic renal effects
            - Other
        - Prevention
        - Treatment

  - Procedural complications

    - Puncture site complications
    - Catheterization-related complications (apart from puncture site)
    - Systemic/generalized complications

  - Pharmacoangiography: agents and uses

    - Vasodilatation
    - Vasoconstriction
    - Other

  - Intravascular Ultrasound
- Ultrasonography

    - Gray scale
    - Duplex Doppler
    - Color flow

- Computed Tomography

    - General
    - Spiral and Multislice CT
    - CT angiography

- Magnetic Resonance Imaging

    - General-vascular & non-vascular
    - Cardiac MRI protocols
    - Blood flow evaluation and MR angiography

3rd Year:

09HLTH10A06-004-C Vascular Intervention: General

- Common Topics: vascular interventional procedures
    - Anatomic considerations
    - Indications and contraindications
    - Techniques, devices, materials
    - Results, efficacy
    - Risks and complications
    - Alternate techniques (surgical and medical therapeutic options)
- Vascular canalization/recanalization: re-establishment of flow
    - Thrombolytic therapy
        - Pharmacologic thrombolysis
            - General principles
            - Specific agents: urokinase, streptokinase, tissue plasminogen activator, others
        - Mechanical techniques
            - Fogarty balloon
            - Suction thromboembolectomy
            - Other/newer devices
    - Balloon angioplasty
    - Atherectomy
    - Laser recanalization
    - Mechanical recanalization
    - Vascular stents
    - Endovascular grafts
    - Other
- Vascular blockade: obliteration of flow
    - Embolization
        - Techniques
            - Transcatheter
            - Direct injection
        - Agents
    - Other methods
        - Ultrasound guided compression repair
- Re-routing of flow
    - Endovascular repair of aneurysms
    - Creation of new vascular channels (e.g. TIPS, fenestration of aortic dissection)
- Vascular filters

- Vascular foreign body removal
- Intravascular/transvascular biopsy
    - Transvenous liver biopsy
    - Other

<u>09HLTH10A06-005-C</u> **Vascular Intervention: Specific territories**

- Lower extremity vascular disease
    - Arterial
        - Occlusive atherosclerotic disease: recanalization
            - Aortoiliac
            - Femoropopliteal
            - Tibioperoneal
        - Intervention for peripheral arterial trauma
        - Thromboembolic disorders: recanalization
        - Peripheral arterial graft failure: recanalization
        - Iatrogenic disorders: therapy for puncture site complications
    - Venous
    - Combined: vascular malformations: obliteration
- Upper extremity vascular disease
    - Arterial
        - Thromboembolic disorders: recanalization
        - Trauma
    - Venous
        - Acute upper extremity venous thrombosis: recanalization
        - Chronic upper extremity venous thrombosis: recanalization
    - Combined: vascular malformations: obliteration
    - Venous varicose-Radiofrequency ablation
- Thoracic vascular disease
    - Hemoptysis
        - Bronchial artery embolization
        - Other techniques
    - Pulmonary arteries and veins
        - Pulmonary thromboembolic disease: thrombolytic therapy, thromboembolectomy
        - Pulmonary arteriovenous malformations: embolization
- Aortic disorders
    - Aortic aneurysm: embolization, endovascular grafting
    - Aortic dissection: endovascular grafting, fenestration
    - Aortic trauma
- Central venous intervention (SVC, IVC)
    - Central venous occlusive disorders
        - Thromboembolic disorders

        - Congenital webs
    - Caval filtration and related techniques for thromboembolic disease
- Vascular diagnosis, abdominal and pelvic viscera
    - Genitourinary system
        - Kidney
            - Renovascular hypertension: recanalization techniques
            - Renal trauma
            - Varicocoele/ Ovarian Vein embolisations
- Uterine Fibroid embolization
- GI Bleeds
- TACE for HCC

Non-vascular Interventions

- Hepatobiliary interventions
    - Hepatic carcinomas-chemoembolization or RFA
    - Common bile ducts abnormalities
    - Liver cirrhosis
    - Other miscellaneous conditions
- Pain management for neoplastic & non-neoplastic conditions by interventional techniques under image guidance (fluoroscopy, CT, USG, MRI)
- Breast imaging & Interventions
- Vertebroplasty-Using alcohol or bone cement
- Kyphoplasty
- HIFU
- GENITOURINARY INTERVENTIONS – ESWL, PCN, PCNL
- Ureteric stenting/ Ureteric occlusions/ Management of Ureteric leaks
- Radiofrequency/ Microwave ablations pf Renal tumors/ Prostate etc.
- RFA/ Microwave ablations of Lung tumors
- Fallopian tube recanalisations
- Transarterial chemo/ embolization of osteosarcomas/ retinoblastomas
- Biopsy and drainage procedures
- Newer techniques and applications of interventional radiology and Interventional Oncology -

- Quality Assurance Issues

    - Outcomes analysis
    - Practice guidelines
    - Complications: classification, documentation

- Legal Aspects of Interventional Radiology
    - Informed consent

    - Malpractice
- Regulatory agencies
    - Investigational devices and procedures
- Administrative Aspects
    - Equipment purchase
    - Inventory management

Evaluation of the Candidate

The assessment of the candidate will be a continuous process. Each candidate will be required to maintain a logbook, wherein his clinical, teaching and research activities through the entire duration of the course will be entered. Evidence of having conducted research should be presented before the candidate is permitted to appear for the DM (final) examination.

Four examiners, two of who will be external examiners, will conduct the DM examination. The general scheme of conducting the examination will be as follows:

Theory

Practical

Viva/Voce

Outcomes

The trainee successfully completing the DM (IR) course will be eligible for the award of a degree in Interventional Radiology.

होमी भाभा राष्ट्रीय संस्थान
Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
PAREL, MUMBAI – 400 012

SYLLABUS
OF
M.CH SURGICAL ONCOLOGY

(Program Code: HLTH10B01)

I. INTRODUCTION

Surgical Oncology is a recognized Super-specialty in General Surgery. With the increasing incidence of cancer in our country and with improved methods of management of cancer in the last two decades, it has become very essential to have trained Surgical Oncologists for comprehensive care of the cancer patient.

II. AIMS & OBJECTIVES

The main aim of the training program is to ensure that at the end of 3 years training, the candidate should be acquainted with comprehensive management, research methodology including medical statistics and must:

1) Be an independent Consultant / Clinician / Teacher in Surgical Oncology.
2) Be a teacher in the discipline, acquainted with current literature on relevant as pact of basic, investigation and clinical oncology.
3) Take up research projects in the discipline either clinical or basic as pects as applied to clinical trials with reference to common cancers in our country.
4) Render medical care to be the individual and the community, integrating preventive, diagnostic, curative and palliative as pects with adequate understanding of sociocultural as pects of the community and knowledge of the epidemiology of common neoplastic disorders in India.

III. NAME OF THE COURSE

M.Ch. (Surgical Oncology)

IV. ELIGIBILITY

M.S. (General Surgery)
M.S. (ENT)
M.S. (Orthopedics)
M.D. (Gynaec)

V. DURATION OF COURSE

Three Years.

VI. No of Seats

As specified from time to time

VII Selection of Candidates

An entrance test will be conducted by the Competent Authority and the admission to the course will be on the basis of merit list prepared on the basis of this test.

VIII Teacher

All eligible faculty members as prescribed by Homi Bhabha National Institute (DU) of the Dept of Surgical Oncology will be teachers in rotation, subject to approval by the University. One student will be registered under one teacher, in rotation.

IX Place of Course
The course will be conducted at affiliated Medical Colleges / Recognized Institutes.

X. TYPE OF COURSE
The selected candidates will undergo a three year residential training as Residents / Trainees at the affiliated Medical Colleges / Recognized Institutes as follows.
1. 1st year – 2 month rotation in the various major surgical specialty services in the Dept. of Surgical Oncology as a 1st year residents.
2. 2nd & 3rd year – 4 month rotation in six major surgical specialty services in the Dept. of Surgical Oncology as Senior Residents / Trainees.
3. In the 2nd & 3rd year the students will also rotate in the following specialties:
a) Medical Oncology – 3 Weeks
b) Radiation Oncology – 3 Weeks
c) Onco – Pathology – 1 Week
d) Radiology – 1 Week
e) Basic Research – 3 weeks
f) Stoma /Pain/ Rehabilitation Clinics – 1 weeks

XII. TEACHING SCHEDULE
A. Clinical:
1) **Outpatient Teaching Schedule**: The Post Graduate students will attend outpatient clinics as per the schedule of the unit assigned to them.
2) **Teaching Ward Rounds:** In addition to daily ward rounds will be conducted by the consultant.
3) **Operation Theatres:** The Post Graduate students will attend the operation theatres as per the schedule of the assigned unit where they will assist in or perform operations under supervision.
B. Academic:
The Post Graduate will attend and actively participate in the following academic activities:
1) Formal course of lectures as fixed by the Dept. for the three-year course to cover the entire syllabus.
2) Case presentations.
3) Seminar / journal club of each specialty service.
4) Weekly Hospital Clinical Meetings.
5) Mortality meetings.
6) All Seminar / Conference / Workshop conducted by the Department.

XIII. INTERNAL ASSESSMENT
1) A Postgraduate student Logbook will be maintained as prescribed by the University.
2) A Log book of operations assisted in and performed will be maintained & periodically signed by the teacher (computerized).
Internal assessment will be carried out while student rotates through each subspecialty (Head/neck, breast, thoracic, Gastro-intestinal, genitourinary,

gyanecology, bone & soft tissue, neurosurgery and paediatric oncology services)

XIV. SYLLABUS

Syllabus shall comprise in four parts:

09HLTH10B01-001-C	Basic Sciences
09HLTH10B01-002-C	Principals of oncology
09HLTH10B01-003-C	Clinical Practice of Surgical Oncology
09HLTH10B01-004-C	Recent Advances in Oncology

XV. ELIGBILITY FOR EXAMINATION

The candidate will be eligible to appear for the M. Ch. Examination in Surgical Oncology conducted by the University only after certification of the following:

1) Completion of three years of Resident training.

2) Satisfactory attendance at Clinical / Academic sessions as duly certified on the logbook by the teacher. A minimum attendance of 85 % is mandatory.

XVI. EXAMINATION

4) Board of Examiners:

Four Examiners: Two internal & two external

All examiners shall be Surgical Oncologists.

5) Assessments of candidates & Results:

a) Assessment of theory, clinical, practical and viva–voce examination shall be done jointly by all the examiners.

b) A candidates shall be declared to have passed the examination if he /she has an adequate knowledge in all subjects as answered by Theory / clinical / practical and viva–voce examination and there shall be no classification or ranking of successful candidates. However, candidates of excellent performance could be recommended for award for distinction.

c) A candidates who fails in an examination shall appear as a casual student for subsequent examination.

d) The Board of examiners shall have the power to refer failed candidates for one year or to put in attendance for one term i.e. Six months before appearing for the ext examination.

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Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
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SYLLABUS
OF
M.Ch GYNAECOLOGICAL ONCOLOGY
(Program Code: HLTH10B02)

CURICULLAM OF M.CH (GYNAECOLOGICAL ONCOLOGY)

AIMS AND OBJECTIVES

The MCh in Gynecological Oncology is designed as a Subspecialty course aimed at training candidates who having obtained a primary MCI-recognized postgraduate qualification in Obstetrics & Gynecology i.e. MS/MD or equivalent (DNB) and desire to pursue a career in the subspecialty of Gynecological Oncology.

The MCh in Gynecological Oncology has been designed as a comprehensive formal 3-year training program in all aspects of gynecologic oncology. It also includes training in the allied surgical subspecialties of Urological, Gastrointestinal and Breast Oncology, as well as Preventive Oncology, Radiation and Medical Oncology.

The candidate will receive comprehensive training in the management of patients with gynecological cancers. The program is designed to provide the candidate with every opportunity to gain proficiency in the principles of prevention and early detection, diagnosis and evidence-based treatment, palliative and terminal care. The program also stresses the importance of clinical and basic research relevant to the Subspecialty.

A candidate who successfully completes the course will be expected to have gained proficiency in the following:

- Ability to function as an independent consultant clinician in Gynecological Oncology
- Understand the epidemiology of gynecological cancers as also the principles underlying screening, early detection and prevention. The candidate should acquire a high level of competency in the performance of colposcopy and LEEP procedures in the management of pre-invasive and micro-invasive lesions of the female genital tract
- Acquire a sound knowledge of gross and microscopic pathology and cytology relevant to gynecological oncology. The candidate should be capable of interpreting the details of cytopathology and histopathology reports and use this effectively in making decisions regarding treatment and prognosis
- Acquire the necessary skillset and competence to safely perform radical surgery for gynecological cancers including the ability to prevent, recognize and manage any complications arising thereof
- Understand the surgical principles and have the skills necessary to perform appropriate surgical procedures on the GI and Urinary tract as and when required in the management of gynecological cancer and its complications
- Be familiar with principles of management of diseases of the breast
- Be able to perform the following invasive diagnostic procedures i.e. cystoscopy, thoracic and abdominal paracentesis, and placement and care of central lines
- Have a detailed knowledge of relevant imaging technologies, (indications and limitations) i.e. Ultrasound, CT, MRI and FDG-PET scans
- Have a sound knowledge of the principles of peri-operative patient care
- Have a sound knowledge of the principles of pain management, palliative care and end-of-life issues

- Acquire an understanding of the principles of radiobiology and radiation physics. Be well informed in the principles and techniques of modern radiation treatments. The candidate must develop the skills necessary to recognize and treat the side-effects and complications of radiation treatment
- Acquire sound knowledge of the clinical pharmacology of cancer chemotherapy and related treatment modalities. The candidate should develop the skills necessary for the appropriate selection of patients for chemotherapy and the practical use of the available chemotherapeutic options used in the management of gynecological cancer patients. The candidate should develop skills in the recognition and management of toxic side effects and acquire the ability to administer them in an independent capacity, if necessary
- Acquire skill in the assessment of the effects of treatment and the care of complications. This includes skill in the assessment of patients after treatment and during follow-up.
- Understand cancer survivorship issues and the principles underlying the management of fertility issues in gynecological cancer patients
- Develop skills in the planning, conduct, reporting and interpretation of research in gynecological oncology
- Understand the psycho-sexual, socio-cultural and economic aspects of cancer management in the Indian setting

ELIGIBILITY

The candidate must fulfill the following requirements to be considered eligible to apply for the course:

- Hold the MBBS degree and be fully registered with either the Medical Council of India (MCI) or possess full registration with the Medical Council of the domicile State
- Hold a MCI-recognized postgraduate degree in Obstetrics & Gynecology or any other qualification declared as equivalent i.e. MD/MS, DNB

ADMISSION

Admission to the course at Tata Memorial Hospital shall be based strictly on merit and as per the guidelines laid down by the MCI & the Homi Bhabha National Institute (HBNI)

TYPE OF COURSE

The MCh in Gynecological Oncology is a Full time Subspecialty course of three years duration

GENERAL RULES

- **T**he course will be strictly in-service training in nature and the candidate will have all clinical responsibilities including emergency duties
- The candidate will actively participate in the weekly Departmental Academic Program which includes didactic lectures, clinico-pathological Meetings, Journal clubs, Case discussions and Unit Grand Rounds

- The candidate will be required to undertake one research project and be responsible for the planning, execution, analysis and presentation of the same. The research topic will be provided by the Teacher and should be approved within the first six months of commencing the course.Threehardcopies and one soft copy on a CD of the same will be submitted to the Dept. of Academics priorto the completion of the course and the number required by the Board will be forwarded for dispatch to the examiners for the evaluation of the same. The defense of the same will be required during the viva voce as a separate session. The conclusions of the study should be presented at aforum within the institution or at a suitable National forum and the same should also ideally be accepted for publication in a peer-reviewed Journal
- The candidate will maintain a daily Training Record/Logbook for recording the following:
    - Clinical attendance
    - Attendance at Departmental/Institutional Meetings
    - Record of the patients in whose management the candidate has been actively involved. This record will need to be checked and signed regularly by the Teacher. The Record Book is intended as a means of continuous self-assessment. It is designed to stimulate the Trainee towards greater efforts in areas where the assessment reveals a standard that is below par and also to record progress in skill acquisition made by the Trainee.
- Regular 6-monthly evaluation of the overall performance of the Trainee will be done by the supervisor in consultation with other departmental Faculty, according to the criteria as indicated below (vide infra). The evaluation is to be discussed with the trainee to facilitate improvements and correct deficiencies in the training system
- Additional formal internal assessments will be performed in the form of a written and oral examination conducted at 6-monthly intervals. This evaluation is independent of the 6-monthly internal assessments of Trainee performance indicated above
- The leave period sanctioned to a Trainee during the course will be as per Institutional and MCI rules. Absence during the course exceeding the number of days specified will have to be made up by the extra days of work in that particular posting in which the candidate availed of leave prior to the acceptance of the candidate for the examination and the payment of the examination fees

CLINICAL ROTATION

The Trainee will undergo a Clinical Rotation during the 3-years as a MCh Gynec. Oncology Trainee as outlined below:

Gynec. Oncology (Parent Unit)	24 months
Urologic Oncology	02 months
GI Surgical Oncology	04 months
Breast Unit	06 weeks
Radiation Oncology	04 weeks
Medical Oncology	04 weeks
Preventive Oncology	06 weeks
Lab (ACTREC)	01 month

- The Trainee will spend 24 months of the Course full-time in the Gynecological Oncology unit

- The Trainee will be expected to rotate through the various relevant clinical specialties as outlined above
- The candidate will spend 12 months of his/her training in relevant allied subspecialty units
- The Trainee will be allowed to sit the MCh examination ONLY after completing all the required formalities as specified by the MCI.

TRAINING MODULES

Specific training modules have been designed and it will be the responsibility of the Faculty and Teachers/Mentors to ensure that the Trainee is trained as per the recommendations provided within each module as given below:

I <u>Gynecological Oncology Modules</u>

<u>09HLTH10B02-001-M: General Assessment of a Gynecological Oncology Patient</u>

Objectives

To trainthe Trainee in the skills required for appropriate clinical assessments of patients with suspected or known gynecological cancers

- Obtain detailed clinical history
- Perform appropriate physical examination
- Consolidate information received from prior investigations if any
- Initiate further investigations
- Communicate clinical plan to patient and relatives

Knowledge Criteria

To Trainee should demonstrate knowledge of the following:

- Indications/limitations of screening for gynecological cancer
- Patterns of clinical presentation
- Investigations required for establishing a diagnosis
- Care pathways for suspected/proven gynecological cancer
- Pre-operative investigations (routine/specific) of patients
- Assessment of fitness for surgery

Criteria of Clinical Competence

To demonstrate clinical competency with respect to the following:

- Counseling patients appropriately about screening and interpreting screening results
- Taking an appropriate clinical history including family history and genetic susceptibility where relevant
- Correlation of presenting symptoms/co-morbid conditions
- Performance of a detailed clinical examination

- Counseling patients re: diagnosis, investigations and appropriate treatment options including adverse effects and complications
- Communicating the results of investigations and treatment
- Discussing prognosis

Professional Skills and Attitudes

- Ability to demonstrate clinical competency as indicated above
- Ability to identify the high-risk surgical patients and liaise with colleagues in anesthesia
- Ability to liaise with colleagues in Radiation and Medical Oncology as also with specialists in palliative care as when appropriate
- Ability to demonstrate counseling skills with respect to screening tests as also treatment/prognosis-related issues

09HLTH10B02-002-M: Pre-, Peri- and Post-operative Care

Objectives

To understand and demonstrate appropriate knowledge, skills and attitudes in relation to patients undergoing surgery for gynecological malignancies

- Plan appropriate surgery
- Identify risk factors if any: Surgical and Anesthetic
- Counsel patients for surgery
- Demonstrate an understanding of peri-, intra- and postoperative patient management
- Principles of peri-operative nutrition and Total Parenteral Nutrition (TPN).

Knowledge Criteria

- Thorough knowledge of the FIGO Staging and TNM staging system (where appropriate) for all gynecological cancer sites
- Type of surgery appropriate for each gynecological cancer (see separate modules)
- Principles of fluid and electrolyte balance
- Elemental feeding and TPN

Criteria of Clinical Competence

- Counsel patients regarding diagnosis, management and risks of surgical treatment
- Assessment of operability/inoperability
- Recognize and appropriately manage intra-operative complications
    - Haemorrhage
    - Unintended visceral injury
    - Planned bowel resection
    - Dealing with unexpected surgical findings
- Post-operative care and management of complications
    - Infection
    - Thrombosis and thromboembolism

    - Bowel obstruction
- Appropriately order and interpret investigations
- Inform patient of results
- Manage peri-operative fluid balance
- Order and supervise appropriate thromboprophylaxis.
- Liaise with nutritional support team and decide when TPN or enteral feeding is appropriate

Professional Skills And Attitudes

- Ability to interpret preoperative investigations and liaise with anesthesia colleagues
- Ability to counsel patients regarding extent of surgical treatment
- Ability to select and perform appropriate surgical procedures according to patient's needs
- Ability to manage postoperative care and complications thereof
- Ability to counsel patients and relatives regarding diagnosis, investigations and to discuss treatment options, advantages and disadvantages of each
- Ability to convey decisions of the multidisciplinary team to patients and relatives
- Ability to liaise with colleagues and other health professionals regarding coordinating investigations and management strategies pertinent to individual patients

<u>09HLTH10B02-003-M: Generic Surgical Skills In Gynecological Oncology</u>

Objectives

To achieve surgical skills appropriate for a subspecialist gynecological oncology surgeon:

- Anatomical knowledge
- Surgical skills
- Personal audit

Knowledge Criteria

- Detailed knowledge of the surgical anatomy of the female abdomen/pelvis
- Working knowledge of anesthesia techniques
- Principles of good surgical technique

Criteria of Clinical Competence

- Diagnosis and surgical management of gynecological cancers:
    - Uterine cervix
    - Ovary
    - Uterine Corpus: Endometrium and uterine sarcomas
    - Vulva
    - Vagina
    - Gestational trophoblastic neoplasms
- Ability to liaise with general surgical oncology colleagues for assistance in

complicated cases, when required

Professional Skills And Attitudes

The candidate should be adequately trained to independently perform the following surgical procedures:

- Fine-needle aspiration cytology (FNAC)/biopsy of superficial lymph nodes
- Trucut biopsy
- Simple hysterectomy.
- Radical hysterectomy.
- Pelvic lymph node dissection
- Para-aortic lymph node dissection
- Groin node dissections
- Infracolic and Supracolic omentectomy.

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The candidate should also receive training in the ability to perform, with the assistance of surgical colleagues if necessary, pelvic exenterative surgery and urinary diversion in selected cases.

It is anticipated that the relevant allied surgical skills will be imparted during the candidate's planned clinical rotation in the relevant Subspecialty services i.e. GI Surgical and Urological Oncology

II <u>Site-Specific Modules</u>

<u>09HLTH10B02-004-M: Cancer of the Cervix</u>

Objectives

- Aetiopathlogy, histogenesis and principles of population screening and prevention of cervical cancer
- Ability to diagnose, investigate, counsel and manage patients with cervical cancer
- Ability to choose the most appropriate treatment approach for a given patient
- Perform appropriate surgery for cervical cancer and manage treatment complications
- Indications and choice of adjuvant treatments
- Plan appropriate follow up
- Diagnosis and management of relapsed disease
- Selection of patients for symptomatic palliation and best supportive care

Knowledge Criteria

- Understanding of the epidemiology and etiology of cervical cancer
- Understanding of the pathophysiology and management of pre-invasive cervical disease (CIN)
- Understanding of the role of human papillomavirus/HPV in the etiology and development of CIN and cervical cancer
- Knowledge of the clinical presentation and diagnosis of cervical cancer
- Knowledge of the pathology and staging of cervical cancer

- Knowledge of the management of all stages of cervical cancer including
- Detailed knowledge of the surgical anatomy of the female pelvis
- In-depth knowledge of radiotherapy principles of treatment and appropriate application to cervical cancer
- Knowledge of appropriate chemotherapy for cervical cancer
- Knowledge of complications and adverse effects of treatment, short- and long-term
- Knowledge of patterns of disease recurrence and their appropriate management
- Knowledge of the physical and psychosexual morbidity of cancer diagnosis and treatment

Criteria of Clinical Competence

- History taking and physical examination
- To obtain cervical smears, perform colposcopy and colposcopicaly-directed procedures i.e. cervical biopsy including punch biopsy, loop electrosurgical excision (LEEP) and ablative/excisional therapy in appropriate cases
- Perform clinical staging for invasive cervical cancer
- Perform appropriate surgery for cervical cancer
- Counsel patients about the diagnosis, investigations and appropriate treatments for cervical cancer, including adverse effects and complications of treatment
- Communicate results of investigations and treatment to the patient, including prognosis and palliative care
- Interpret results of radiological investigations appropriate to cervical cancer
- Assist in delivery of brachytherapy
- Assist in delivery of chemotherapy/chemoradiation
- Manage adverse effects and recognize complications of treatment
- Diagnose, investigate and manage recurrent cervical cancer
- Select patients for exenterative surgery
- Detect and manage physical and psychosexual morbidity

Professional Skills And Attitudes

- Ability to take history and examination
- Ability to perform colposcopy
- Ability to perform cervical biopsy and LLETZ
- Ability to perform clinical staging, including cystoscopy with biopsy where indicated
- Ability to perform the following surgical procedures relevant to cervical cancer:
    - Hysterectomy (abdominal/vaginal)
    - Class II and III Radical hysterectomy
    - Pelvic lymph node dissection
    - Para-aortic lymph node dissection
- Ability to assist with execution of relevant radiotherapy procedures and chemotherapy
- Ability to interpret:
    - Intravenous urograms
    - Pelvic MRI
    - Computed tomography scans (CECT)
    - FDG-PET

- Ability to perform with the assistance of surgical colleagues where necessary pelvic exenterative surgery, urinary and bowel diversion procedures
- Ability to initiate discussion of management at multidisciplinary team meetings
- Ability to counsel patients and relatives regarding diagnosis, investigations and discuss treatment options and advantages and disadvantages of each
- Ability to convey information regarding prognosis and decisions regarding selection of patients for palliative care
- In units where advanced laparoscopic surgery has been established and is offered as a matter of course, the trainee should be exposed to and be trained in the following:
    - Bilateral laparoscopic adnexectomy
    - Laparoscopic Assisted Radical Vaginal Hysterectomy (LARVH)
    - Total Laparoscopic Radical Hysterectomy (TLRH)
    - Laparoscopic pelvic lymph node dissection
    - Laparoscopic para-aortic lymph node dissection

09HLTH10B02-005-M: Ovarian Cancer

Objectives

- To demonstrate appropriate skills and attitudes in relation to clinical work-up and management of patients with all varieties of suspected/clinically overt ovarian cancer
- Initial assessment and investigations of suspected/clinically overt ovarian cancer i.e. epithelial ovarian cancer, germ cell tumors of the ovary, non-epithelial and other variants of ovarian cancer
- Plan subsequent management of patients with a suspicious adnexal mass
- Plan subsequent management of patients with clinically overt ovarian cancer
- Perform appropriate diagnostic or treatment surgery
- Communicate with multidisciplinary team and organize adjuvant treatment
- Plan follow-up

Knowledge Criteria

- Etiology and clinical presentations of ovarian cancer
- Population screening for ovarian cancer
- Pathology of ovarian cancer
- Radiological assessment for preoperative diagnosis and guided biopsy
- Indications, techniques, limitations and complications of surgical treatment of ovarian cancer
- Clinical work-up of suspected ovarian cancer
- Clinical work-up and treatment selection of clinically over ovarian cancer
- Multidisciplinary team meeting discussions and management planning.
- Role of laparoscopy in assessment
- Case selection for surgery:
    - Fertility conserving surgery
    - Primary cytoreductive surgery
    - Interval cytoreductive surgery
    - Selection of cases for secondary cytoreductive surgery

- Medical management of ascites, pleural effusions and bowel obstruction
- Consideration of all management options including best supportive and palliative care

Criteria of Clinical Competence

- Counsel patient and relatives about:
  - Diagnosis and further therapy
  - Surgical options and complications
  - Medical options
  - Prognosis.
- Discuss results of the surgery with patients, relatives and carers
- Communicate with referral doctor/unit and primary care
- Perform appropriate surgery for diagnosis and surgical management of ovarian cancer, including optimal debulking surgery
- Management of recurrent disease
- Discharge from hospital and produce appropriate follow-up plan
- Detect and manage physical and psychosexual morbidity

Professional Skills And Attitudes

- Ability to counsel patients sensitively about available treatment options available and to respect patient confidentially
- Ability to explain clearly and openly about treatments, complications and adverse effects of surgical treatment
- Ability to formulate and implement a plan of management and modify if necessary
- Ability to liaise effectively with colleagues in other disciplines, clinical and non-clinical
- Ability to appropriately stage ovarian cancer
- Ability to perform optimal debulking surgery
- Ability to decide appropriate extent of surgery including resection of bowel and formation of stoma
- Ability to select patients for conservative surgery
- Ability to perform a laparoscopic assessment and biopsy in suspected advanced ovarian cancer to obtain histology
- Ability to counsel patients regarding entry into clinical trial**s**

<u>09HLTH10B02-006-M: Cancers of the Uterine corpus</u>

Objectives

- To demonstrate appropriate skills and attitudes in relation to clinical work-up and management of patients with endometrial cancer and other malignant tumors of the uterine corpus
- Understand the principles of management of any comorbid conditions likely to impact choice and delivery of appropriate treatment
- Undertake primary surgical management
- Manage recurrent disease

Knowledge Criteria

- Epidemiology and aetiopathology of cancers of the uterine corpus
- Histological types of endometrial cancer and prognostic factors
- Preoperative investigation of patients, including assessment of fitness for surgery
- Risks of major surgery (surgical and anesthetic)
- Type of surgery appropriate for endometrial cancer
- Role of radiotherapy and chemotherapy in the treatment of endometrial cancer
- Risk factors for- and patterns of recurrence
- Management options for recurrent disease

Criteria of Clinical Competence

- Take a history, examine and investigate patients with suspected and proven endometrial cancer
- Order and interpret appropriate investigations of endometrial cancer
- Formulate a management plan
- Ability to liaise with anesthesia department
- To counsel patients regarding diagnosis, management and risks of treatment.
- Perform appropriate surgical procedures for endometrial and other uterine cancer
- Recognize and manage intraoperative complications
- Postoperative care and complications
- Inform patient of results
- Understand the indications for- and principles underlying choice of appropriate adjuvant treatments
- Planning follow-up
- Recognition of- investigation and management of disease recurrence

Professional Skills And Attitudes

- Ability to take a clinical history and appropriately work-up patients with suspected or proven uterine cancer
- Ability to recognize histological patterns of disease
- Ability to interpret preoperative investigations
- Ability to counsel patients regarding treatment options and histology
- Ability to select and perform the following surgical procedures for endometrial cancer:
    - Total abdominal hysterectomy and bilateral salpingo-oophorectomy
    - Pelvic lymph node dissection
    - Para-aortic lymph node dissection
- Ability to manage postoperative care and complications thereof
- Ability to assign a surgicopathological FIGO Stage
- Ability to decide need for adjuvant therapy
- Ability to follow up patients appropriately
- In units where advanced laparoscopic surgery has been established and is offered as a matter of course the trainee should be exposed to and be trained in the following:
    - Bilateral laparoscopic adnexectomy

    - Laparoscopic Assisted Vaginal Hysterectomy (LAVH)
    - Total Laparoscopic Hysterectomy (TLH)
    - Laparoscopic pelvic lymph node dissection
    - Laparoscopic para-aortic lymph node dissection
    - Laparoscopic omentectomy

09HLTH10B02-007-M: Cancer of the Vulva

Objectives

- To diagnose, investigate and manage a patient with cancer of the vulva
- Perform appropriate surgery in a patient with vulva cancer
- Manage complications of treatment

Knowledge Criteria

- Anatomy of the vulva, vagina and the inguino-femoral region
- Epidemiology and etiology of vulval cancer
- Histopathology and patterns of spread of vulval cancer
- Staging of vulval cancer
- Diagnosis and investigations for vulval cancer
- Principles of treatment of all stages of vulval cancer
- Complications of treatment and their appropriate management
- Patterns of recurrence of vulval cancer
- Recognition and management of recurrent cancer of the vulva
- Long-term complications of treatment of vulval cancer
- Knowledge of the psychosexual morbidity of treatment

Criteria of Clinical Competence

- Take an appropriate history and perform appropriate clinical investigations
- Perform vulval biopsies and vulvoscopy in indicated cases
- Perform appropriately tailored surgical procedures for vulval cancer
- Perform sentinel node assessment procedures for vulval cancer
- Liaise with plastic surgeons to select and manage patients requiring major skin flaps to close vulval wounds
- Perioperative management of vulval cancer patients
- Manage recurrences of vulval cancer
- Manage physical and psychosexual morbidity

Professional Skills And Attitudes

- Ability to take a clinical history and to perform appropriate physical examination and plan treatment on an individualized basis
- Ability to investigate and counsel patients regarding treatments
- Ability to select and perform competently diagnostic and therapeutic surgical procedures for vulval cancer
    - Vulval biopsy
    - Wide local excision

    - Skinning vulvectomy
    - Radical vulvectomy
    - Groin node dissection
    - Sentinel node detection.
    - Simple skin flaps.
- Ability to perform major skin flaps with assistance of plastic surgeons
- Ability to manage patient’s postoperative care
- Ability to manage complications of treatment

<u>09HLTH10B02-008-M: Vaginal Cancer</u>

Objectives

- To diagnose, investigate and manage a patient with cancer of the vulva
- Understand the indications for primary surgical management
- Understand management options to address comorbidity
- Manage recurrent disease

Knowledge Criteria

- Anatomy of the vagina
- Etiology of vaginal cancer, including sarcoma botyroides and metastatic lesions.
- Vaginal infections and benign pathology
- Pathophysiology of vaginal intraepithelial neoplasia (VAIN)
- Multifocal lower genital tract malignancy
- Clinical presentation, investigation and FIGO staging.
- Detailed management of vaginal cancer
- Physical and psychosexual morbidity of cancer

Criteria of Clinical Competence

- Take a history and perform an appropriate examination
- Perform vaginoscopy and vaginal biopsy
- Arrange staging and imaging investigations
- Arrange and aid delivery of radio- or chemotherapy
- Perform partial and radical vaginectomy
- Detect and manage physical and psychosexual morbidity

Professional Skills And Attitudes

- Ability to perform vaginal biopsy
- Ability to perform partial (Abdominal/Vaginal) and radical vaginectomy
- Ability to perform radical exenterative surgery when appropriate

III   <u>Allied Surgical Specialty Modules</u>

<u>09HLTH10B02-009-M: Uro-oncological surgery</u>

Objectives

- To understand the impact of gynecological cancer and its treatment on the renal tract.
- To be aware of possible urological complications associated with gynecological cancers and their management
- To Identify and manage urological complications.

Knowledge Criteria

- Anatomy and physiology of the female urinary tract
- Effects of gynecological cancer and its treatment (surgery, radiotherapy and chemotherapy) upon the urinary tract.
- Ability to request relevant investigations and interpret the results
- Recognition and management of injury to the urinary tract
- Principles of repair of injury to the urinary tract
- Selection of patients who would benefit from intervention surgery involving the urinary tract
- Pre- and postoperative care of patients undergoing a urological procedure

Criteria of Clinical Competence

- Ability to communicate the possible urological implications of gynecological cancer and it's treatment on the urinary tract
- Ability to appropriately investigate and diagnose disorders of the urinary tract in a gynecological cancer setting.
- Ability to request appropriate investigations in patients with a suspected involvement/injury of the urinary tract and to liaise with the urology team
- Ability to Investigate diseases of urinary tract i.e. UTI detrusor dysfunction, incontinence etc.
- Detailed knowledge of injuries to the lower urinary tract during/after surgery or radiotherapy
- Perform diagnostic cystoscopy/bladder biopsy/placement and removal of ureteric stents
- Perform suprapubic cystostomy
- Surgical repair of intraoperative injury to the bladder and ureters
- Principles of urinary diversion and ability to perform with the aid of a urology colleague, basic urinary diversion surgery i.e. ilea conduit

Professional Skills And Attitudes

- Effectively manage patients with suspected disorders of urinary tract.
- Request and interpret investigations of urinary tract.
- Appropriate selection of patients for intervention surgery involving the urinary tract.
- Ability to safely perform relevant urological surgical procedures as outlined above

Objectives

- To understand the impact of gynecological cancer and its treatment on the GI tract.
- To be aware of possible GI complications associated with gynecological cancers and their management

- To Identify and manage GI complications
- To understand the role of fluid balance and nutrition in a patient undergoing major surgery for gynecological cancer
- To understand the indications and principles of bowel resection and repair in the context of gynecological oncology
- To understand the principles of elective bowel resection in gynecological cancer surgery an the principles of management of an accidental surgical injury to the bowel

Knowledge Criteria

- Anatomy and physiology of the gastrointestinal tract
- Pathophysiology of intestinal function
- Appropriate selection of patients who will benefit from bowel surgery.
- Preoperative preparation required for a patient who may or will have bowel surgery.
- Principles of gastrointestinal surgery, including exposure and handling of the bowel
- Principles underlying repair of surgical bowel injuries
- Principles of resection and repair of intestinal tissues: Primary and secondary surgical repair/bowel diversion
- Indications to perform bowel surgery in a gynecological oncology setting

Criteria of Clinical Competence

- Counseling patients preoperatively and postoperatively regarding bowel surgery and stoma management, including benefits, risks and complications
- Order appropriate bowel preparation preoperatively.
- Select patients preoperatively and intraoperatively who will benefit from bowel surgery.
- Ability to select an appropriate location for bowel stomas
- Ability to independently perform:
    - Appendectomy
    - Primary repair of serosal/mucosal injury to the small/large bowel
    - Resection-anastomoses of small/large bowel
    - Diversion stomas: Ileostomy, transverse/end colostomy
    - Mobilization of the colon, sigmoid and rectum
    - Standard sigmoid colectomy, anterior rectal resection, abdomino-perineal rectal resection
- Manage postoperative care of patients following bowel surgery.

Professional Skills And Attitudes

- Effectively manage patients with involvement of the GI tract in the gynecological oncology setting
- Request and interpret relevant investigations
- Appropriately select patients for intervention surgery involving the GI tract.
- Ability to safely perform relevant GI surgical procedures as outlined above

<u>09HLTH10B02-011-M: Breast Cancer Surgery</u>

Objectives

- Understanding the role/limitations of screening for breast cancer
- Clinical care and counseling of women with breast symptoms and breast lumps
- Understanding hereditary breast cancer syndromes, BRCA testing and the implications
- Imaging in breast cancer
- Understanding the principles underlying the multidisciplinary management of breast cancer and evidence-based guidelines
- Understanding principles of treatment in different stages of breast cancer including metastatic breast cancer

Knowledge Criteria

- Ability to counsel women about screening issues
- Ability to conduct a comprehensive physical assessment of the female breast
- Ability to counsel patients with a breast lump and advise regarding clinical management pathways
- Ability to plan surgical management of breast cancer an be familiar with relevant surgical approaches including principles of breast reconstruction

Criteria of Clinical Competence

- To have a good overview of the relevant literature of the subject
- Ability to do a comprehensive clinical/diagnostic workup of patients with suspected or clinical breast cancer
- Ability to discuss management plans with colleagues from the Breast Cancer unit

IV <u>Allied Non-Surgical Specialties</u>

<u>09HLTH10B02-012-M: Radio-Diagnostics</u>

Objectives

- To understand the role of imaging in gynecological cancer.
- To understand the principles underlying selection of different imaging modalities.

Knowledge Criteria

- To have a working knowledge of the theory underlying the main imaging modalities used in gynecological oncology i.e. USG, CECT, MRI, FDG-PET
- Indications and limitations of each of these imaging modalities
- Principles of nuclear medicine in radiodiagnostics
- Indications for Intervention radiology procedures in gynecological oncology: Guided biopsies, percutaneous nephrosotomy/antegrade ureteric stenting

Criteria of Clinical Competence

- Ability to request appropriate imaging tests
- Ability to assessment and interpret the results with relevance to the clinical scenario

- Ability to recognize the indications for interventional radiology procedures

Professional Skills And Attitudes

- Liaising with the radiology team to discuss images with reference to a given clinical scenario

<u>09HLTH10B02-013-M: Medical Oncology</u>

Objectives

- To understand the role of chemotherapy in the management of gynecological cancers
- To understand the pharmacology of the major drugs used in chemotherapy.
- To understand the principles underlying the use of chemotherapeutic and newer targeted therapies in the management of gynecological cancers

Knowledge Criteria

- Relevant cell biology including:
    - Cell-cycle kinetics
    - Log kill hypothesis
    - Cycle and phase-specificity
- Classes of chemotherapeutic agents and their mechanisms of action
- Pharmacology of the main agents used in gynecological cancers
- Principles of dose calculation and scheduling
- Understand the benefits and limitations of single-agent and combination chemotherapy
- Principles of Phase I, II, and III drug trials in clinical research
- Understand the concepts of neoadjuvant adjuvant chemotherapy
- Short- and long-term toxicity, both general and drug-specific
- The role of hormonal therapy
- Therapeutic options for recurrent disease
- Role of newer targeted therapies in ovarian cancer

Criteria of Clinical Competence

- Take an appropriate history and perform clinical examination
- Know the indications for chemotherapy
- Principles of response assessment in patients undergoing chemotherapy
- Counsel patients about their chemotherapy regimens including adverse effects/complications of treatment
- Know when to change or stop treatment
- Ability to recognize, assess and manage acute and chronic toxicity

Professional Skills And Attitudes

- Ability to discuss management at multidisciplinary team meeting, including most appropriate chemotherapy regimen, according to patient’s disease and medical

status
- Ability to counsel patients about chemotherapy, including adverse effects and complications of treatment
- Ability to liaise with colleagues and other health professionals regarding management strategies pertinent to individual patients
- Ability to recognize, investigate and management of toxicity
- Ability to counsel patients about clinical trials

<u>09HLTH10B02-014-M: Radiation Oncology</u>

Objectives

- To be familiar with the principles and practice of radiotherapy in the management of gynecological cancer

Knowledge Criteria

- Cell-cycle kinetics
- Principles of radiobiology and radiation effects
- Principles of tissue repair and recovery
- Principles of radiation protection.
- Radiosensitivity of different organs
- Principles of radiation physics
- Principles of fractionation.
- CT planning and dosimetry.
- Types of radiation sources and techniques
- Principles of planning standard external beam radiotherapy and brachytherapy
- Principles of concurrent chemoradiation
- Side effects and toxicity of radiotherapy

Criteria of Clinical Competence

- Selecting patients for radiotherapy according to disease site, tumor type and stage
- Understand the principles of treatment planning
- Counsel patients regarding radiotherapy and it's potential side-effects and complications
- Understand the difference between curative and palliative treatment
- Management of long-term side-effects of radiotherapy:
- Recognition, investigations and management of recurrent gynecological cancer following primary radiotherapy and chemoradiation.

Professional Skills And Attitudes

- Ability to select patients for radiotherapy
- Ability to counsel patients regarding radiotherapy
- Ability to plan radiotherapy treatment
- Ability to counsel patients regarding complications
- Ability to recognize and manage adverse effects of radiotherapy:

- Ability to recognize and manage major complications of radiotherapy in liaison with other colleagues
- Ability to recognize and investigate tumor recurrence

CANDIDATE EVALUATON METRICS

Outlined below is a representative scheme, which could be used while evaluating the trainees during their periodic appraisals:

Metrics

- Theoretical knowledge of the subject
- Knowledge of current, relevant evidence-based literature
- Ability to practically apply his/her knowledge to clinical scenarios
- Involvement with patient care
    - Outpatient clinics
    - Inpatients
- Surgical skill set commensurate with seniority
- Keenness and aptitude to learn
- Rapport with peers/colleagues - ability to be a part of a team
- Rapport with Senior colleagues - ability to take criticism constructively
- Understanding of the of ethics of clinical medicine
- Research ability/aptitude
- Leadership and people management qualities

Grades of Evaluation

- Excellent
- Exceeds objectives
- Just meets objectives
- Needs improvement
- Below par

EXAMINATION SCHEMA

The MCh examination in Gynecological Oncology will be conducted as per the norms laid down by the Department of Academics, Tata Memorial Hospital, Mumbai. The examination has been planned along the lines of the MCh Examination in General Surgical Oncology.

The examination will have the following two components as detailed below:

Written Examination

This will consist of four written papers of three hour duration each with a total of 100 marks per paper. The candidate will have to write 10 out of 12 short notes. Each short note will carry a maximum of 10 marks.

Paper I: Basic Sciences applied to Gynecological Oncology
Paper II: General Principles of Oncology

Paper III:	Clinical Practice of Gynecological Oncology
Paper IV:	Recent Advances in Gynecological Oncology

Practical Examination

This will include two sections:

Clinical (One long case and two short cases)	200 marks
Viva Voce	200 marks

होमी भाभा राष्ट्रीय संस्थान

Homi Bhabha National Institute

TATA MEMORIAL HOSPITAL
PAREL, MUMBAI – 400 012

SYLLABUS

OF

M.Ch PLASTIC SURGERY

(Program Code: HLTH10B03)

Basic Science

09HLTH10B03-001-BS	Embryology and development of human tissues
09HLTH10B03-002-BS	Genetics and congenital abnormalities
09HLTH10B03-003-BS	Mechanism of healing of tissues, factors affecting the healing
09HLTH10B03-004-BS	Infection and its management
09HLTH10B03-005-BS	General principles of Surgery
09HLTH10B03-006-BS	The suture materials and suture techniques
09HLTH10B03-007-BS	Clinical examination of various systems and clinical photography
09HLTH10B03-008-BS	General anesthesia pre and post-operative care for general anesthesia
09HLTH10B03-009-BS	Local, regional and other nerve blocks
09HLTH10B03-010-BS	Hypertensive and hypothermic anesthesia
09HLTH10B03-011-BS	Management of benign and malignant lesions
09HLTH10B03-012-BS	Wound healing, wound care, dressings and splints
09HLTH10B03-013-BS	Fluid and electrolyte balance, acid base balance
09HLTH10B03-014-BS	Shock and pulmonary failure, blood transfusions, ventilator support and critical care
09HLTH10B03-015-BS	Assessment of trauma, vascular emergencies embolism

General Topics

09HLTH10B03-001-G	History of Plastic Surgery
09HLTH10B03-002-G	Scope of Plastic Surgery
09HLTH10B03-003-G	Tissue distortion, tissue loss and its management
09HLTH10B03-004-G	Tissue culture, Transplantation biology and its applications
09HLTH10B03-005-G	Plastic Surgery instruments and equipments
09HLTH10B03-006-G	Maintenance of medical records, informed consent
09HLTH10B03-007-G	Applications of computer and related programs
09HLTH10B03-008-G	Social psychological, ethical and medico legal aspects communication skills
09HLTH10B03-009-G	Implants, orthotics and prosthesis and applied to Plastic Surgery
09HLTH10B03-010-G	Tissue expansion and tissue distraction
09HLTH10B03-011-G	Management of Leprosy, leprosy deformities and leprosy reconstructive surgery
09HLTH10B03-012-G	Endoscopic Plastic Surgery
09HLTH10B03-013-G	Advances, recent advances and current trends in Plastic Surgery
09HLTH10B03-014-G	Principles of surgical audit, understanding journal and review articles, text books and reference books, critical assessment of articles
09HLTH10B03-015-G	Research methodology and biostatistics
09HLTH10B03-016-G	Arteriovenous malformations, varicose veins, chronic venous insufficiency
09HLTH10B03-017-G	Meningomyelocoele, encephalocoele, spinal fusion defects, ventral defects, anorectal anomalies

होमी भाभा राष्ट्रीय संस्थान
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SYLLABUS
OF
M.CH Head & Neck Surgery
(Program Code: HLTH10B04)

I. INTRODUCTION

Head and Neck surgery is a recognized Super-specialty after M.S Otorhinolayngology/General surgery. Head and Neck cancers are most common cancers in India. With improvements in the management of cancer over the last two decades, it has become essential to have trained Head and Neck Oncologists for the comprehensive care of these patients.

II. AIMS & OBJECTIVES

The main aim of the training program is to ensure that at the end of 3 years, the candidate should be acquainted with comprehensive management and research methodology including medical statistics.

He/She must:

1) Be an independent Consultant / Clinician / Teacher in Head and Neck surgery.

2) Be acquainted with the current literature on relevant aspects of basic oncology, investigation and clinical oncology.

3) Take up clinical or basic research projects, with reference to Head and Neck cancers in our country.

4) Render medical care to be the individual and the community, integrating preventive, diagnostic, curative and palliative aspects with adequate understanding of sociocultural aspects of the community and knowledge of the epidemiology of Head and Neck cancers in India.

III. NAME OF THE COURSE

M.Ch. (Head and Neck Surgery)

IV. ELIGIBILITY

M.S. (General Surgery)

M.S. (ENT)

V. DURATION OF COURSE

Three Years.

VI. No of Seats

As specified from time to time

VII Selection of Candidates

An entrance test will be conducted by the Competent Authority and the admission to the course will be on the basis of merit list prepared on the basis of this test.

VIII Teacher

All eligible faculty members as prescribed by Homi Bhabha National Institute (DU) will be teachers in rotation, subject to approval by the University. One student will be registered under one teacher. The teacher should have minimum 8 years of experience in the field of Head and Neck surgery. He/ She should also have minimum 4 years' experience after being appointed as Assistant Professor in the department of Head and Neck Surgery.

IX Place of Course
The course will be conducted at affiliated Medical Colleges / Recognized Institutes.

X. TYPE OF COURSE
The selected candidates will undergo a three year residential training as Residents / Trainees at the affiliated Medical Colleges/Teaching Hospitals / Recognized Institutes.

XII. TEACHING SCHEDULE
A. Clinical:
1) **Outpatient Teaching Schedule**: The Post Graduate students will attend outpatient clinics as per the schedule of the assigned unit.
2) **Teaching Ward Rounds:** In addition to daily ward rounds, teaching ward rounds are conducted every Thursday morning by the consultant, for all students in the Head and Neck Surgery Department.
3) **Operation Theatres:** The Post Graduate students will attend the operation theatres as per the schedule of the assigned unit where they will assist in or perform operations under supervision.
B. Academic:
The Post Graduate will attend and actively participate in the following academic activities:
1) Formal course of lectures as fixed by the Department for the three-year course to cover the entire syllabus.
2) Case presentations.
3) Seminar / journal club.
4) Weekly Hospital Clinical Meetings.
5) Mortality meetings.
6) All Seminar / Conference / Workshops conducted by the Department.

XIII. INTERNAL ASSESSMENT
1) A Postgraduate student Logbook will be maintained as prescribed by the University.
2) A Log book of operations assisted in or performed will be maintained & periodically signed by the teacher (computerized).
Internal assessment will be carried out yearly for post-graduate students.

XIV. SYLLABUS
Syllabus shall comprise in four parts:

09HLTH10B04-001-C Oral cavity and Oropharynx
09HLTH10B04-002-C Parotid and Thyroid
09HLTH10B04-003-C Nasopharynx, Paranasal sinus, Neck, other sites - Eye, Ears etc
09HLTH10B04-004-C Larynx and Hypopharynx

This will cover all aspects of the diagnosis, management and treatment of these cancers with special emphasis on translational and molecular aspects as well as newer technologies and treatments.

XV. ELIGBILITY FOR EXAMINATION

The candidate will be eligible to appear for the M. Ch. Examination in Head and Neck surgery conducted by the University only after certification of the following:

1) Completion of three years of Resident training.

2) Satisfactory attendance at Clinical / Academic sessions as duly certified on the logbook by the teacher. A minimum attendance of 85 % is mandatory.

XVI. EXAMINATION

4) Board of Examiners:

Four Examiners: Two internal & two external

All examiners shall be Surgical Oncologists/ Head and Neck surgeon.

5) Assessments of candidates & Results:

a) Assessment of theory, clinical, practical and viva–voce examination shall be done jointly by all the examiners.

b) A candidates shall be declared to have passed the examination if he /she has an adequate knowledge in all subjects as answered by Theory / clinical / practical and viva–voce examination and there shall be no classification or ranking of successful candidates. However, candidates of excellent performance could be recommended for award for distinction.

c) A candidates who fails in an examination shall appear as a casual student for subsequent examination.

d) The Board of examiners shall have the power to refer failed candidates for one year or to put in attendance for one term i.e. Six months before appearing for the ext examination.

Homi Bhabha National Institute

(a deemed to be University)

Post M. Sc. Diploma in Radiological Physics (Dip. R. P.)

(PROGRAM CODE: HLTH11)

SYLLABUS - 2017

FIRST SEMESTER

01HLTH11-001-C: RADIATION PHYSICS & RADIATION GENERATORS (42 Lectures)

1.1 Nuclear Physics 10 Lectures

Radioactivity - General properties of alpha, beta and gamma rays - Laws of radioactivity - Laws of successive transformations - Natural radioactive series - Radioactive equilibrium - Alpha ray spectra - Beta ray spectra - Theory of beta decay - Gamma emission - Electron capture - Internal conversion - Nuclear isomerism - Artificial radioactivity - Nuclear cross sections - Elementary ideas of fission and reactors - Fusion.

1.2 Particle Accelerators 10 Lectures

Particle accelerators for industrial, medical and research applications - The Resonant transformer - Cascade generator - Van De Graff Generator - Pelletron - Cyclotron – Betatron - Synchro-Cyclotron-Linear Accelerator - Klystron and magnetron - Travelling and Standing Wave Acceleration - Microtron - Electron Synchrotron-Proton synchrotron. Details of accelerator facilities in India.

1.3 X-ray Generators 10 Lectures

Discovery - Production - Properties of X-rays - Characteristics and continuous spectra - Design of hot cathode X-ray tube - Basic requirements of medical diagnostic, therapeutic and industrial radiographic tubes - Rotating anode tubes - Hooded anode tubes - Industrial X-ray tubes - X-ray tubes for crystallography - Rating of tubes - Safety devices in X-ray tubes – Ray proof and shock proof tubes - Insulation and cooling of X-ray tubes - Mobile and dental units - Faults in X-ray tubes - Limitations on loading.

Electric Accessories for X-ray tubes - Filament and high voltage transformers - High voltage circuits - Half-wave and full-wave rectifiers - Condenser discharge apparatus - Three phase apparatus - Voltage doubling circuits - Current and voltage stabilisers - Automatic exposure control - Automatic Brightness Control-Measuring instruments - Measurement of kV and mA - timers - Control Panels - Complete X-ray circuit - Image intensifiers and closed circuit TV systems - Modern Trends.

1.4 Interaction of Radiation with Matter (oriented towards Radiology) 12 Lectures

Interaction of electromagnetic radiation with matter Exponential attenuation - Thomson scattering - Photoelectric and Compton process and energy absorption - Pair production - Attenuation and mass energy absorption coefficients - Relative importance of various processes.

Interaction of charged particles with matter - Classical theory of inelastic collisions with atomic electrons - Energy loss per ion pair by primary and secondary ionization - Dependence of collision energy losses on the physical and chemical state of the absorber - Cerenkov radiation - Electron absorption process - Scattering Excitation and Ionization - Radiative collision - Bremmstrahlung - Range energy relation - Continuous slowing down approximation (CSDA) - straight ahead approximation and detour factors - transmission and depth dependence methods for determination of particle penetration - empirical relations between range and energy - Back scattering.

Passage of heavy charged particles through matter - Energy loss by collision - Range energy relation - Bragg curve - Specific ionization - Stopping Power - Bethe Bloch Formula. Interaction of neutrons with matter - scattering - capture - Neutron induced nuclear reactions.

01HLTH11-002-C: APPLIED MATHEMATICS (48 Lectures)

2.1 Probability, Statistics and Errors 12 Lectures

Probability - addition and multiplication laws of probability, conditional probability, population, variates, collection, tabulation and graphical representation of data

Basic ideas of statistical distributions frequency distributions, averages or measures of central tendency, arithmetic mean, properties of arithmetic mean, median, mode, geometric mean, harmonic mean, dispersion, standard deviation, root mean square deviation, standard error and variance, moments, skewness and kurtosis

Application to radiation detection - uncertainty calculations, error propagation, time distribution between background and sample, minimum detectable limit

Binomial distribution, Poisson distribution, Gaussian distribution, exponential distribution - additive property of normal variates, confidence limits, Bivariate distribution, Correlation and Regression, Chi- Square distribution, t-distribution, F-distribution

2.2 Counting and Medical Statistics 6 Lectures

Statistics of nuclear counting - Application of Poisson's statistics - Goodness-of-fit tests - Lexie's divergence coefficients Pearson's chi-square test and its extension - Random fluctuations Evaluation of equipment performance - Signal-to-noise ratio - Selection of operating voltage - Preset of rate meters and recorders - Efficiency and sensitivity of radiation detectors - Statistical aspects of gamma ray and beta ray counting - Special considerations in gas counting and counting with proportional counters - Statistical accuracy in double isotope technique.

Sampling and sampling distributions - confidence intervals. Clinical study designs and clinical trials. Hypothesis testing and errors. Regression analysis.

2.3 Numerical Methods 20 Lectures

Why numerical methods, accuracy and errors on calculations - round-off error, evaluation of formulae. Iteration for Solving $x = g(x)$, Initial Approximation and Convergence Criteria, Newton-Raphson Method. Taylor series, approximating the derivation, numerical differentiation formulas. Introduction to numerical quadrature, Trapezoidal rule, Simpson's rule, Simpson’s Three-Eighth rule, Boole rule, Weddle rule. Initial value problems, Picard’s method, Taylor’s method, Euler’s method, the modified Euler’s method, Runge-Kutta method

Monte Carlo: Random variables, discrete random variables, continuous random variables, probability density function, discrete probability density function, continuous probability distributions, cumulative distribution function, accuracy and precision, law of large number, central limit theorem, random numbers and their generation, tests for randomness, inversion random sampling technique including worked examples, integration of simple 1-D integrals including worked examples.

2.4 Computational Tools & Techniques 10 Lectures

Computational packages: Overview of programming in C++, MATLAB/ Mathematica, and STATISTICA in data analysis and graphics.

01HLTH11-003-C: RADIATION DOSIMETRY AND STANDARDIZATION (55 Lectures)

3.1 Radiation Quantities and Units 6 Lectures

Radiation quantities and units – Radiometry – Particle flux and fluence – Energy flux and fluence – Cross Section – Linear and mass attenuation coefficients - Mass energy transfer and mass energy absorption coefficients - Stopping power - LET - Radiation chemical yield - W value - Dosimetry - Energy imparted - Absorbed dose - Kerma - Exposure - Air kerma rate constant - Charged particle equilibrium (CPE) – Relationship between Kerma, absorbed dose and exposure under CPE - Dose equivalent - Ambient and directional dose equivalents [(H*(d) and H'(d)] - Individual dose equivalent penetrating Hp(d) - Individual dose equivalent superficial Hs(d)

3.2 Radiation Sources 5 Lectures

Radiation sources - Natural and artificial radioactive sources - Large scale production of isotopes - Reactor produced isotopes - Cyclotron produced isotopes - Fission products - industrial uses – Telecobalt and Brachy Caesium sources – Gold seeds - Tantalum wire - ^{125}I Sources - Beta ray applicators - Thermal and fast neutron sources - Preparation of tracers and labeled compounds - Preparation of radio colloids.

3.3 Dosimetry & Standardization of X- and Gamma Ray Beams 15 Lectures

Standards - Primary and Secondary Standards, Traceability, Uncertainty in measurement. Charged Particle Equilibrium (CPE), Free Air Ion Chamber (FAIC), Design of parallel plate FAIC, Measurement of Air Kerma/ Exposure. Limitations of FAIC. Bragg-Gray theory, Mathematical expression describing Bragg-Gray principle and its derivation. Burlin and Spencer Attix Cavity theories. Transient Charged Particle Equilibrium (TCPE), Concept of D_{gas}, Cavity ion chambers, Derivation of an expression for sensitivity of a cavity ion chamber. General definition of calibration factor - N_X, N_K, $N_{D, air}$, $N_{D,W}$. IAEA TRS277: Various steps to arrive at the expression for D_W starting from N_X. TRS398: $N_{D, W, Q}$: $N_{D, W}$: $K_{Q,Q0}$:K_Q , Derivation of an expression for $K_{Q,Q0}$. Calorimetric standards - Intercomparison of standards.

Measurement of D_W for External beams from ^{60}Co teletherapy machines: Reference conditions for measurement, Type of ion chambers, Phantom, Waterproof sleeve, Derivation of an expression for Machine Timing error, Procedure for evaluation of Temperature and pressure correction: Thermometers and pressure gauges. Measurement of temperature and pressure. Saturation correction: derivation of expression for charge collection efficiency of an ion chamber based on Mie theory. Parallel plate, cylindrical and spherical ion chambers, K_{sat}, Two voltage method for continuous and pulsed beams, Polarity correction. Measurement of D_W for high-energy photon beams from Linear accelerators: Beam quality, beam quality index, beam quality correction coefficient, Cross calibration. Measurement of D_W for high energy Electron beams from linear accelerators: Beam quality, beam quality index, beam quality correction coefficient, Cross calibration using intermediate beam quality. Quality Audit Programmes in Reference and Non- Reference conditions.

Standardization of brachytherapy sources - Apparent activity - Reference Air Kerma Rate - Air Kerma Strength - Standards for HDR ^{192}Ir and ^{60}Co sources - Standardization of ^{125}I and beta sources - IAEA TECDOC 1274 - room scatter correction. Calibration of protection level instruments and monitors.

3.4 Neutron Standards & Dosimetry 9 Lectures

Neutron classification, neutron sources, Neutron standards - primary standards, secondary standards, Neutron yield and fluence rate measurements, Manganese sulphate bath system, precision long counter, Activation method. Neutron spectrometry, threshold detectors, scintillation detectors & multispheres, Neutron dosimetry, Neutron survey meters, calibration, neutron field around medical accelerators.

3.5 Standardization of Radionuclides 8 Lectures

Methods of measurement of radioactivity - Defined solid angle and 4π counting - Beta gamma coincidence counting - Standardization of beta emitters and electron capture nuclides with proportional, GM and scintillation counters - Standardization of gamma emitters with scintillation spectrometers - Ionization chamber methods – Extrapolation chamber - Routine sample measurements - Liquid counter – Windowless counting of liquid samples - Scintillation counting methods for alpha, beta and gamma emitter - Reentrant ionization chamber methods - Methods using (n, γ) and (n, p) reactions - Determination of yield of neutron sources - Space integration methods - Solid state detectors.

3.6 Radiation Chemistry and Chemical Dosimetry 12 Lectures

Definitions of free radicals and G-value-Kinetics of radiation chemical transformations - LET and dose-rate effects - Radiation Chemistry of water and aqueous solutions, peroxy radicals, pH effects - Radiation Chemistry of gases and reactions of dosimetry interest - Radiation polymerization, effects of radiation on polymers and their applications in dosimetry - Formation of free radicals in solids and their applications in dosimetry - Description of irradiators from dosimetric view point - Dosimetry principles - Definitions of optical density, molar absorption coefficient, Beer- Lambert's law, spectrophotometry - Dose calculations - Laboratory techniques - Reagents and procedures - Requirements for an ideal chemical dosimeter - Fricke dosimeter - FBX dosimeter - Free radical dosimeter - Ceric sulphate dosimeter - Other high and low level dosimeters - Applications of chemical dosimeters in Radiotherapy and industrial irradiators.

01HLTH11-004-C: RADIATION DETECTION, MEASUREMENT AND NUCLEAR ELECTRONICS

(40 Lectures)

4.1 Radiation Detection and Measurement 20 lectures

Principles of radiation detection and general properties of detectors: Principles of radiation detection, modes of detector operation, Pulse height spectra, Counting curves and plateaus, Energy resolution, Detector efficiency, Dead time, detector window.

Gas filled radiation detectors: Various regions of operation of gas filled detectors - Ionization chambers, Proportional counters and GM counters - basic detection mechanism, types of radiation detected, mode of operation, different variants of detectors (e.g. sealed, flow type, high pressure, multi-wire, position sensitive), Types of instruments which uses gas filled detectors – radiation dosimeters, survey meters, contamination monitors - Cylindrical, plane parallel, spherical and well-type ionization chambers, Extrapolation chamber.

Scintillation (organic/inorganic) and semiconductor detectors: Advantages of scintillation detectors, properties of ideal scintillatior, basic electronic blocks in scintillation detector setup. Radiation detection mechanism of organic and in-organic scintillators, types of scintillators for various applications. Radiation detection by TLD. Photon detection devices - PMT, Photo diodes. Principles of detection mechanism in semiconductor detectors and its application for gamma and alpha spectrometry, Diode and MOSFET dosimeters.

Neutron detectors: Neutron detection by activation, Nuclear track detectors, Self powered neutron detectors (SPND), BF_3, ^3He, Bubble detectors.

New types of detectors: Radiation detection by direct ion storage (DIS), OSL, Diamond, Radiation litmus, Radiographic and radiochromic films.

4.2 Nuclear Electronics and Instrumentation 20 lectures

Analog electronics: Operational amplifiers (ideal characteristics, different operational circuits - inverting, non-inverting amplifiers, adder, sub-tractor, integrator.

Interfacing concepts: Fundamental concepts of interfacing an instrument to PC/Computer, interfacing methods.

Power Supply: Low voltage and high voltage power supplies for radiation instruments, Generation of low and high voltages and their specifications, Types of batteries and their specifications.

Basic building blocks used in nuclear measurements: Pre amplifiers, types of preamplifiers and selection of proper preamplifier for specific detector, Types of amplifier - linear, bias amplifier, log amplifier, shaping amplifier, Counters, rate meters - diode pump and IC rate meters, SCA, MCA, Coincidence and anti-coincidence circuit blocks.

Radiation Monitoring Instruments:

Dosimeters based on condenser chamber, quartz fibre electrometer, dosimeter based on current measurement, secondary standard dosimeter, Farmer dosimeter, beam therapy dosimeter, clinical dosimeter, isotope calibrator, Radiation field analyzer (RFA)

Instruments for personal monitoring: TLD Reader for medical & research applications, TLD Badge Reader, OSLD badge reader, Film Badge Reader, Densitometer, Digital pocket dosimeter.

Area monitoring instruments: Portable and fixed area monitors, fixed area monitors, beta-gamma zone monitor, Survey meters, wide range survey instrument, teletector,

Contamination monitoring instruments: portable contamination monitor, hand &foot surface contamination monitor, portal monitor, laundry monitor, floor monitor

Neutron monitoring instruments, REM counter

Method of estimating activity present inside the body - whole body counter.

Calibration of Radiation Protection Instruments: Fundamental concepts of instrument calibration, Basic requirements for calibration, Various parameters checked during calibration, Selection of radioactive sources and source strength for calibration check.

01HLTH11-001-P:

1. Production and attenuation of bremsstrahlung.
2. Range of beta particles by Feather analysis.
3. Backscattering of beta particles and its applications.
4. Statistics of radioactive counting.
5. Study of voltage and current characteristics of an ion-chamber.
6. Calibration of survey instruments and pocket dosimeters.
7. Construction and calibration of a G.M. monitor.
8. Calibration of a therapy level dosimeter.
9. Calibration of TL phosphor & TLD reader and its use in dose distribution measurements.

10. Determination of plateau and resolving time of a G.M. counter and its application in estimating the shelf-ratio and activity of a beta source.
11. (a) Output measurement of a gamma chamber using Fricke dosimeter, and (b) Dose rate measurement of teletherapy machines using FBX dosimeter.
12. Calibration of a TLD personnel monitoring badge and dose evaluation.
13. Characteristics of a flow counter and beta activity measurement.
14. Calibration of Gamma ray spectrometer [NaI(Tl), HPGe] and identification of unknown sources using multichannel analyser.
15. Calibration and use of alanine dosimeter using ESR technique.
16. Preparation and standardization of unsealed sources.

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SECOND SEMESTER

01HLTH11-005-C: CLINICAL AND RADIATION BIOLOGY (56 Lectures)

5.1 Cell Biology 6 Lectures

Cell physiology and biochemistry - Structure of the cell - Types of cells and tissue, their structures and functions - Organic constituents of cells - Carbohydrates, fats, proteins and nucleic acids - Enzymes and their functions - Functions of mitochondria, ribosomes, golgi bodies and lysosomes - Cell metabolism - DNA as concepts of gene and gene action - Mitotic and meiotic cell division - Semi conservative DNA synthesis, Genetic variation Crossing over, mutation, chromosome segregation - Heredity and its mechanisms.

5.2 Anatomy, Physiology and Pathology 10 Lectures

Anatomy and physiology as applied to radiodiagnosis and radiotherapy - Structure & function of organs and systems & their common diseases: Skin, Lymphatic system, Bone and muscle, Nervous, Endocrine, Cardiovascular, Respiratory, Digestive (Gastro-Intestinal), Urinary, Reproductive, Eye and ear.

Anatomy of human body, nomenclature & Surface anatomy, Radiographic Anatomy (including cross sectional anatomy - identify the different organs/ structures on plain x-rays, CT scans and other available imaging modalities. Normal anatomy & deviation for abnormalities.

Tumour pathology and carcinogenesis, common pathological features of cancers and interpretation of clinico-pathological data

5.3 Interaction of Radiation with Cells 6 Lectures

Action of radiation on living cells - Radiolytic products of water and their interaction with biomolecule - Nucleic acids, proteins, enzymes, fats - Influence of oxygen, temperature - Cellular effects of radiation - Mitotic delay, chromosome aberrations, mutations and recombinations - Giant cell formation, cell death - Recovery from radiation damage - Potentially lethal damage and sublethal damage recovery - Pathways for repair of radiation damage. Law of Bergonie and Tribondeau.

Survival curve parameters - Model for radiation action - Target theory - Multihit, Multitarget - Repair misrepair hypothesis - Dual action hypothesis - Modification of radiation damage - LET, RBE, dose rate, dose fractionation - Oxygen and other chemical sensitizers - Anoxic, hypoxic, base analogs, folic acid, and energy metabolism inhibitors - Hyperthermic sensitization - Radio-protective agents.

5.4 Biological Effects of Radiation 9 Lectures

Somatic effects of radiation - Physical factors influencing somatic effects - Dependence on dose, dose rate, type and energy of radiation, temperature, anoxia, - Acute radiation sickness - LD 50 dose - Effect of radiation on skin and blood forming organs, digestive tract - Sterility and cataract formation - Effects of chronic exposure to radiation - Induction of leukaemia - Radiation Carcinogenesis - Risk of carcinogenesis - Animal and human data - Shortening of life span - In-utero exposure - Genetic effects of radiation - Factors affecting frequency of radiation induced mutations - Dose-effect relationship - first generation effects - Effects due to mutation of recessive characteristics - Genetic burden - Prevalence of hereditary diseases and defects - Spontaneous mutation rate - Concept of doubling dose and genetic risk estimate.

5.5 Clinical Aspects of Medical Imaging & Radiation Oncology 15 Lectures

Radiation Therapy, Surgery, Chemotherapy, Hormone Therapy, Immunotherapy & Radionuclide therapy, Benign and malignant disease, Methods of spread of malignant disease, Staging and grading systems, Treatment intent - Curative & Palliative, Cancer prevention and public education and Early detection & Screening.

Site specific signs, symptoms, diagnosis and management: Head and Neck, Breast, Gynaecological, Gastro-Intestinal tract, Genito-Urinary, Lung & Thorax, Lymphomas & Leukemias & Other cancers including AIDS related cancers.

Patient management on treatment - side effects related to radiation and dose - Acute & Late - Monitoring and common management of side effects - Information and communication.

Professional aspects and role of medical physicists: General patient care - Principles of professional practice - Medical terminology - Research & Professional writing - Patient privacy - Ethical & cultural issues. Legal aspects - Confidentiality, Informed consent, Health and Safety.

5.6 Biological Basis of Radiotherapy 5 Lectures

Physical and biological factors affecting cell survival, tumour re-growth and normal tissue response -Non-conventional fractionation scheme and their effect of re-oxygenation, repair, redistribution in the cell cycle - High LET radiation therapy.

5.7 Time Dose Fractionation 5 Lectures

Time dose fractionation - Basis for dose fractionation in beam therapy - Concepts for Nominal Standard Dose (NSD), Roentgen equivalent therapy (RET) - Time dose fractionation (TDF) factors and cumulative radiation effects (CRE) - Gap correction, Linear and Linear Quadratic models.

01HLTH11-006-C: MEDICAL IMAGING (52 Lectures)

6.1 Principles of X-ray Diagnosis & Conventional Imaging 12 Lectures

Physical principle of diagnostic radiology: Interactions of X-rays with human body, differential transmission of x-ray beam, spatial image formation, visualization of spatial image, limitations of projection imaging technique Viz. superimposition of overlying structures and scatter, application of contrast media and projections at different angles to overcome superimposition of overlying structures

Radiography techniques: Prime factors (kVp, mAs and SID/SFD), influence of prime factors on image quality, selection criteria of prime factors for different types of imaging, different type of projection and slices selected for imaging, objectives of radio-diagnosis, patient dose Vs image quality

Filters: inherent and added filters, purpose of added filters, beryllium filter, filters used for shaping X-ray spectrum (K-edge filters: holmium, gadolinium, molybdenum).

Scatter reduction: Factors influencing scatter radiation, objectives of scatter reduction, contrast reduction factor, scatter reduction methods; beam restrictors (diaphragms, cones/cylinders & collimators), grids (grid function, different types of stationary grids, grid performance evaluation parameters, moving grids, artifacts caused by grids, grid selection criteria), air gap technique

Intensifying screens: Function of intensifying screens, screen function evaluation parameters, emission spectra and screen film matching, conventional screens Vs rare earth screens

Radiographic Film: Components of radiographic film, physical principle of image formation on film, double and single emulsion film, sensitometeric parameters of film (density, speed, latitude etc.), QA of film developer

Image quality: Image quality parameters; sources of un-sharpness, reduction of un-sharpness, factors influencing radiographic contrast, resolution, factors influencing resolution, evaluation of resolution (point spread function (PSF), line spread function (LSF), edge spread function (ESF), modulation transfer function (MTF)), focal spot size evaluation

QA of conventional diagnostic X-ray equipment: Purpose of QA, QA protocols, QA a test methods for performance evaluation of x-ray diagnostic equipment

6.2 Digital X-Ray Imaging and Computed Tomography 10 Lectures

Xero-radiography, mammography, Interventional radiology, digital radiography (CR and DR systems), digital subtraction techniques, Conventional tomography (principle only), orthopan tomography (OPG), Computed Tomography (CT), QA of CT equipment

6.3 Nuclear Medicine & Internal Dosimetry 20 Lectures

Physics of Nuclear Medicine (12 L)

Introduction to Nuclear Medicine, Unsealed Sources, Production of Radionuclide used in Nuclear Medicine; Reactor based Radionuclides, Accelerator based Radionuclides, Photonuclear activation, Equations for Radionuclide Production, Radionuclide Generators and their operation principles. Various usages of Radiopharmaceuticals.

In-vivo Non-imaging procedures; Thyroid Uptake Measurements, Renogram, Life Span of RBC, Blood Volume studies, Life Span of RBC etc. General concept of Radionuclide Imaging and Historical developments.

Radionuclide Imaging: Other techniques and Instruments; The Rectilinear Scanner and its operational principle, Basic Principles and Design of the Anger Camera / Scintillation Camera; System components, Detector System and Electronics, Different types of Collimators, Design and Performance Characteristics of the Converging, Diverging and Pin hole Collimator, Image Display and Recording Systems, Digital Image Processing Systems, Scanning Camera, Limitation of the Detector System and Electronics.

Different Imaging Techniques: Basic Principles, 2D Imaging Techniques, 3D Imaging Techniques - Basic Principles and Problem, Focal Plane Tomography, Emission Computed Tomography, Single Photon Emission Computed Tomography, Positron Emission Tomography. Various Image Reconstruction Techniques during Image formation such as Back Projection and Fourier based Techniques, Iterative Reconstruction method and their drawbacks. Attenuation Correction, Scatter Correction, Resolution Correction, Other requirements or Sources of Error.

Image Quality Parameters: Spatial Resolution, Factor affecting Spatial Resolution, Methods of Evaluation of Spatial Resolution, Contrast, Noise. NEMA Protocols followed for Quality Assurance / Quality Control of Imaging Instruments.

In-vitro Technique: RIA/IRMA techniques and its principles.

Physics of PET and Cyclotron: Principles of PET, PET Instrumentations, Annihilation Coincidence Detection, PET Detector ad Scanner Design, Data Acquisition for PET, Data corrections and Quantitative Aspect of PET, Working of Medical Cyclotron, Radioisotopes Produced and their characteristics.

Treatment of Thyrotoxicosis, Thyroid cancer with I-131, use of P-32 and Y-90 for palliative treatment, Radiation Synovectomy and the isotopes used. Concept of Delay Tank and various Waste Disposal Methods used in Nuclear Medicine.

Planning and Shielding Calculations during the installation of SPECT, PET/CT and Medical Cyclotron in the Nuclear Medicine Department.

Internal Dosimetry (8 L)

Internal Radiation Dosimetry: Different Compartmental Model; Single Compartmental Model, Two Compartmental Model with Back Transference, Two Compartmental Model without Back Transference. Classical Methods of Dose Evaluation; Beta particle Dosimetry; Equilibrium Dose Rate Equation, Beta Dose Calculation Specific Gamma Ray Constant, Gamma Ray Dosimetry, Geometrical Factor Calculation, Dosimetry of Low Energy Electromagnetic Radiation.

MIRD Technique for Dose calculations; Basic procedure and some practical problems, Cumulative Activity, Equilibrium Dose Constant, Absorbed Fraction, Specific Absorbed Fraction, Dose Reciprocity Theorem, Mean Dose per unit Cumulative Activity and Problems related to the Dose Calculations. Limitation of MIRD Technique.

6.4 Magnetic Resonance Imaging (MRI) 6 Lectures

Magnetic Resonance image - proton density, relaxation time T1 & T2 images - Image characteristics - MRI system components - Magnets, Magnetic fields, Gradients, Magnetic field shielding, Radio Frequency systems, computer functions - Imaging process – Image artifacts – MRI safety.

6.5 Ultrasound Imaging 4 Lectures

Interaction of sound waves with body tissues, production of ultrasound - transducers – acoustic coupling - image formation - modes of image display - colour Doppler.

01HLTH11-007-C: RADIATION THERAPY (66 Lectures)

7.1 Beam Therapy 30 Lectures

Description of low kV therapy x-ray units - spectral distribution of kV x-rays and effect of filtration - thoraeus filter - output calibration procedure.

Construction and working of telecobalt units - source design - beam collimation and penumbra - trimmers and breast cones. Design and working of medical electron linear accelerators - beam collimation - asymmetric collimator - multileaf collimator - dose monitoring - electron contamination. Output calibration of ^{60}Co gamma rays, high energy x-rays and electron beams using IAEA TRS 398, AAPM TG 51 and other dosimetry protocols. Relative merits and demerits of kV x-rays, gamma rays, MV x-rays and electron beams. Radiotherapy simulator and its applications. CT and virtual simulations.

Central axis dosimetry parameters - Tissue air ratio (TAR) Back scatter/ Peak scatter factor (BSF/PSF) - Percentage depth doses (PDD) - Tissue phantom ratio (TPR) - Tissue maximum ratio (TMR) - Collimator, phantom and total scatter factors. Relation between TAR and PDD and its applications - Relation between TMR and PDD and its applications. SAR, SMR, Off axis ratio and Field factor. Build-up region and surface dose. Tissue equivalent phantoms. Radiation filed analyzer (RFA). Description and measurement of isodose curves/charts. Dosimetry data resources.

Beam modifying and shaping devices - wedge filters - universal, motorized and dynamic wedges- shielding blocks and compensators. Treatment planning in teletherapy - target volume definition and dose prescription criteria- ICRU 50 and 62 - SSD and SAD set ups - two and three dimensional localization techniques - contouring - simulation of treatment techniques - field arrangements - single, parallel opposed and multiple fields - corrections for tissue inhomogeneity, contour shapes and beam obliquity - integral dose. Arc/ rotation therapy and Clarkson technique for irregular fields - mantle and inverted Y fields. Conventional and conformal radiotherapy. Treatment time and Monitor unit calculations.

Clinical electron beams - energy specification - electron energy selection for patient treatment - depth dose characteristics (D_s, D_x, R_{100}, R_{90}, R_{50}, R_p etc.) - beam flatness and symmetry - penumbra - isodose plots - monitor unit calculations - output factor formalisms - effect of air gap on beam dosimetry - effective SSD.

Particulate beam therapy - Relative merits of proton, electron, neutron, x-ray and gamma ray beams - Neutron capture therapy - Heavy ion therapy.

Quality assurance in radiation therapy - precision and accuracy in clinical dosimetry - quality assurance protocols for telecobalt, medical linear accelerator and radiotherapy simulators - IEC requirements - acceptance, commissioning and. quality control of telecobalt, medical linear accelerator and radiotherapy simulators. Portal and in-vivo dosimetry. Electronic portal imaging devices.

7.2 Brachytherapy 12 Lectures

Definition and classification of brachytherapy techniques - surface mould, intracavitary, interstitial and intraluminal techniques. Requirement for brachytherapy sources - Description of radium and radium substitutes - ^{137}Cs, ^{60}Co, ^{192}Ir, ^{125}I and other commonly used brachytherapy sources. Dose rate considerations and classification of brachytherapy techniques - Low dose rate (LDR), high dose rate (HDR) and pulsed dose rate (PDR). Paterson Parker and Manchester Dosage systems. ICRU 38 and 58 protocols. Specification and calibration of brachytherapy sources – RAKR/AKS and Absorbed Dose to Water calibration - IAEA TECDOC 1274 and ICRU 72 recommendations – Point and line source dosimetry formalisms - Sievert Integral - AAPM TG-43/43U1 and other dosimetry formalisms.

Afterloading techniques - Advantages and disadvantages of manual and remote afterloading techniques. AAPM and IEC requirements for remote afterloading brachytherapy equipment. Acceptance, commissioning and quality assurance of remote after loading brachytherapy equipment. ISO requirements and QA of brachytherapy sources. Integrated brachytherapy unit.

Brachytherapy treatment planning - CT/MR based brachytherapy planning - GEC ESTRO recommendations - forward and inverse planning – DICOM image import / export from OT - Record & verification. Brachytherapy treatment for Prostate cancer. Ocular brachytherapy using photon and beta sources. Intravascular brachytherapy - classification - sources - dosimetry procedures - AAPM TG 60 protocol. Electronic brachytherapy (Axxent, Mammosite, etc.).

7.3 Computers in Treatment Planning 12 Lectures

Scope of computers in radiation treatment planning - Review of algorithms used for treatment planning computations - Pencil beam, double pencil beam, Clarkson method, convolution superposition, lung interface algorithm, fast Fourier transform, Inverse planning algorithm, Monte Carlo based algorithms.

Treatment planning calculations for photon beam, electron beam, and brachytherapy - Factors to be incorporated in computational algorithms. Plan optimization - direct aperture optimization - beamlet optimization - simulated annealing - dose volume histograms - Indices used for plan comparisons - Hardware and software requirements - beam & source library generation. Networking, DICOM and PACS. Acceptance, commissioning and quality assurance of radiotherapy treatment planning systems using IAEA TRS 430 and other protocols.

7.4 Special and Advanced Techniques of Radiotherapy 12 Lectures

Special techniques in radiation therapy - Total body irradiation (TBI) - large field dosimetry - total skin electron therapy (TSET) - electron arc treatment and dosimetry - intraoperative radiotherapy.

Stereotactic radiosurgery/radiotherapy (SRS/SRT) - cone and mMLC based X-Knife - Gamma Knife - immobilization devices for SRS/SRT - dosimetry and planning procedures - Evaluation of SRS/SRT treatment plans - QA protocols and procedures for X- and Gamma Knife units - Patient specific QA. Physical, planning, clinical aspects and quality assurance of stereotactic body radiotherapy (SBRT) and Cyber Knife based therapy.

Intensity modulated radiation therapy (IMRT) - principles - MLC based IMRT - step and shoot and sliding window techniques - Compensator based IMRT - planning process - inverse treatment planning - immobilization for IMRT - dose verification phantoms, dosimeters, protocols and procedures - machine and patient specific QA. Concept of Intensity Modulated Arc Therapy (IMAT e.g. Rapid Arc), Image Guided Radiotherapy (IGRT), and Volumetrically Modulated Arc Therapy (VMAT) - Imaging modality, kV cone beam CT (kVCT), MV cone beam CT (MVCT), image registration, plan adaptation, QA protocol and procedures - special phantom, 4DCT. Tomotherapy - principle - commissioning - imaging - planning and dosimetry - delivery - plan adaptation - QA protocol and procedures.

01HLTH11-008-C: RADIATION SAFETY (64 Lectures)

8.1 Radiation Protection Standards 7 Lectures

Radiation dose to individuals from natural radioactivity in the environment and man-made sources. Basic concepts of radiation protection standards - Historical background - International Commission on Radiological Protection and its recommendations – The system of Radiological Protection – Justification of Practice, Optimisation of Protection and individual dose limits – Radiation and tissue weighting factors, equivalent dose, effective dose, committed equivalent dose, committed effective dose – Concepts of collective dose- Potential exposures, dose and dose constraints – System of protection for intervention - Categories of exposures – Occupational, Public and Medical Exposures - Permissible levels for neutron flux
- Factors governing internal exposure - Radionuclide concentrations in air and water - ALI, DAC and contamination levels

8.2 Principles of Monitoring and Protection 6 Lectures

Evaluation of external radiation hazards - Effects of distance, time and shielding - Shielding calculations - Personnel and area monitoring - Internal radiation hazards – Radio toxicity of different radionuclides and the classification of laboratories – Control of contamination – Bioassay and air monitoring – chemical protection – Radiation accidents – disaster monitoring

8.3 Safety in the Medical Uses of Radiation 15 Lectures

Planning of medical radiation installations – General considerations – Design of diagnostic, deep therapy, telegamma and accelerator installations, brachytherapy facilities and medical radioisotope laboratories.

Evaluation of radiation hazards in medical diagnostic and therapeutic installations - Radiation monitoring procedures - Protective measures to reduce radiation exposure to staff and patients - Radiation hazards in brachytherapy departments and teletherapy departments and radioisotope laboratories - Particle accelerators Protective equipment - Handling of patients - Waste disposal facilities - Radiation safety during source transfer operations Special safety features in accelerators, reactors.

8.4 Applications & Safety in the Industrial, Agricultural and Research uses of Radiation (**18 L**)

Physical principles of industrial radiography - Comparison of X-ray radiography and gamma radiography - Choice of source - Exposure containers - Photographic film technique - Radiographic contrast Definition of sensitivity - Intensifying screens - Penetrameters.

Industrial Fluoroscopy - Comparison of fluoroscopy and radiography - Image intensifier. Special techniques - Microradiography, flash radiography_ stereo - radiography - X-ray diffraction - Neutron radiography and electron radiography.

Physical principles in the industrial application of radioisotopes - Use of sealed sources - Radioisotope gauges – Use of transmission and scattering gauges for measurement of thickness, density and composition - Level indicators - Bremsstrahlung gauges Beta and gamma backscattering gauges and their applications - Neutron scattering gauges - Principles and applications of X-ray fluorescence techniques.

Applications in agriculture and research – Radioisotope tracer applications - General principles - Selection of radiotracer Dilution technique - Some examples of applications in agriculture, biology and research areas.

Planning of radiation installations and isotope laboratories in industry - Facilities for storage, handling and field operations, Planning of radioisotope laboratories for agriculture and research Institutions - Design of gamma gardens for agriculture.

Radiation protection measures and hazards evaluation in industrial and agricultural establishments - X and gamma ray radiography - X-ray diffraction apparatus - Radioisotope gauges - Tracer applications for radioisotopes in agriculture and industry Gamma chamber - Radiation sterilization - Irradiation of food and drugs - PANBIT and ISOMED - Luminising industry - Radiation protection in Industrial Radiographic Installations - Enclosed, open top, open field and sky shine.

Tritium and C-14 monitoring – Monitoring of Spillage - Contamination and control.

8.5 Radioactive Waste Disposal 4 Lectures

Radioactive wastes – sources of radioactive wastes - Classification of waste - Treatment techniques for solid, liquid and gaseous effluents – Permissible limits for disposal of waste - Sampling techniques for air, water and solids – Geological, hydrological and meteorological parameters – Ecological considerations.

Disposal of radioactive wastes - General methods of disposal - Management of radioactive waste in medical, industrial, agricultural and research establishments.

8.6 Transport of Radioisotopes 4 Lectures

Transportation of radioactive substances - Historical background - General packing requirements - Transport documents - Labeling and marking of packages - Regulations applicable for different modes of transport - Transport by post - Transport emergencies - Special requirements for transport of large radioactive sources and fissile materials - Exemptions from regulations – Shipment approval – Shipment under exclusive use – Transport under special arrangement – Consignor’s and carrier’s responsibilities

8.7 Legislation 5 Lectures

Physical protection of sources - Safety and security of sources during storage, use, transport and disposal – Security provisions: administrative and technical – Security threat and graded approach in security provision

National legislation – Regulatory framework – Atomic Energy Act – Atomic Energy (Radiation Protection) Rules – Applicable Safety Codes, Standards, Guides and Manuals – Regulatory Control – Licensing, Inspection and Enforcement – Responsibilities of Employers, Licensees, Radiological Safety Officers and Radiation Workers – National inventories of radiation sources – Import, Export procedures

8.8 Radiation Emergencies and their Medical Management 5 Lectures

Radiation accidents and emergencies in the use of radiation sources and equipment in industry and medicine - Radiographic cameras and teletherapy units - Loading and unloading of sources - Loss of radiation sources and their tracing - Typical accident cases. Radiation injuries, their treatment and medical management - Case histories. Prophylaxis and decorporating agents

01HLTH11-002-P:

17. Quality assurance of a diagnostic x-ray machine.
18. Evaluation of characteristics of a radiographic image.
19. Study and calibration of thyroid uptake measurement unit.
20. Dose output measurement of photon (^{60}Co gamma rays and high energy x-rays) beams used in radiotherapy treatment.
21. Dose output measurement of electron beams used in radiotherapy treatment.
22. Determination of percentage depth dose of photon and electron beams.
23. Integrity check and calibration of low activity brachytherapy sources.
24. AKS/ RAKR measurement of an HDR brachytherapy source using well type and cylindrical ionisation chambers.
25. In-phantom dosimetry of a brachytherapy source.
26. Familiarisation with treatment planning procedure using a computerised radiotherapy treatment planning system.
27. Survey of a radioisotope laboratory and study of surface and air contamination.
28. Protection survey of neutron installations - Calibration and evaluation of neutron badge.
29. Protection survey of industrial radiography camera.
30. Absorption and backscattering of gamma rays - Determination of HVT.
31. Radiation protection survey of teletherapy installations.
32. Radiation protection survey of diagnostic radiology installations.

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Suggested Books for References

Radiation Physics & Radiation Generators

1. R. D. Evans, Atomic Nucleus
2. Preston M.A. Physics Of Nucleus
3. Lapp R.E. Nuclear Radiation Physics
4. Segre E. Experimental Nuclear Physics
5. Slack L. Radiations From Radioactive Atoms
6. Oliver R. Radiation Physics in Radiology
7. Crouthamel C.E. Applied Gamma-Ray Spectrometry

Radiological Mathematics

1. Hoffman. Numerical Methods for Engineers and Scientists – 2nd Edition Revised and Expanded, Marcel Dekker, Inc., 270 Madison Avenue, blew York, NY 10016, Marcel Dekker AG, Hutgasse 4, Postfach 812, CH-4001 Basel, Switzerland.
2. A. C. Bajpai, I. M. Calus and J. A. Fairley Numerical Methods for Engineers and Scientists – A student's course book, John Wiley & Sons
3. Band W. Introduction to Mathematical Physics.
4. Croxton. Elementary Statistics
5. Dahlberg G. Statistical Method of Medical &Biology Students
6. Krasnor M.L. Ordinary Diff. Equation

Radiation Dosimetry and Standardization

1. Joseph Magill and Jean Galy. Radioactivity Radionuclides Radiation, European Commission Joint Research Centre, Institute for Transuranium Elements, P. O. Box 2340, 76125 Karlsruhe, Germany
2. IAEA TRS 374, Calibration of Dosimeters used in Radiation Therapy
3. F. H. Attix. Introduction to Radiological Physics and Radiation Dosimetry, Viley-VCH, Verlog, 2004.
4. Field. Clinical Use of Radioisotopes

Radiation Detectors and Instrumentation

1. Price W.J. Nuclear Radiation Detection
2. Stepanor B.I. Theory Of Luminescence
3. Glenn F Knoll. Radiation Detection & Measurement
4. Albert Paul Malvino. Electronics Principles
5. Robert L. Boylestad. Electronics Devices and Circuit Theory
6. Paul-Horowitz. Art of Electronics
7. Greiner R.A. Semiconductor Devices & Application
8. Crawford R.H. MOSFET in Circut Design

Clinical and Radiation Biology

1. Meschan. Normal Radiation Anatomy
2. Hollinshead W.H. Text Book Of Anatomy

Medical Imaging

1. Curry, T.S., Dowdey, J.E., Murry, R.C., (1990), Christensen's introduction to the physics of diagnostic radiology (4th ed.), Philadelphia : Lea & Febiger.
2. Bushberg, S.T., Seibert, J.A, Leidholt, E.M. & Boone, J.M. (1994), The essential physics of medical imaging, Baltimore: Williams & Wilkins.
3. Dendy, P.P. & Heaton, B. (2nd ed.), Physics for diagnostic radiology, Bristol & Philadelphia: Institute of Physics Publishing.
4. Johns, H.E. & Cunningham, J.R. (1983), The physics of radiology (4th ed.), Springfield, IL : Charles C. Thomas
5. E. Seeram. X-ray imaging equipment, An introduction (1985), Springfield, IL: Charles C. Thomas.
6. Hendee, W.R. & Ritenour, R. (1993), Medical Imaging Physics (3rd ed.), St. Louis: C.V. Mosbey.

7. Chesney, D.N. & Chesney, M.O., X-ray equipment for student radiographers (3^{rd} ed.), New Delhi: CBS Publishers & Distributors.
8. Chesney, D.N. & Chesney, M.O., Radiographic imaging (4^{th} ed.), New Delhi: CBS Publishers & Distributors.
9. Hashemi, R.H, Bradley, W.G. & Lisanti, C.J. MRI the basics, Philadelphia: Lippincot Williams & Wilkins.
10. Sprawls, P., Magnetic resonance imaging principles, methods and techniques, Madison, Wisconsin: Medical Physics Publishing.
11. Simon R. Cherry, James A. Sorenson, Michael E. Phelps, Physics in Nuclear Medicine (3^{rd} ed.), SAUNDERS an imprint of Elsevier.
12. Ramesh Chandra, Nuclear Medicine Physics (5^{th} ed.), Lea & Febiger, Philadelphia.
13. Antonio Fernando Goncalves Rocha and John Charles Harbert, Text Book of Nuclear Medicine: Basic Science, Lea & Febiger, Philadelphia.
14. Pail J. Early, M.A. Razzak and D, Bruces Sodee, Text book of Nuclear Medicine Technology. The C.V. Mosby Company.
15. A.L. Baert and K. Sartor, Diagnostic Nuclear Medicine (2^{nd} ed.). Springer.
16. Gopal B. Saha, Fundamental of Nuclear Pharmacy (5^{th} ed.). Springer.
17. Dale L. Bailey, David W. Townsend, Peter E. Valk and Michael N. Maisey. Springer.Janet F. Eary and Winfried Brenner, Nuclear Medcine Therapy. Informa Health Care.
18. J. F. Fowler, Nuclear Particles in Cancer Treatment, Adam Hilger Ltd., Philadelphia, 1981.

Radiation Therapy

1. H. E. Johns and Cunningham. The Physics of Radiology
2. Faiz M. Khan, The Physics of Radiation Therapy, Lippincott Williams & Wilkins, Philadelphia, 3^{rd} edition, 2003.
3. Faiz M. Khan, Roger A. Potish, Treatment Planning in Radiation Oncology, Williams & Wilkins, Baltimore, 1998.
4. S. Webb. The physics of three dimensional radiation therapy, Institute of Physics publishing, Philadelphia, 1993.
5. S. Webb. The physics of conformal radiotherapy, Institute of Physics publishing, Philadelphia, 1997.
6. S. Webb. Intensity Modulated radiation therapy, Institute of Physics publishing, Philadelphia, 2001.
7. S.K. Jani. CT simulation for radiotherapy, Medical Physics Publishing, Madison, WI, 1993
8. J. Van Dyk. The Modern Technology of Radiation Oncology, Medical Physics Publishing, Madison, WI, 1999.
9. S.C. Klevenhagen Physics and dosimetry of therapy Electron beams, Medical Physics Publishing, Madison, WI, 1996.
10. Thomas Bortfeld · Rupert Schmidt-Ullrich, Wilfried De Neve · David E.Wazer (Editors). Image-Guided IMRT. Springer Berlin Heidelberg, 2006.
11. D. Baltas, L. Sakelliou and N. Zamboglou The Physics of Modern Brachytherapy for Oncology CRC Press, Taylor and Francis Group, 6000 Brooken Sound Parkway NW Suite 300, Boca Raton – FL 33487-2742.
12. S. H. Levitt, J. A. Purdy, C. A. Perez and S. Vijayakumar (Editors). Technical Basis of Radiation Therapy Practical Clinical Applications - 4^{th} Revised Edition, Springer Berlin Heidelberg New York
13. Jack Van Dyke. Physics of Radiation Oncology.

Radiation Safety

1. Herman Cember. Introduction to Health Physics
2. Atomic Energy Act 1962
3. AERB Radiation Protection Rules 2004
4. ICRP 1990 Recommendations
5. ICRP 2007 Recommendations
6. IAEA Basic Safety Standards 115, 1997
7. IAEA Basic Safety Standards, 2012
8. Shapiro J. Radiation Protection
9. Mckenzie. Radiation Protection in Radiotherapy
10. Mawson C.A. Management Of Radioactive Wastes

BACK TO MAIN

SYLLABUS FOR

Integrated M.Sc. Chemical Sciences under NISER (Program Code: CHEM13)

SCHOOL OF CHEMICAL SCIENCES

DETAILED COURSE STRUCTURE

FOR

INTEGRATED M.Sc. COURSE

Revised Jan 2017

SYLLABUS

Integrated MSc. in Chemistry

Applicable from the Admission Year 2016 onwards

SCHOOL OF CHEMICAL SCIENCES

NATIONAL INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

JATNI, BHUBANESWR

Course Structure for Integrated MSc. in Chemistry

Year/Semester	Course No.	Credits	Course
1/Semester I	C101	3	Chemistry-I
	C141	2	Chemistry Laboratory-I
	M101	3	Mathematics-I
	CS141	2	Programming & Data Structure Lab-I
	B101	3	Biology-I
	B141	2	Biology Laboratory-I
	P101	3	Physics-I
	P141	2	Physics Laboratory-I
	H109	2	Technical Communication-I
	H125	2	Introduction to Psychology
1/Semester II	C102	3	Chemistry-II
	C142	2	Chemistry Laboratory-II
	M102	3	Mathematics-II
	CS142	2	Programming & Data Structure Lab-II
	B102	3	Biology-II
	B142	2	Biology Laboratory-II
	P102	3	Physics-II
	P142	2	Physics Laboratory-II
	H110	2	Technical Communication-II
	H133	2	Introduction to Sociology
2/Semester III	C201	4	Basic inorganic Chemistry
	C203	4	Reaction Mechanisms in Organic Chemistry
	C207	4	Mathematical Methods for Chemists
	C245	4	Inorganic Chemistry Lab.
	****	4	Elective-I
	****	2	Elective-II(Humanities)
	****	2	Elective-III(Humanities)
2/Semester IV	C204	4	Reagents in Organic Syntheses
	C205	4	Main group and Organometallic Chemistry
	C206	4	Quantum Chemistry I
	C243	2	Physical Chemistry Lab I
	C244	2	Biomolecular Chemistry Lab
	****	4	Elective-IV
	****	2	Elective-V(Humanities)
	****	2	Elective-VI(Humanities)

3/Semester V	C301 C302 C307 C341 C342 ****	4 4 4 4 4 4	Physical Organic Chemistry Molecular Spectroscopy and group Theory Thermodynamics and Electrochemistry Organic Chemistry Lab I Inorganic Chemistry Lab I Elective-VII
3/Semester VI	C304 C305 C306 C343 C344 ****	4 4 4 4 4 4	Coordination Chemistry Chemical Binding Physical Methods in Chemistry I Physical Chemistry Lab II Organic Chemistry Lab II Elective-VIII
4/Semester VII	C401 C403 C498 ****	4 4 12 4	Physical Methods in Chemistry II Chemistry of Heterocycles and Natural Products Chemistry project Elective-IX
4/Semester VIII	C402 C499 **** ****	4 12 4 4	Chemical Rate Processes Chemistry Project Elective-X Elective-XI
5/Semester IX	C598 **** ****	16 4 4	Chemistry Project Elective-XII Elective-XIII
5/Semester X	C599 ****	20 4	Chemistry Dissertation Elective-XIV

Out of 48 credits as Electives, at least 8 credits from the School of Humanities and Social Sciences and at least 16 credits from other science schools must be taken.

Course Structure for a Minor in Chemistry

1. To obtain a chemistry minor degree, a student has to accumulate 34 credits from the courses offered by SCS, including the courses in the first year.

2 The list of courses that required to be credited are:

Code	Credits	Course Name
C101	3	Chemistry-I
C141	2	Chemistry Laboratory-I
C102	3	Chemistry-II
C142	2	Chemistry Laboratory-II
C201	4	Basic Inorganic Chemistry
C203	4	Reaction Mechanism in Organic Chemistry
C206	4	Quantum Chemistry-I
C207	4	Mathematical methods for Chemists
C306	4	Physical Methods in Chemistry-I
C307	4	Thermodynamics and Electrochemistry
Total	34	

The total credit points for the above mentioned courses are 26. The rest 8 credit points are to be accumulated by crediting any other two theory courses of students' choice, provided pre-requisite criteria are duly fulfilled for the courses.

The list of pre-requisites for SCS courses are given below

Code	Course Name	Pre-requisite Course Code
C204	Reagents in Organic Synthesis	C203
C205	Main Group and Organometallic Chemistry	C201
C301	Physical Organic Chemistry	C204
C302	Molecular Spectroscopy and Group Theory	C206
C304	Coordination Chemistry	C201
C305	Chemical Binding	C206
C402	Chemical rate Process	C206
C403	Chemistry of Heterocycles and Natural Products	C204
C557	Nuclear Magnetic Resonance	C206
C561	Advanced Bio-organic Chemistry	C204
C562	Polymer Chemistry	C201, C203
C568	Advanced Fluorescence Spectroscopy	C206, C306
C570	Advanced Heterocyclic Chemistry	C204
C571	Statistical Mechanics	C307

List of Compulsory Courses

Year/Semester	Course No.	Credits	Course Name
1/Semester I	C101 C141	3 2	Chemistry I Chemistry Lab I
1/Semester II	C102 C142	3 2	Chemistry II Chemistry LabII
2/Semester III	C201 C203 C207 C245	4 4 4 4	Basic inorganic Chemistry Reaction Mechanisms in Organic Chemistry Mathematical Methods for Chemists Inorganic Chemistry Lab.
2/Semester IV	C204 C205 C206 C243 C244	4 4 4 2 2	Reagents in Organic Syntheses Main group and Organometallic Chemistry Quantum Chemistry I Physical Chemistry Lab I Biomolecular Chemistry Lab
3/Semester V	C301 C302 C307 C341 C342	4 4 4 4 4	Physical Organic Chemistry Molecular Spectroscopy and group Theory Thermodynamics and Electrochemistry Organic Chemistry Lab I Inorganic Chemistry Lab I
3/Semester VI	C304 C305 C306 C343 C344	4 4 4 4 4	Coordination Chemistry Chemical Binding Physical Methods in Chemistry I Physical Chemistry Lab II Organic Chemistry Lab II
4/Semester VII	C401 C403 C498	4 4 12	Physical Methods in Chemistry II Chemistry of Heterocycles and Natural Products Chemistry project
4/Semester VIII	C402 C499	4 12	Chemical Rate Processes Chemistry Project
5/Semester IX	C598	16	Chemistry Project
5/Semester X	C599	20	Chemistry Dissertation

List of elective Courses

Year/Semester	Course No.	Credits	Course Name
3rd or 4th year students of other streams	C351 C352 C353	4 4 4	Photochemistry Pharmaceutical Chemistry Classics in Molecules
	C551	4	Molecular Modeling
	C552	4	Solid State Chemistry
	C554	4	Crystallography
	C555	4	Principles of Drug action
	C556	4	Advanced Bio-inorganic Chemistry
	C557	4	Nuclear Magnetic Resonance
	C558	4	Advanced Functional Materials
	C559	4	Supramolecular Chemistry
	C560	4	Chemistry of Nanomaterials
	C561	4	Advanced Bio-organic Chemistry
	C562	4	Polymer Chemistry
	C563	4	Molecular Reaction Dynamics
	C564	4	Theory of Molecular Spectroscopy
	C565	4	Advanced Organic Chemistry
	C566	4	Catalysis: Reaction Mechanisms and Applications
	C567	4	Advanced Main group Chemistry
	C568	4	Advanced Fluorescence Spectroscopy
	C569	4	Biomacromolecules
	C570	4	Advanced Heterocyclic Chemistry
	C571	4	Statistical Mechanics

Compulsory Courses

L	P	T	C
2	0	1	3

C101: Chemistry I

1. **Thermodynamics and Chemical equilibrium:** Laws of thermodynamics; Thermochemistry; Joule-Thompson Effect; entropy, Helmholtz and gibbs free energies, Maxwell Relations, partial molar quantities, chemical potential, Gibbs-Duhem equation. [5]

   Equilibrium constant and its relation with free energy changes, variation of chemical equilibrium constant with temperature and pressure, vant Hoff equation, applications of Gibbs-Helmholtz equation. [5]

2. **Elementary Chemical Kinetics:** Rate laws for first, second and third order reactions, reversible, parallel and consecutive reactions, steady state approximation, enzyme kinetics (Michaelis-Menten equation). [4]

3. **Rate Theories and Dynamics:** Temperature dependence of the rates of chemical reactions, Collision theory, qualitative concepts of transition state theory, introduction to reaction dynamics. [5]

4. **Atomic and molecular Structure:** introduction to quantum mechanics: particle in a box, atomic structure: H atom, concept of atomic orbitals and wave functions, many electron atoms, Spin and pauli principle. Molecules: Bonding in homo and heteronuclear diatomic molecules. [5]

5. **Spectroscopy:** interaction of light with matter, Electronic spectroscopy, Beer- Lamberts law, Fluorescence, phosphorescence, Rotation and vibrational spectroscopy, introduction to nuclear magnetic resonance, application of spectroscopy to biomolecules. [6]

Recommended Books:

1. Physical Chemistry, I. Levine, Tata Mcgraw Hill, 5th Edn., 2007.
2. Physical Chemistry: A Molecular approach, D. a. McQuarrie and J. D. Simon, University Science Books, 1997.
3. Physical Chemistry, G. M. Barrow, Mcgraw Hill, 5th Edn., 2007
4. Chemical Kinetics, K.J. Laidler, 3rd Edn., Harper and Row, 1987.

C141: Chemistry Laboratory I

L	P	T	C
1	3	0	2

1. Determination of acid-neutralizing power of commercial antacids.
2. Estimation of phosphoric acid in cola drinks by molybdenum blue method.
3. Element detection and characterization of organic compounds.
4. Extraction of Caffeine, an alkaloid, from Tea Leaves.
5. Synthesis of aspirin.
6. Identification of unknown mixtures containing 4 radicals, by dry and wet tests.
7. photochemical reduction of ferric oxalate in cyanotype blue printing.
8. Synthesis of hexamminenickel(ii) chloride.
9. Synthesis of paracetamol.
10. Estimation of acid strength in a citrus fruit.

Recommended Books:

1. The Systematic Identification of Organic Compounds, R. L. Shriner, C. K. F. Hermann, T. C. Morrill, D. Y. Curtin and R. C. Fuson, John Wiley, 8th Edn., 2004.
2. practical Organic Chemistry, a. i. Vogel, ELBS, 2002.
3. Laboratory Manual in Organic Chemistry, R. K. Bansal, Wiley Eastern, 1980.
4. Comprehensive practical Organic Chemistry: Qualitative analysis, V. K. ahluwalia and S.Dhingra, Universities press (india) Ltd, 2000.
5. A Collection of general Chemistry Experiments, a. J. Elias, Universities press, 2007.

C102: Chemistry II

L	*P*	*T*	*C*
2	0	1	3

1. Structure of simple inorganic molecules; VSEPR theory; Coordination complexes; Brief description of VBT, CFT and MO theory; Distortion in Octahedral complexes. [6]

2. Organometallic chemistry; metal carbonyls; metal nitrosyls; 18 electron rule; Ferrocene and its basic reactions; Catalysis of organometallic complexes; Hydrogenation and other industrially important reactions. [6]

3. Chemistry of biological systems; Hemoglobin, Myoglobin and Heme containing systems. [2]

4. Structure of organic molecules (Lewis structures, acid-Base, HSaB principles, Hybridization, Resonance, Hyper- conjugation, aromaticity, Functional groups, nomenclature, isomerism). [8]

5. Conformational analysis of acyclic and cyclic systems; Molecular chirality; Cohn- ingold-prelog R-S notational system; Optical activity; Chiral induction; importance of chirality in chemical biology. [8]

Recommended Books:

1. S. H. pine, Organic Chemistry, 5th Ed. Tata Mcgraw Hill Book Co., 2007.
2. T. W. G. Solomons, C. B. Fryhle, Organic Chemistry, 8th Ed. Wiley, 2007.
3. T. W. G. Solomons, C. B. Fryhle, R. g. Johnson, Study guide and Solutions Manual to accompany: Organic Chemistry, 8th Ed. John wiley & Sons, 2005.
4. J. Karty, The Nuts and Bolts of Organic Chemistry: a Student's guide to Success, pearson, 2008.
5. R. J. Morrison and R. N. Boyd, Organic Chemistry, 6th Ed. prentice Hall, 2007.
6. J. E. Huheey, E. A. Keiter, R. L. Keiter, O. K. Medhi, Inorganic Chemistry: principles of Structure and Reactivity, 4th Ed. Pearson, 2007.
7. P. Atkins, T. Overton, J. Rourke, M. Weller, F. Armstrong, Shriver & Atkins Inorganic Chemistry, 4th Ed. Oxford, 2009.
8. B. D. Gupta, A. J. Elias, Basic Organometallic Chemistry: Concepts, Syntheses and applications, Universities press, 2010

References

1. Physical Chemistry, R. S. Berry, S. A. Rice and J. Ross, Oxford Univ. Press, 2nd Edn., 2000.
2. Physical Chemistry, R. J. Silby and R. A. Alberty, Wiley, New York, 3rd Edn., 2000.

C142: Chemistry Laboratory II

L	P	T	C
1	3	0	2

1. Determination of Critical Solution Temperature (CST) of phenol-Water system. Study the effect of added impurity (naCl) on CST.
2. Determine the solubility of oxalic acid (benzoic acid) in water at different temperatures. Calculate the heat of solubilization (.6H).
3. Determination of partition coefficient of acetic acid in water and butanol.
4. Study the kinetics of acid catalysed hydrolysis of methyl acetate in the presence of HCl and H2SO4. Determine the order with respect to [acid], and compare the strengths of the two acids.
5. Standardization of pH meter. Titration of strong acid against strong base, using the pH meter.
6. (i) Calibrate the conductometer by using standard KCl solution. (ii) Titrate a solution of a strong acid; weak acid; and a mixture of the two acids, conductometrically, against a standard alkali.
7. Verification of Debye-Huckel-Onsager equation $\Lambda = \Lambda 0 - S\sqrt{C}$ for strong univalent electrolytes.
8. Estimation of calcium in milk powder through EDTa complexometry.
9. Verification of Beer - Lamberts Law: Determination of the concentration of coloured solutions of copper sulfate and potassium dichromate.
10. Estimation of potassium ions in coconut water, by Flame photometry.
11. Estimation of cane sugar by polarimetry.

Recommended Books:

1. Experimental physical Chemistry, R. C. Das and B. Behera, Tata Mcgraw Hill, 1983.
2. practical physical Chemistry, a. Findlayand J. a. Kitchener, 8th Edn., Longmans, 1967.
3. A Collection of interesting general Chemistry Experiments, a. J. Elias, Universities press, 2007.

C201: Basic Inorganic Chemistry

L	*P*	*T*	*C*
3	0	1	4

1. **Basic Solid State Chemistry:** The ionic bond, Lattice Energy, Size effects, Covalent character in predominantly in ionic bonds, Structures of complex solids, imperfections in Crystals, Conductivity in ionic solids, Solids held together by Covalent bonding. [6]

2. **Molecular Structure and Chemical Forces:** Molecular symmetry, point groups and introduction to Character Tables; Types of Chemical forces covalent bonding, Hydrogen bonding, Effects of Chemical forces. [4]

3. **Basic Main Group Chemistry:** First and Second Row anomalies, Use of porbitals in pi bonding, Use (or not) of dorbitals by nonmetals, reactivity of dorbital participation, periodic anomalies of the nonmetals and post-transition metals, Chains catenation, Rings, Cages, Boron cage compounds. [8]

4. **Coordination Chemistry:** Structure, isomerism, stability, Reactions, Kinetics and Mechanisms: Coordination number 1 - 8, Higher coordination number, Types of isomerism, Thermodynamic stability, Chelate Effect, Substitution reactions in Square planar complexes, Thermodynamic and Kinetic stability, Kinetics of Octahedral substitution and Mechanisms of redox reactions. [7]

5. **Oxidation and Reduction:** Reduction potentials; Redox half reactions; Trends in standard potentials, Electrochemical series, the nernst equation, Redox stability in water; Representation of electrode potential data diagrammatically. Latimer- Frost Diagrams, Chemiical extraction of the elements through oxidation, reduction and electrochemical extraction. [7]

6. **Introduction to f-block Elements:** Special features of f-block elements, lanthanide contraction, coordination number, structures, and simple reactions. [3]

7. **Nuclear Chemistry:** nuclear reactions and their characteristics, radioactivity, detecting and measuring radioactivity, radioactive decay rates, nuclear stability, energy changes during nuclear reactions, nuclear fission and fusion, nuclear transmutation, biological effects of radiation; Some applications of nuclear Chemistry: Dating with radioisotopes, medical uses therapeutic and imaging procedures. [7]

Recommended Books:

1. Inorganic Chemistry- principles of Structure and Reactivity, J.E. Huheey, E. a. Keiter, R.L. Keiter and O. K. Medhi, pearson Education, 2007.
2. Concise inorganic Chemistry, J. D. Lee, 4th Edn., ELBS, 1991.
3. Advanced inorganic Chemistry, F. A. Cotton, C. A. Murillo, and M. Bochmann, Wiley interscience, 2001.
4. Inorganic Chemistry, D. F. Shriver and P. W. atkins, Oxford University, 1999.
5. Molecular Symmetry and Group Theory: A Programmed Introduction to Chemical

Applications, A. Vincent, John Wiley, 2001.

References:

1. Chemistry of the Elements, N. N. greenwood and A. Earnshaw, 2nd Edition, Elsevier, 2005.
2. Chemistry, J. McMurry, R. C. Fay, 4th Edition, pearson Education, 2005.
3. Group Theory and Chemistry, D. M. Bishop, Dover publications, new York, 1973.
4. Chemical Applications of Group Theory, F. A. Cotton, John Wiley and Sons, 2003.

C203: Reaction mechanisms in Organic Chemistry

L	*P*	*T*	*C*
3	0	1	4

1. **Structural effects on Stability and Reactivity:** Thermodynamic Stability; Chemical Kinetics; Thermodynamic Stability vs Reaction Rates; Electronic Substituent Effects on Reaction intermediates; Kinetic isotope Effects; Linear Free- Energy Relationships for Substituent Effects; Catalysis; Solvent Effects; HighlyStrained Molecules. [5]

2. **Nucleophilic Substitution Reaction:** Nucleophiles, Electrophiles and Leaving groups; Mechanisms for nucleophilic Substitution; Kinetic and Stereochemical analysis; Substituent Effects on Reactivity; Sn 2 Reaction vs Sn 1 Reaction; neighboring group participation; Sn i Reactions; preparatively Useful Sn 2 Reactions; Carbocationic Rearrangements. [9]

3. **Addition Reactions:** The Concept of cis- and trans-addition; Electrophilic addition of alkenes; Selected examples- Hydrohalogenation, Halogenations, Hydration, Epoxidation, Dihydroxylation, Sulfenylation, Halolactonization, Metal ions, Hydroboration, Cyclopropanation; Electrophilic addition of alkynes and allenes; Vocabulary of Chemoselectivity, Diastereoselectivity, Enantioselectivity, Stereospecificity, Stereoconvergence; Asymmetric Catalysis-Sharpless Oxidations of allylic alcohols and Dihydroxylation; noyori Hydrogenation. [9]

4. **Elimination Reactions:** Concepts of Elimination Reactions; Mechanism of E2, E1 and E1cb Reactions; Regioselectivity and Stereoselectivity of Elimination Reactions; the Competition between Elimination and nucleophilic Substitution Reactions-Substrate Effects, Base Effects, Stereoelectronic Effect; Heck Reaction, Carbene, nitrene. [9]

5. **Aromatic Substitution:** Aromaticity; annulenes; Electrophilic aromatic Substitution Reactions; Substituent Effects on Reactivity; nucleophilic aromatic Substitution; Ortho Metallation; Cross Coupling Reactions. [7]

Recommended Books:

1. F. A. Carey, R. J. Sundberg “Advanced Organic Chemistry part A and B: Structure and Mechanisms” 5th Edition, Springer, 2007.
2. R. Bruckner “Organic Mechanisms: Reactions, Stereochemistry and Synthesis” Springer, 2010.
3. J. Clayden, N. Greeves, S. Warren, P. Wothers “Organic Chemistry” Oxford University press, 2001.
4. M. B. Smith, J. March “March’s advanced Organic Chemistry” 6th Edition, Wiley-VCH, 2007.
5. E. V. Anslyn, D. A. Dougherty “Modern physical Organic Chemistry” California University Science Books, 2006.

L	P	T	C
3	0	1	4

C207: Mathematical Methods for Chemists

1. **Matrix Algebra:** Matrices, determinants, matrix rank, orthogonal and unitary transformations, eigenvalues and eigenvectors, diagonalization of matrices, spectral theorem, few applications. [6]

2. **Vectors and Tensors:** Introduction to vectors; vector operations; coordinate system transformation; covariant and contravariant vector components; few applications; Vector spaces, inner products, linear independence, bases Brief introduction to tensors, tensor algebra. [9]

3. **Ordinary Differential Equations:** Linear first and second order ODEs, homogeneous and inhomogeneous ODEs with constant coefficients, system of linear ODEs, power series solution of differential equations and special functions. [12]

4. **Fourier Series and Integral Transforms:** Fourier series and transform, properties and theorems, multi-dimensional FT, complex FT, discrete and digital FT, few applications. Brief introduction to Laplace transform, inverse Laplace transform convergence of Laplace integral, few applications. [9]

5. **Data and Error Analysis:** Interpolation and extrapolation, errors in physical system, random errors in measurements, uncertainties as probabilities, error propagation, normal distribution, curve fitting. [6]

Recommended Books:

1. Maths for Chemists: Graham Doggett, Martin Cockett, E Abel: RSC (Tutorial Chemistry Texts), 2012
2. Basic Mathematics for Chemists: Peter Tebbutt: Wiley-Blackwell, 1998
3. Mathematical Methods in the Physical Sciences: Mary L. Boas, Wiley,2005
4. A student’s guide to vectors and tensors, Daniel Fleisch, Cambridge Univ Press, 2008
5. Measurements and their uncertainties, Ifan G. Hughes and Thomas P. A. Hase, Oxford Univ press, 2010

References:

1. Mathematical Methods for Physicists: Arfken and Weber, Elsevier Academic Press, 2005
2. The Fourier transform and its applications, 3rd Ed, Ronald N. Bracewell, McGraw Hill Intl. editions, 2000

C245: Inorganic Chemistry Laboratory

L	P	T	C
2	6	0	4

1. Praparation of metallic nanoparticles by chemical reduction method
2. Preparation of an organic light emitting diode from a ruthenium complex $[Ru(bpy)_3](BF_4)_2$.
3. Fabrication of a battery and the chemistry involved in it.
4. Nickel dihalide phosphine complexes
5. A carbene transfer agent:Preparation of $[(C_6Me_3H_2)_2N_2(CH)_2C]AgCl$
6. Inorganic (Carbon-Free) Chelate rings: A Dithioimdodiphosphinato ligand and some of its metal complexes
7. Nano-chemistry: Preparation of manganese dioxide nanoparticles
8. Non-metal complex: Synthesis and characterization of bispyridine iodide nitrate
9. Solid phase synthesis of trans-bis glycinato copper(II).
10. Synthesis of $[Ti(urea)_6]I_3$: An air stable d^1 Complex
11. Synthesis, Electrochemistry and Luminescence of $[Ru(bpy)_3]^{2+}$
12. Synthesis and Characterization of a Macrocyclic Nickel(II) Complex
13. Synthesis and Electrochemistry of Ferrocene and its Derivitives
14. Standardisation of sodium thiosulphate solution and volumetric estimation of Cu(II) iodometrically.
15. Volumetric estimation of Zn (II), Ca(II) and Mg(II) by EDTA titration, using Eriochrome black-T indicator.
16. Gravimetric estimation of nickel(II), using dimethylglyoxime.
17. Estimation of : (a) total manganese content in manganese ore (pyrolusite); (b) total iron content in Fe_2O_3 (haematite).
18. Study of the composition of ferric-sulfosalicylic acid complex by Jobs method of continuous variation, and to determine the stability of the complex, spectrophoto- metrically.
19. Determination of the composition of a binary mixture (potassium Dichromate and potassium permanganate), spectrophotometrically.
20. To study the luminescence behaviour of quantum dots using photoluminescence Spectrophotometer.
21. Synthesis of 3,5-dimethyl pyrazole.
22. Synthesis of antipyrene from ethyl acetoacetate.
23. Synthesis of 1,3-disubstituted bulky aryl thiourea.
24. Extraction and identification of DNA from green peas and onions
25. Synthesis of Rinecke Salt, $NH_4[Cr(NCS)_4(NH_3)_2].H_2O$, and study of its UV-Visible and IR spectra.

26. TLC activity i: Selection of solvent for TLC (known compound/unknown compound). Activity ii: Separation of compounds using TLC (e.g. o- and p- nitroaniline) separation using appropriate solvent systems. Activity iii: Separation of components present in Turmeric powder extract (alcohol) or spinach extract using TLC and Column Chromatography (silica columns at microscale level can be prepared; 10 ml syringe can be used).

***Recommended Books*:**

Vogels Text Book of Qualitative Chemical analysis, G. H. Jeffery, J. Bassett, J. Mendham and R. C. Denny, 5th Edn., ELBS, 1991.

C204: Reagents in Organic Syntheses

L	P	T	C
3	0	1	4

1. **Chemistry of Carbonyl Groups:** Nucleophilic addition to Carbonyl groups; nucleophilic Substitution at Carbonyl groups and with Complete Removal of Carbonyl Oxygen; Carbanions and Enolisation; Building Organic Molecules from Carbonyl Compounds (including Well-known name Reactions); nitrogen, phosphorus and Sulfur Ylides; Micheal addition. [20]

2. **Oxidation Reactions:** Transition Metal-based Oxidation Reagents; DMSO-based Oxidation Reactions; Other Oxidation Reagents; Oxidation of Functional groups; Oxidative Cleavage of C=C bonds and glycols; Ozonolysis; Barton Reaction; Oxidations at Unfunctionalized CH Bonds. [7]

3. **Reduction Reactions:** Reduction of Carbonyl groups: Conformational Effects; Stereochemistry of Hydride Reduction Reactions-aluminum Hydride and Borohydride Reducing agents; Hydride Reductions of Functional groups; Dissolving Metal Reductions; Other Reduction Methods; Corey-Bakshi-Shibaki Reduction. [8]

4. **Retrosynthesis:** Principles and applications; Target-Oriented and Diversity-Oriented Organic Synthesis; Selected Examples. [7]

Recommended Books:

1. F. A. Carey, R. J. Sundberg “Advanced Organic Chemistry part B: Structure and Mechanisms” 5th Edition, Springer, 2007.
2. R. Bruckner “Organic Mechanisms: Reactions, Stereochemistry and Synthesis” Springer, 2010.
3. J. Clayden, N. greeves, S. Warren, P. Wothers “Organic Chemistry” Oxford University press, 2001.
4. M. B. Smith, J. March “March’s advanced Organic Chemistry” 6th Edition, Wiley-VCH, 2007.
5. E. J. Corey, X.-M. Cheng “The Logic of Chemical Synthesis” Wiley-interscience, 1995.
6. T. Hudlicky, J. W. Reed “The Way of Synthesis: Evolution of Design and Methods for natural products” Wiley-VCH, 2007.

C205: Main-Group and Organometallic Chemistry

L	P	T	C
3	0	1	4

1. Basic Characterization techniques of main-group and organometallic compounds (nMR, Mass, iR). **[5]**

2. Representative chemistry of main group elements : [14]

a. Organometallic chemistry of lithium and magnesium: synthesis, structures andreactivity

b. Chemistry of boron: Boranes, bonding in boranes, topology of boranes, synthesis and reactivity, Carboranes and metallacarboranes. new Lewis acids based on boron; polymer-supported Lewis acids.

c. Chemistry of Aluminum: Aluminum alkyls. Use of aluminum alkyls in polymerization of olefins.

d. C_{60} and carbon nanotubes: discovery, preparation and selected reactions.

e. Chemistry of Silicon: Organosilicon compounds, Silicates and aluminosilicates.

3. Unusual compounds of main group elements: [6]

a. Chemistry of multiple bonding: Multiple bonding in heavier main-group elements. Unusual compound of main group elements: Si=Si, Si≡Si, P=P double bond, Bi=Bi double bond. Synthesis, Structure and reactivity. Controversies.

b. Chemistry of low valent compounds: Synthesis, Structure and bonding models and reactivity examples of al(i), Si(ii) low valent compounds.

c. Low oxidation state main group metal hydrides: synthesis and reactivity studies.

d. Inorganic rings and polymers. Cyclo and heterocyclophosphazenes and the polymers derived from them. polysilanes. Borazine and boron nitride.

e. Chemistry of halogens and noble gases-recent trends. CFCs and ozone layer.

4. Organometallic Chemistry : [17]

a. σ - bonded ligands : Metal alkyls, aryls and hydrides. Stability, preparation and reactivity. Metal- carbonyls / Metal- phosphines / metalnitrosyls / metal iso- cyanide: structures, reactivity and bonding. Metalcarbenes, metal-carbynes, Fischer carbenes, Schrock carbenes, N-heterocyclic carbenes, olefin metathesis.

b. π- bonded ligands: Metal-olefins, metal alkynes, metal-dienes, Metal-Cp Metal- Cp* complexes. Synthesis, structure, bonding and reactivity.

c. applications of organometallics in organic synthesis: C-C bond coupling reactions (Heck, Sonogoshira, Suzuki etc). C-n bond coupling reactions. Reduction reactions using transition metal hydrides; asymmetric hydrogenation.

Recommended Books:

1. Organometallics: A Concise Introduction, C. Elschenbroich and a. Salzer, 3rd Edn. 1999.
2. Chemistry of the Elements, N. N. Greenwood and A. Earnshaw, 2nd Edn., Elsevier, 2005.

3. Modern Inorganic Chemistry, W. L. Jolly, Mcgraw Hill, New York, 2nd Edn., 1991.

4. Concepts and Models of Inorganic Chemistry, B. Douglas, D. McDaniel and J. Alexander, John Wiley, New York, 3rd Edn., 1993.

5. Organometallic Chemistry of the Transition Metals, R. H. Crabtree, Wiley, New York, 1988.

C206: Quantum Chemistry I

L	P	T	C
3	0	1	4

1. **Origin of quantum mechanics:** Historical perspective, The photoelectric effect, Wave-particle duality, electron diffraction, black body radiation, uncertainty principle. [5]

2. **Wave Functions:** Concepts of wave function, operators, eigen values and eigen functions, commutation relations, introduction to linear algebra and matrix representation of operators.[6]

3. **Basic postulates of quantum mechanics:** Time dependent Schrdinger equation, Stationary states, time independent Schrodinger equation, concept of quantization. [6]

4. **Simple exactly solvable systems:** particle in one dimensional box and extensions to two and three dimensions, One dimensional harmonic oscillator, Rigid rotor, an- gular momentum, concept of space quantization. [8]

5. **Applications to atomic systems:** Hydrogen atom, orbitals, shapes of orbitals, radial distribution function, and electron spin. [6]

6. **Many electron atoms:** Helium atom and many electron wave functions, concept of screened nuclear charge, spin orbitals, Pauli Exclusion Principle and Slater determinants to represent many-electron wave functions, introduction to variational and perturbation methods. [11]

Recommended Books:

1. Physical Chemistry : A Molecular approach, D. a. McQuarrie and J. D. Simon, Viva Books, new Delhi, 1998.

2. Introduction to Quantum Chemistry, a. K. Chandra, Tata Mcgraw Hill, 1997.

3. Molecular Quantum Mechanics, P. W. atkins and R. S. Freidman, 3rd Edn., Oxford University press, 1997.

4. Quantum Chemistry, D. A. McQuarrie and J. D. Simon, Viva Books, new Delhi, 1998.

5. Quantum Chemistry, I. N. Levine, 5th Edn., Pearson Education, 2003.

6. Elementary Quantum Chemistry, F. L. pilar, Mcgraw-Hill Book Company, new York, 1968.

C243: Physical Chemistry Laboratory I

L	*P*	*T*	*C*
2	6	0	4

1. Study of the pH dependence of uv-visible spectrum of 4-nitrophenol/methyl orange and determination of its pK by spectrophotometric method.
2. Study of the kinetics of inversion of cane sugar, catalyzed by acid, polarimetrically.
3. Study of the dimerization of benzoic acid by partition method.
4. Adsorption of acetic acid on activated charcoal, and verification of Freundlich / Langmuir adsorption isotherm.
5. Verification of Beer-Lambert's Law and determination of the dissociation constant (pKa) of methyl red, spectrophotometrically.
6. Study of the phase diagram of a two-component system (diphenylamine-benzophenone) with congruent melting point.
7. Determination of the isotherm for a three-component system (diphenylamine-acetic acid-water).
8. Determination of glass transition tempertature of hydrated calcium nitrate, conductometrically.
9. Estimation of halides in a mixture of halides by potentiometric titrations.
10. Study of the Solvent Effects on the fluorescence of fluoroscein and other fluorescent molecules.
11. Synthesis and chemiluminescence of Luminol.
12. Estimation of halides in a mixture of halides, by potentiometric titrations. 13.Study of the kinetics of the iodide - hydrogen peroxide clock reaction.
13. Study of the photochromic and kinetic behaviour of a nitrospiropyran derivative.
14. Determination of the bond lengths of diatomic and triatomic molecules, and functional group determination of small molecules, using the FT-iR spectrometer.
15. Laser : Measurement of wave length of light emitted by He-neon laser from the interference spectrum of Fresnels biprism and mirror.

Recommended Books:

1. Experimental physical Chemistry, R. C. Das and B. Behera Tata Mcgraw-Hill, 1983.
2. practical physical Chemistry, a. Findlay and J. a. Kitchener, 8th Edn., Longmans, 1967.
3. a Collection of interesting general Chemistry Experiments, a. J. Elias, Universities press, 2007.

C244: Biomolecular Chemistry Laboratory

L	*P*	*T*	*C*
2	6	0	4

1. Analysis of kidney stones by permanganometric titration.
2. Determination of strength of acid in lemon juice.
3. Kinetics of an enzyme catalysed reaction--chymotrypsin catalysed hydrolysis of an ester, p-nitrophenyl trimethylacetate.
4. Identification of sugars present in fruit juice by TLC.
5. Determination of the pKs of an amino acid (pK1 and pK2) by potentiometric titration.
6. Estimation of carbohydrates by anthrone method.
7. Determination of the free amino acid end group of some proteins, using Sangers reagent.
8. Determination of iodine number of a fat.
9. Determination of isoelectric point of glycine.
10. Separation of sugar in a solution by TLC.
11. Estimation of iodine in the iodized common salt by iodometry.
12. Estimation of ascorbic acid content in commercially available celin sample.
13. Paper and column chromatography of plant pigments : Extraction and separation of Chlorophyll a and Chlorophyll b.

Recommended Books:

1. An introduction to practical Biochemistry, D. T. plumer, Tata Mcgraw Hill, 2000.
2. A Collection of interesting general Chemistry Experiments, a. J. Elias, Universities press, 2007.
3. Experimental physical Chemistry: a Laboratory Textbook, a. M. Halpern and g. C. McBane, W. H. Freeman and Company, new York, 2006.

C301: Physical Organic Chemistry

L	P	T	C
3	0	1	4

1. **Stereoelectronic effects:** anomeric & Related Effects; acetals, Esters, amides and Related Functions; Reactions at sp3, sp2, and sp Carbons; Examples in Synthesis and Biological processes; Felkin-ahn Model, Houk Model, Cieplak Model, EFOE Model, and Cation-Complexation Model as Applied to π-Facial Selectivity; Baldwin's Rule. [10]

2. **Pericyclic Reactions:** The nature of pericyclic Reactions; The Woodward-Hoffmann Rules and Molecular Orbitals; Cycloaddition reactions; Electrocyclic Reactions; Sigmatropic Rearrangements-[1,2], [1,3], [1,5], [2,3] and [3,3]; Cheletropic Reactions; Cope Rearrangements; Claisen Rearrangements; Enantioselective pericyclic Reaction. [16]

3. **Photochemistry:** Electronic Configurations-Multiplicity, S0, S1, T1; Electronic Transitions - π toπ*, n to π*; Selection Rules and Solvent Effect on π to π*, n to π* Transitions; Photochemistry of Olefins, Dienes and Carbonyl Compounds; Chemistry of Vision. [10]

4. **Radical Reactions:** generation and Characterization of Free Radicals; nucleophilic and Electrophilic Radicals; Substitution Reaction; addition Reactions; Radical Coupling; Barton Reaction. [6]

Recommended Books:

1. F.a. Carey, R. J. Sundberg"Advanced Organic Chemistrypart B: Structureand Mechanisms" 5th Edition, Springer, 2007.
2. R. Bruckner "Organic Mechanisms: Reactions, Stereochemistry and Synthesis" Springer, 2010.
3. J. Clayden, N. Greeves, S. Warren, P. Wothers "Organic Chemistry" Oxford University press, 2001.
4. M. B. Smith, J. March "Marchs advanced Organic Chemistry" 6th Edition, Wiley-VCH, 2007.
5. E. V.anslyn, D. A. Dougherty "Modern Physical Organic Chemistry" California University Science Books, 2006.
6. I. Fleming "Molecular Orbitals and Organic Chemical Reactions" Wiley-VCH, Student Edition,2010.
7. J. M. Coxon, B. Halton "Organic photochemistry" Cambridge University press, 1974.
8. C. H. Depuy and O. L. Chapman "Molecular Reactions and photochemistry", prentice Hall of india, 1975.

C302: Molecular Spectroscopy and Group Theory

L	P	T	C
3	0	1	4

1. **Group Theory:** Symmetry Elements, Symmetry Operations, point groups, Symmetry Representations, applications of symmetry to Molecular Orbital diagrams of simple molecules (examples: H_2O, BeH_2, BF_3 ($\sigma + \pi$)). Definition of a group and basic theorems, molecular symmetry groups and classes, great orthogonality theorem, Matrix representation of groups, irreducible representations and Character Tables. Symmetry properties of wave functions, orbitals as basis sets for irreducible representations, symmetry adapted linear combinations. assignment of symmetry representations of d-orbitals for specific geometries. [12]

2. **Introduction to Spectroscopy:** interaction of light with matter, transition moments and transition probabilities, Einsteins coefficients, oscillator strength. [2]

3. **Diatomic molecules:**

   a. Electronic Spectra: Born-Oppenheimer approximation, potential energy curves of diatomic molecules, Frank-Condon principle, electronic transitions in homonuclear and heteronuclear diatomics. [4]

   b. Microwave and infrared Spectroscopy: Simple harmonic oscillator and rigid rotor model, Rotational spectra of diatomic molecules, Stark effect, vibrational spectra of diatomic molecules, anharmonic corrections, selection rules, fundamental and overtone bands, isotope effects, vibrational rotational coupling. [6]

4. **Polyatomic molecules:**

   a. Electronic Spectra: Electronic structure, electronic spectra of polyatomic molecules - linear conjugated molecules, aromatic molecules, transition metal compounds, fluorescence, phosphorescence, internal conversion and charge trans- fer. [9]

   b. Rotational, Vibrational and Electronic Spectroscopy of polyatomic Molecules : Symmetric and asymmetric top molecules, normal modes of vibration and their classification by group theory, coupling between rotational and vibrational degrees of freedom. Symmetry and normal modes of vibration. Rovibrationic spectra, Concept of anisotropic polarizability and Raman spectra. [9]

Recommended Books:

1. Chemical applications of group Theory, F. A. Cotton, John Wiley, 3rd Edn., 2003.
2. Symmetry and Spectroscopy: an introduction to Vibrational and Electronic Spectroscopy, D. C. Harris and M. D. Ber- tolucci.
3. Fundamentals of Molecular Spectroscopy, C. N. Banwell and E. M. McCash, Tata Mcgraw Hill, 1995.
4. Molecular Spectroscopy, G. M. Barrow, Mcgraw Hill, 1985.
5. Spectra of atoms and Molecules, P. F. Bernath, Oxford Univ. press, 2005.
6. Modern Spectroscopy, J. M. Hollas, John Wiley, 4th Edn., 2004.
7. Molecular Symmetry and group Theory, R. L. Carter, John Wiley and Sons, 1998.

C307: Thermodynamics and Electrochemistry

L	P	T	C
3	0	1	4

6. **Recap:** Review of thermodynamics and chemical equilibrium. Phase equilibrium: Multicomponent systems, Ideal solution, Vapor-liquid equilibrium, Raoults law, Henrys law, colligative properties. [7]

7. **Surfaces:** Thermodynamics of surfaces and interfaces, surface tension, vapour pressure; surface films on liquids, Gibbs adsorption equation; adsorption of gases on solids: Freundlich, Langmuir and BET adsorption isotherms; determination of surface areas; colloids. [7]

8. **Electrochemistry:** Arrehnius theory of electrolytic dissociation, Conductance of electrolytes in solutions, Debye-Huckel theory of electrolytes; ionic strength principle, activities of ions and activity coefficients, Debye-Huckel-Onsager theory of electrolytic conductance, ion association in electrolytic solution. [10]

   Electrochemical cells and Electromotive Force(EMF), thermodynamics of cell reactions, Applications of EMF measurements: equilibrium constant, thermodynamic parameters, potentiometric titrations; basic principles of ion-selective membrane electrodes, batteries, bioelectrochemistry. [8]

9. **Statistical Thermodynamics:** The Canonical Ensemble, Canonical Partition Function for a System of Noninteracting Particles, Canonical Partition Function of a Pure Ideal Gas, The Boltzmann Distribution Law for Noninteracting Molecules, Statistical Thermodynamics of Ideal Monoatomic and Diatomic Gases, Statistical Thermodynamics of Ideal Polyatomic Gases, Equilibrium Constants, Entropy and the Third Law of Thermodynamics. [10]

Recommended Books

1. Physical Chemistry, I. Levine, Tata McGraw Hill, 5th Edn., 2007.
2. Physical Chemistry of Surfaces, A. W. Adamson and A. P. Gast, John Wiley and Sons, Inc., 1997.
3. Modern Electrochemistry, J.OM. Bockris and A. K. N. Reddy, Springer, 2006.
4. Physical Chemistry, R. S. Berry, S. A. Rice and J. Ross, Oxford Univ. Press, 2nd Edn., 2000.
5. Physical Chemistry, P. W. Atkins and J. de Paula, W. H Freeman and Company, 9th Edn., 2010.

C341: Organic Chemistry Laboratory I

L	P	T	C
2	6	0	4

Organic Synthesis and analysis

1. Separation of organic compounds from a mixture of compounds using the techniques of solvent extraction, preparative TLC and column chromatography and identification of the individual components by spectroscopic techniques(IR, NMR, UV-ViS), preparation of dry solvents.
2. Synthesis of the following compounds using name reactions :
   a. Diels-alder reaction of anthracene and Maleic anhydride
   b. Synthesis of Cinnamic acid from Benzaldehyde (perkin reaction)
   c. Synthesis of Triphenyl Carbinol (grignard Reaction)
   d. Synthesis of 2-hydroxy-5-methyl benzophenone (Fries rearrangement)
   e. Synthesis of Benzilic acid from Benzil (Benzil- Benzilic acid rearrangement)
   f. Synthesis of p-methoxycinnamic acid (Knoevenagel reaction).
3. Synthesis of Benzanilide from benzophenone oxime (Beckman rearrangement)
4. Synthesis of 2-phenylindole from acetophenone phenylhydrazone (Fischer-indole synthesis)
5. protection and deprotection technique: Synthesis of a ketal of cyclohexanone with ethylene glycol and regeneration of the ketone from the intermediate.
6. Esterification of p-methoxycinnamic acid.
7. preparation of o-benzoylbenzoic acid from phthalic anhydride and benzene. The following activities also will be included. Use of chemical data base (from Merck or CRC Handbook); use of iSiS/Chemdraw or any other software for drawing structures and indicating mechanisms; use of models for drawing various projections.

Recommended Books:

1. Vogels Textbook of Quantitative Chemical analysis, g. H. Jeffery, J. Bassett, J. Mendham and R. C. Denny, 5th Edn., ELBS, 1991.
2. Spectrometric Identification of Organic Compounds, R. M. Silverstein, G. C. Bassler and T. C. Morrill, 6^{th} Edn., Wiley, 1998.
3. A Collection of interesting general Chemistry Experiments, anil J. Elias, Universities press, 2007.
4. Laboratory Manual of Organic Chemistry, B. B. Dey and M. V. Sitaraman, allied publishers, 1992.
5. Laboratory Manual of Organic Chemistry, R. K. Bansal, new age international publishers, 2006.

C342: Inorganic Chemistry Laboratory I

L	P	T	C
2	6	0	4

1. a) Synthesis of Mn(acac)3 and Fe(salen)Cl Complexes.

   b) Elucidation of Redox behavior of the Mn(iii) and Fe(iii).

   c) Elucidation of magnetic properties

2. preparation and characterization of (mesitylene) tricarbonyl molybdenum (0).

3. a) Synthesis and characterization of 2,6-bis(diphenylmethyl)-4-methylaniline.

   b) Synthesis and characterize compound n,n-bis(2,6-bis(diphenylmethyl) 4-methylphenyl) diazabutadiene.

4. Synthesis and characterization of the monoanionic and bidentate amidine ligand.

5. a) Synthesis of meso tetratolul porphyrin from pyrrole and p-tolualdehyde.

   b) Synthesis and characterization of zinc-porphyrin(meso-tetratolyl porphyrin) complex.

6. a) preparation of dimethyl ester of pyridine 2,6-dicarboxylic acid. b) Synthesis and Characterization of 7E n-(1-3(E- 1-(2,6-diisopropylphenylimino)ethyl)phenyl)ethylidene)2,6 diisopropyl- benzenamine

7. Separation of the chromium complexes by using ion exchange column.

8. Synthesis and study of Mni i i (Salen)Cl by Cyclic Voltammetry and Differential pulse Voltammetry (DpV), and determination of the following: the formal reduction potential (Eo!); the number of electrons transferred in the redox process (n); the diffusion coefficient (D); electrochemical reversibility; and the effects of varying concentration (C) and scan rate.

9. Synthesis and analysis of nanoparticles by using Disc Centrifuge.

10. Preparation and determination of the effective magnetic moment and number of unpaired electrons in Mn(acac)3.

11. Preparation and determination of the aquation rate of [Co(nH3)5Cl]Cl2.

12. Preparation and resolution of the optically active compound Co(en)3+.

Recommended Books:

1. Handbook of preparative inorganic Chemistry, Vol. i & ii (edited by g. Brauer), academic press, 1963.

2. Experimental Electrochemistry for Chemists, D.T. Sawyer and J. L. Roberts, Jr., John Wiley & Sons, new York, 1974.

3. Vogels Textbook of Quantitative Chemical analysis, g. H. Jeffery, J. Bessett, J. Medham and R. C. Denny, 5th Edn., ELBS, 1999.

L	P	T	C
3	0	1	4

C304: Coordination Chemistry

1. **Theories of bonding:** CFT (including Jahn-Teller). Effects of ligand field (spectrochemical series, enthalpies of hydration, spinel structures. Shortcomings of CFT. MO theory of coordination complexes. Electronic Spectra of complexes including Orgel diagrams and Tanabe Sugano diagrams. [10]

2. **Magnetism:** introduction to Magnetism. Origin of diamagnetism. paramagnetism: Van Vleck formula and its approximated forms, Curie law. Magnetic susceptibility, orbital quenching and spin-only moment. Magnetic exchange interactions in coordination compounds: ferrimagnetism and antiferromagnetism. Bulk magnetic properties and ferromagnetism. Molecule-based magnetic materials: organic magnets and single molecule magnets. [10]

3. **Mechanisms of reactions of transition metal complexes:** Substitution (Kinetic effects: labile vs inert) and electron- transfer reactions (Outer-sphere, Self- exchange; inner-sphere). [7]

4. **Bioinorganic Chemistry:** Basic principles (why specific metal ions are present in certain proteins/enzymes): Heme proteins, types, structure and function (including mechanism of function): Hemoglobin, myoglobin, Cytochrome C, Cytochrome p450, Catalases, peroxidases. non-Heme proteins: Hemeerythrin, Ribonucleotide reductase, Methanol monooxygenase (a) iron-Sulfur proteins: Ruberodoxin, Ferredoxin; (b) Dna / Rna : Ribozymes. [10]

5. **Transition metal based supramolecular structures:** Ligand design and applications.[5]

Recommended Books:

1. Advanced inorganic Chemistry, F. a. Cotton, C. a. Murillo, and M. Bochmann, Wiley interscience, 2001.
2. Inorganic Chemistry, D. F. Shriver and p. W. atkins, Oxford University press, 1999.
3. Supramolecular Chemistry: Concepts and perspectives, J. M. Lehn, VCH, 1995.
4. Principles of Bioinorganic Chemistry, S. J. Lippard and J. M. Berg, panima publications, new Delhi, 1997.
5. Bioinorganic Chemistry; inorganic Elements in the Chemistry of Life. Kaim, B. Schwederski Wiley, 1994
6. Biological inorganic Chemistry: Structure and Reactivity Harry B. gray, Edward i. Stiefel, Joan Selverstone Valentine, ivano Bertini University Science Book; 2006
7. Reaction Mechanism of inorganic and Organometallic Systems, R B Jordan, 2nd Edn., Oxford University press, 1991.

References:

1. Bioinorganic Chemistry, asim K. Das, allied Books, Kolkata, 2004.
2. Molecular Symmetry and group Theory: a programmed introduction to Chemical applications, a. Vincent, John Wiley, 2001.
3. Mechanism of inorganic Reactions, F. Basolo and R. g. pearson, 2nd Edn. Wiley, 1967
4. Inorganic Reaction Mechanisms, M L Tobe and J Burgess, 1st Edn., Wesley Longmans Ltd. 1999.
5. inorganic Chemistry- principles of Structure and Reactivity, J.E. Huheey, E. a. Keiter, R.L. Keiter and O. K. Medhi, pearson Education, 2007.

C305: Chemical Binding

L	*P*	*T*	*C*
3	0	1	4

1. **Introduction:** Review of basic principles of quantum mechanics, atomic structure, variation and perturbation methods. [3]
2. **Electronic structure of diatomic molecules:** Born-Oppenheimer approximation, H+ ion, molecular orbitals of ground state and excited states of H+ (LCAO- 22 MO), homo and heteronuclear diatomic molecules, electronic term symbols, valence bond theory of diatomic molecules, comparison of valence bond and molecular orbital theories. Term Symbols for diatomic molecules. [12]
3. **Self-consistent Field methods:** Hartree-Fock theory of atoms and molecules, post-Hartree-Fock theories, configuration interaction wave functions. [8]
4. **Electronic structure of polyatomic molecules:** SCF-MO treatment of closed shell systems and applications to molecules (H_2O, NH_3, CH_4) ; potential energy surface and equilibrium geometry, molecular vibrational frequencies. Brief introduction to density functional theory.[9]
5. Virial theorem and chemical bonding. The Hellman-Feynman theorem. [4]
6. Semi-empirical and molecular mechanics treatment of molecules, Huckel molecular orbital theory for conjugated organic molecules and its applications to ethylene, butadiene, benzene; delocalization energy and stability. [6]

Recommended Books:

1. Modern Quantum Chemistry: introduction to advanced Electronic Structure, a. Szabo and n. S. Ostlund, Dover, 1996.
2. Molecular Quantum Mechanics, p.W. atkins and R.S. Friedman, OxfordUniversity press, 3rd Edn., 1997.
3. Quantum Chemistry, i. n. Levine, 5th Edn., pearson Education, 2000.

C306: Physical Methods in Chemistry I

L	*P*	*T*	*C*
3	0	1	4

1. **General introduction to spectroscopy:** Electromagnetic radiation and its interaction with atoms and molecules. Holistic view of spectroscopy. [2]

2. **Ultraviolet Spectroscopy:** Electronic Transition; definitions of related terms and designation of UV-absorption band. Studies of conjugated and extended conjugated systems. WoodwardFieser rules. Analytical use of UV-spectroscopy. [8]

3. **Infrared and Raman Spectroscopy:** Molecular Vibrations, instrumentation of iR and Raman spectroscopic techniques. Interpretation of infrared and Raman spectra, Identification of functional groups, hydrogen bonding, Complexity of IR spectra, Utility of iR spectroscopy in structural elucidation. Raman spectroscopy in material science; SERS. [8]

4. **Fluorescence spectroscopy:** Phenomena of fluorescence. Photochemical laws, general characteristics, Quantum yield and its measurements. Radiationless transitions. Spin states and their interconversion. Kashas rule and solvent effect. Spin orbit coupling. Energy transfer processes. Donoracceptor complexes, excimers, exiplexes.

   Fluorescence quenching (static and dynamic). SternVolmer analysis, Timescale of molecular processes in solution. Steadystate and timeresolved fluorescence. Fluorescence anisotropy. Biochemical fluorophores. New fluorescence technologies: Multiphoton Excitation, Fluorescence correlation Spectroscopy, Singlemolecule detection. [12]

5. **Photoelectron spectroscopy:** Experimental methods, ionisation processesses and Koopmans theorem. photoelectron spectra and their interpretation. applications. [5]

6. **Mass Spectrometry:** Basic concepts. instrumentation, Fragmentation and rearrangements (including McLafferty rearrangement) of different classes of organic molecules. isotope effects. [5]

Recommended Books:

1. Modern Spectroscopy J. M. Hollas.Wiley, 2004.
2. Physical Methods in Chemistry, R. S. Drago, 2nd Ed., Saunders, 1992.
3. Essentials of Photochemistry, A. Gilbert and J. Baggot, Blackwell Scientific Publications, 1992.
4. Fundamentals of photochemistry, K. K. RohatgiMukherjee, Wiley Eastern Ltd., 1978.
5. Molecular Fluorescence, Bernard Valeur, WileyVCH, 2002.
6. Principles of Molecular photochemistry: an introduction, p. Walsh, n. J. Turro, V. Ramamurthy, J. C. Scaiano, University Science Books, 2008.
7. Principles of Fluorescence Spectroscopy. Joseph R. Lakowicz, 3rd Edition, Springer, 2006.
8. Interpretation of Mass Spectra, F. W. McLafferty, 1980.
9. Spectrometric Identification of Organic Compounds, R. M. Silverstein, G. C. Bassler and T. C.Morrill, John Wiley, New York, 5th Ed., 1991.

C343: Physical Chemistry Laboratory II

L	*P*	*T*	*C*
2	6	0	4

1. Synthesis and characterization of flourescein by absorption and fluorescence spectroscopy.
2. Quantum Yield Calculation for anthracene.
3. Estimation of Halides in a Mixture of Halides by potentiometric Titration.
4. Fluorescence Quenching by Ki.
5. Solvatochromic study of a Donor acceptor system.
6. Determination of viscosity - average molecular weight of polyvinyl alcohol, and the fractions of head-to-head monomer linkages in the polymer.
7. Static and Dynamic Fluoresence quenching and verification of the Stern-Volmer relationship.
8. Study of the excited state properties of 2-naphthol: (a) excited state acidity constant; (b) deprotonation and protonation rate constants in the excited state.
9. Visualization of atomic orbitals and molecular orbitals. 10. Modeling of elimination/migration reaction of isopropylazide.
11. Computation of the transition state for simple reactions.
12. Structure and vibrational frequency analysis of hydrogen bonded clusters: Water dimer and water trimer structures, naphthalwater hetero clusters.
13. Computation of potential energy profile for the isomerization of n-butane.
14. Calculation of thermodynamic parameters (ΔGo, ΔH o, ΔSo) for the equilibrium N2O4 += 2NO2 .
15. Computational studies on the ground state and excited state properties of some simple molecules.
16. Chemical Dynamics Simulations of simple reactions.

Recommended Books:

1. Experimental physical Chemistry, R. C. Das and B. Behera, Tata Mcgraw Hill, 1983.
2. A Collection of interesting general Chemistry Experiments, a. J. Elias, Universities press, 2007.
3. Experimental physical Chemistry, V. D. athawale, p. Mathur, new age international publishers, 2001.
4. Experimental physical Chemistry: a Laboratory Textbook, a. M. Halpern, prentice Hall, 2nd edition, 1997.
5. G. C. McBane, 3rd edition., W. H. Freeman and Company, new York, 2006.
6. http://cdssim.chem.ttu.edu

L	P	T	C
2	6	0	4

C344: Organic Chemistry Laboratory II

Multistep Synthesis of Organic Compounds and Characterization by Spectroscopic Techniques

1. phenylacetylene from cinnamic acid (via dibromocinnamic acid and phenylpropiolic acid).
2. Friedel Crafts Reaction and Wolff Kishner Reduction : 4-phenylbutyric acid from benzene (via -benzoylpropionic acid, and reduction of the carbonyl group employing hydrazine hydrate).
3. nitration, reduction and diazotization reaction : mhydroxyacetophenone from acetophenone (via-mnitroacetophenone and aminoacetophenone).
4. Dimedone from acetone (via mesityl oxide).
5. 3-Hydroxycoumarin from glycine (via hippuric acid).
6. Quinoline-2-carboxylic acid from aniline (via 2-methylquinoline and ω- tribromo-quinalidine).
7. 2-aminobenzothiazole from aniline (via phenyl thiouea).
8. Synthesis of a drug (Uramil) : aminobarbituric acid (Uramil) from diethylmalonate (via barbituric acid and nitro barbituric acid).
9. Beckmann Rearrangement: 6-Phenanthridone from fluorenone (via fluorenone oxime).
10. Synthesis of n,O-Heterocycle : 2,4,5-Triphenyloxazole from benzoin (via desylben- zoate).
11. 9-acridone from o-chlorobenzoic acid (via n-phenylanthranilic acid).
12. 3,4-Dihydro-4-oxo-1,2,3-benzotriazine from methyl anthranilate (via anthranilohy- drazide).
13. Synthesis of Mesoionic compound (p-chlorophenylsydnone) : p-Chlorophenylsydnone from p-chloroaniline (via n-p- chlorophenylglycine- ethyl ester, n-(p-chlorophenyl) glycine), and n-nitroso-n-(p-chlorophenyl) glycine.
14. Diastereoselective reduction of benzil.

Recommended Books:

1. intermediates for Organic Synthesis, V. K. ahluwalia, p. Bhagat, R. aggarwal, R. Chandra, i. K. international, new Delhi, 2005.

practical Heterocyclic Chemistry, a. O. Fitton and R. K. Smalley, academic press, London, 1968.

C401: Physical Methods in Chemistry II

L	P	T	C
3	0	1	4

1. **Nuclear magnetic Resonance Spectroscopy:** Basic principles, Chemical shifts, Spin-spin interactions. application of 1H and 13C NMR spectroscopy including NOE, COSY, NOESY, and other 2D techniques in the structure determination of bioorganic compounds. application in conformational analysis. Multinuclear (31p, 19F , 29Si) nMR of various inorganic and organo-metallic compounds. instrumental aspects. nMR of paramagnetic sample: Contact shifts and pseudo contact shifts, shift reagents. pulsed NMR: modern multiple-pulsed experiments including 2D NMR. [20]

2. **Electron Spin Resonance Spectroscopy (ESR):** a brief review of theory. analysis of ESR spectra of systems in liquid phase, radicals containing single set, multiple sets of protons, triplet ground states: Transition metal ions; Fe, Cu, Mo, Cr, Mn, VO2+ containing systems: g values, symmetry. The practical interpretation of ESR spectra, in solid state and solution states. Multiple electron systems; Triplet ground state, Zerofield splitting, Kramers degeneracy, Spectral line-shapes when D « hν, D ~ hν and D » hν. EPR of photoexcitedtriplet states. [7]

3. **Doubleresonance Techniques (ENDOR):** ENDOR in liquid solution, ENDOR in powders and nonoriented solids. ENDOR spectra of free-radicals coupled to multiple sets of nuclei with spin. ENDOR of paramagnetic metals and complexes. Biological Applications: Substrate free radical, Flavins and metal free flavin proteins, Photosynthesis, Heme proteins, Iron- Sulfur proteins, Spin labels. [7]

4. **Mossbauer Spectroscopy:** Basic physical concepts, spectral line shape, isomer shift, quadrupole splitting, magnetic hyperfine interaction. Interpretation of Moss- bauer parameters of 57Fe, 99Ru, 101Ru, 195Pt, 193Ir and 110Sn. Some special applications: Solid state reactions, thermal decomposition, ligand exchange, electron transfer, isomerism, surface studies and biological applications. [7]

Recommended Books:

1. nMR Spectroscopy: Basic principles, Concepts and applications in Chemistry, H. gunther, 2nd Ed., John Wiley & Sons, 1995.
2. Spectrometric Identification of Organic Compounds, R. M. Silverstein, G. C. Bassler and T. C. Morrill, John Wiley, New York, 5th Ed., 1991.
3. Basic 1 H and 13 C nMR Spectroscopy, M. Balci, Elsevier Science, 2005.
4. Electron paramagnetic Resonance: Elementary Theory and practical applications, J. a. Weil, J. R. Bolton and J. E. Wertz, Wiley interscience, new York, 1994.
5. physical Methods in Chemistry, R. S. Drago, 2nd Ed., Saunders, 1992.
6. Mossbauer Spectroscopy : an introduction for inorganic Chemists and geochemists, Mcgraw Hill, UK, 1973.
7. Mossbauer Spectroscopy, n. n. greenwood and T. C. gibb, Chapman & Hall, 1971.
8. Electron Spin Resonance : Elementary Theory and practical applications, J. E. Wertz and J. R. Bolton, Mcgraw Hill, 1984.

C403: Chemistry of Heterocycles and Natural Products

L	*P*	*T*	*C*
3	0	1	4

1. **Chemistry of Heterocycles:** introduction and application of Heterocycles; nomenclature of aromatic and non-aromatic Heterocycles; Synthesis and Reactivity of 5&6-membered aromatic Heterocycles with One or Two Hetero atoms.
   [12]
2. **Chemistry of Natural Products:** introduction and application of Carbohydrates; Steroids, Terpenoids, Fatty Lipids, prostaglandins and alkaloid; Biogenesis and Total Synthesis of Selected natural products. [20]
3. **Chemistry of Biomolecules:** Classification and Structures of Amino Acids; Pipe- tides, Proteins and Nucleic Acids; Solid phase Synthesis; nucleic acids Synthesizer.
   [10]

Recommended Books:

1. J. a. Joule, K. Mills "Heterocyclic Chemistry" 5th Edition, Blackwell, 2010.
2. T. Eicher, S. Hauptmann "The Chemistry of Heterocycles" 2nd Edition, Wiley-VCH, 2003.
3. R. J. Simmonds, "Chemistry of Biomolecules: an introduction" RSC, 1992.
4. i. L. Finar, "Organic Chemistry" Vol. ii, ELBS, 1990.
5. S. V. Bhat, B. a. nagasampagi, M. Sivakumar "Chemistry of natural products" Springer, 2005.
6. E. J. Corey, X.-M. Cheng "The Logic of Chemical Synthesis" Wiley-interscience, 1995.
7. T. Hudlicky, J. W. Reed "The Way of Synthesis: Evolution of Design and Methods for natural products" Wiley-VCH, 2007.

C402: Chemical Rate Processes

L	P	T	C
3	0	1	4

1. **Kinetic Measurements:** General features of fast reactions; study of fast reactions by flow techniques, relaxation methods (T-Jump, P-Jump, ultrasonic, pulse radiolysis, NMR); flash photolysis; salt and solvent effects on reactions in solutions. [5]
2. **Chain Reactions :** Features of chain reactions; thermal and photochemical reactions (hydrogen-bromine reaction, decomposition of aldehydes and ketones). [5]
3. **Kinetics of oscillatory reactions :** introduction to oscillatory reactions; Belousov-Zhabotinsky and Field-Koros-noyes models. [4]
4. **Rate Theory:** Concept of potential energy surfaces, transition state theory including its statistical mechanical treatment, phenomenological theories of unimolecular reactions (Lindemann, Hinshelwood), statistical mechanical theories of unimolecular reactions (RRKM). [10]
5. **Chemical Dynamics:** Collision theory and Reaction Dynamics, Reaction Cross section and rate constant, Brief idea of Molecular Beam Scattering, Dynamics in condensed phase. [10]
6. **Femtochemistry :** Concepts and perspectives; applications to studies of dynamics and control of chemical reactions. [6]

Recommended Books:

1. Physica Chemistry, i. Levine, Tata Mcgraw Hill, 5th Edn., 2007.
2. Physical Chemistry : a Molecular approach, D. a. McQuarrie and J. D. Simon, University Science Books, 1997.
3. Chemical Kinetics and Dynamics, J. i. Steinfeld, J. S. Francisco and W. L. Hase, prentice Hall, 1999.
4. Chemical Dynamics in Condensed phases: Relaxation, Transfer and Reactions in Condensed Molecular Systems, a. nitzan, Oxford Univ. press, 2006.

References:

1. Basic Chemical Kinetics, H. Eyring, S. H. Lin and S. M. Lin, John Wiley & Sons, new York, 1980.
2. The World of physical Chemistry, K. J. Laidler, Oxford University press, 1993.

Elective Courses

C351: Photochemistry

L	P	T	C
3	0	1	4

1. **Introduction:** importance of photochemistry; Electromagnetic Radiation; Colour perception and the Colour Circle; Beer- Lambert Law; Electronic Configurations: Multiplicity, S0, S1, T1 etc.; Electronic Transitions and Solvent Effects: π to π^*, n to π^* etc. Molecular Orbitals (FMO Approach). [6]

2. **Unimolecular Photophysical Processes:** Jablonski Diagram; Frank-Condon principle; Fluorescence; inter-System Crossing; phosphorescence; Delayed Fluorescence; Quantum Yield. [6]

3. **Bimolecular Photophysical Processes:** Thermodynamics and Kinetics of Excited State Bimolecular interactions; Excimer and Exciplex; photosensitization and Quenching; Heavy atom Effect; photoinduced Electron and Charge Transfer; Resonance Energy Transfer: Coulombic and Exchange mechanisms. [8]

4. **Fluorescence Spectroscopy:** Characteristics of Excitation and Emission Spectra; Basic Theories involving Various Fluorescence Spectral parameters; Fluorescence anisotropy; introduction to Fluorescence probing Techniques and applications; Fluorescent Molecular Sensors of ions and Molecules. [10]

5. **Photochemistry of Organic Compounds:** photochemistry of alkenes; pericyclic Reactions; photo-oxidation and photo-reduction; photochemistry of Carbonyl Compounds. [8]

6. **Applied Photochemistry:** Chemistry of Vision; photochemistry in nature; photochemistry in atmosphere; Supramolecular photochemistry; Solar Cell; Fuel cell. [4]

Recommended Books:

1. Fundamentals of photochemistry, K. K. Rohatgi Mukherjee, Wiley Eastern Ltd., 1978.
2. Modern Molecular photochemistry, n. J. Turro, University Science Books, 1991.
3. Molecular Fluorescence, B. Valeur, Wiley-VCH, 2002.
4. principles of Molecular photochemistry: an introduction, p. Walsh, n. J. Turro, V. Ramamurthy, J. C. Scaiano, University Science Books, 2008.
5. Organic photochemistry, J. M. Coxon and B. Halton, Cambridge University press, 1974.
6. Molecular Reactions and photochemistry, C. H. Depuy and O. L. Chapman, prentice Hall of india.
7. photochemistry and pericyclic Reactions, J. Singh and J. Singh, new age international publishers, 2003.
8. pericyclic Reactions, ian Fleming, Oxford Science publications 1998.

C352: Pharmaceutical Chemistry

L P T			C
3	0	1	4

1. **Drug discovery and development:** The why and wherefore of drugs; Stereochemistry and solubility factors; principles of drug design (molecular and biochemical); 'Lead' modification approach, SAR/QSAR; Computer-aided drug design; natural products drug discovery.[15]
2. **Basic Principles of medicinal chemistry:** Drug action at enzymes; Drug action at receptors; physico-chemical aspects of drug molecules; Selected examples of drugs and natural products. [15]
3. **Pharmacodynamics and Pharmacokinetics:** Drug distribution and survival; Concept of prodrug; pharmacokinetic models; Drug metabolism. [10]

Recommended Books:

1. Essentials of pharmaceutical Chemistry, D. Cairns, pharmaceutical press, 2nd Edition 2003.
2. Fundamentals of Medicinal Chemistry, g. Thomas, Wiley-Blackwell, 1st Edition, 2003.

C353: Classics in Molecules

L	P	T	C
3	0	1	4

1. introduction, Understanding Structural Diagrams of Organic Molecules, protein and Three-Dimensional protein Structure, nucleic acids, Synthesis, Biosynthesis. [7]
2. Urea & acetic acid, glucose, aspirin, Camphor, Terpineol, Tropinone, Haemin, Quinine, Morphine, Steroids & the pill, Strychnine, penicillin, Longifolene, prostaglandins & Leukotrienes, Vitamin B12, Erythronolide B & Erythromycin a, Monensin, Avermectin, Amphotericin B, Ginkgolide B, Cyclosporin, FK506 & Rapamycin, Calicheamicin γ1, Palytoxin, Taxol, Mevacor, Zaragozic acids & Cp Molecules, Brevetoxin B, Ecteinascidin 743, Epothilones, Resiniferatoxin, Vancomycin, Thiostrepton. [20]
3. Modern Drug Discovery and Developments, Designed Small Drug Molecules for Mental illness, Viral infections, gastrointestinal Disorders, Heart diseases and Sexual Dysfunction [12]
4. Dna Technologies, Vaccines, antibodies, Diabetes, anemia, Rheumatoid arthritis, Breast Cancer, Biologics. [7]

Recommended Books:

1. K.C. nicolaou and Tamsyn Montagnon, "Molecules that Changed the World", VCH, 2008.
2. E.J. Corey, L´aszl´o Ku¨rti and Barbara Czak´o, "Molecules and Medicine", VCH, 2008.
3. J. Block and J. M. Beale "Wilson and gisvold's Textbook of Organic Medicinal and pharmaceutical Chemistry", 11th Ed., Lippincott Williams & Wilkins, 2003.

C551: Molecular Modeling

L	P	T	C
3	0	1	4

1. **Introduction:** What is molecular modeling? Computable quantities. [1]

2. **Concept of Potential energy Surface:** Stationary points, Born-Oppenheimer approximation, geometry optimization, normal modes of vibration. [3]

3. **Molecular mechanics:** Basic principles, properties that can be calculated, Strengths and weaknesses. [3]

4. **Quantum mechanics:** Hartree-Fock-Self-Consistent-Field theory, post-Hartree- Fock (Electron correlation) methods, Density functional theory, Semi-empirical methods. [7]

5. **Chemical Dynamics:** Unimolecular and Bimolecular reactions, Reaction path and transition states, Classical trajectories, Direct dynamics, Quantum dynamics. [6]

6. **Simulations of molecular ensembles:** properties as ensemble and time averages, Molecular dynamics simulations, Monte Carlo simulations. [10]

7. **Modeling Lab:** Hands-on experience for using different simulations methods and algorithms pertaining to the course. [10]

Recommended Books:

1. C. J. Cramer, Essentials of Computational Chemistry, Wiley, 2004.
2. i. n. Levine, Quantum Chemistry, prentice-Hall of india, 2006.
3. p. W. atkins, Molecular Quantum Mechanics, Oxford, 2008.
4. M. p. allen and D. J. Tildesley, Computer Simulation of Liquids, Oxford, 1987.
5. a. R. Leach, Molecular Modelling, prentice Hall, 2001.
6. F. Jensen, introduction to Computational Chemistry, John Wiley & Sons, 2007.

C552: Solid State Chemistry

L	P	T	C
3	0	1	4

1. **Crystal Chemistry:** a brief introduction to crystallography, Lattices, unit cells, symmetry, point groups, space groups. packing: CCp, HCp, voids, radius ratio rules. Bonding in crystals: ionic, covalent, metallic, van der Waals, hydrogen bonds. Description of crystal structures: metallic & nonmetallic structures, aB, aB2, aB3 (ReO3), spinels, pyrochlores, perovskites, K2niF4 etc. paulings rules for ionic crystal structures and the concept of bond valence. Methods of crystallography: powder, single crystals, X-ray, neutron and electron diffraction. [7]

2. **Defects in solids:** Origin of defects in crystals; perfect and imperfect crystals; thermodynamics of defect formation; types of defects : point defects, line defects, plane defects;Schottky and Frenkel defects; thermodynamics of Schottky and Frenkel defect formation; crystal classifications; Madelung constant and lattice energy. [7]

3. **Electronic structure of solids:** atoms to molecules to crystals; orbitals to bonds to bands; Electronic structure of crystalline solids, elementary band theory: metals, insulators and semi-conductors., Solid

state ionics; intrinsic and extrinsic semiconductors. Transport property measurement techniques: electrical resistivity, thermopower, Hall effect Magnetism of d vs. f metal compounds. [8]

4. **Critical Phenomena:** phase transitions (Order-disorder, Martensite-austenite, Spinoidal decompositions); liquid crystals; structure-property relations (magnetic, electrical, superconductivity, optical and thermal). powder synthesis by conventional and modern chemical methods, reactivity of solids, decomposition mechanisms, powder processing (sintering and diffusion processes), tailoring of solids, special methods for single crystal growth and thin film depositions. [10]

5. **Synthesis of solids:** Chemistry behind synthesis; intercalations; synthesis/preparation of single crystals; hydrothermal methods. Framework Solids; Zeolites, aluminophosphates and related structures; Metal-organic framework compounds - their structures and properties. [6]

6. **Superconductivity:** Superconductivity : General aspects of superconductivity; effects of magnetic field; BCS Theory; oxide Superconductors. [4]

Recommended Books:

1. Solid State Chemistry and its applications, a. R. West, John Wiley, 1987.
2. Solid State Chemistry, L. Smart and E. Moore, Chapman and Hall, 1992.
3. principles of the Solid State, H. V. Keer, Wiley Eastern Ltd., 1994.
4. new directions in solid state chemistry, C.n.R. Rao and J. gopalakrishnan, Cambridge University press, 2008.
5. The Electronic Structure and Chemistry of Solids, p.a. Cox, Oxford University press, 2005.
6. ionic crystal, lattice defect and non-stoichiometry, n.n. greenwood, Chemical pub. Co., new York, 1970.
7. an introduction tocrystal chemistry, R.C. Evans, Cambridge Universitypress, 1964.

L	*P*	*T*	*C*
3	0	1	4

C554: Crystallography

1. Origin of X-rays, Filters, monochromators, sealed tube, rotating anode synchroton radiation, safety considerations. [5]
2. Crystals and their properties- Concepts of symmetry, direct and reciprocal lattice, planes, indices, unit cell, Braggs law in direct and reciprocal lattices. primitive and non-primitive lattices, point and space groups, equivalentpositions, systematic absences and space group determination, occupancy factors.[15]
3. Theory of structure factors, argand diagram and its use, Lorentz and polarization corrections, absorption corrections, absolute scale of intensities; unit cell determination, data collection parameters, data reduction, phase problem and structure solution by patterson and direct methods. [15]
4. Structure refinement techniques, presentation and interpretation of structural data, examination of CIF file and critical evaluation of a structure. Errors and pitfalls, twinning and disorder, Renninger effect, extinctions, anomalous scattering andits use. [10]

Recommended Books:

1. X-raystructuredetermination: apractical guide, g.H. Stout and L.H. Jensen, Springer, 1992.
2. Fundamentals of crystallography, C giacavazzo, Oxford University press
3. X-ray analysis and the structure of organic molecules, Jack. D. Dunitz, Wiley,1996.
4. Crystal Structure Determination, Werner Massa, Springer.
5. Structural inorganic Chemistry, a. F. Wells, Clarendon press, 1986.

L	*P*	*T*	*C*
3	0	1	4

C555: Principles of Drug Action

1. **Pharmacodynamic Phase in Drug action:** introduction to pharmacodynamics, Biochemical Basis of Drug action, Drug absorption, distribution and bioavailability, passive diffusion, active transport mechanisms, Excretion and reabsorption of drugs. [7]
2. **Pharmacokinetic Phase in Drug action:** General classification of pharmacokinetic properties, Pharmacokinetic models, intravascular administration, Extravascular administration, Estimation of pharmacokinetic parameters, The use of pharmacokinetics in drug design. [7]
3. **Novel Therapeutic agents: Synaptic Pharmacology:** Cholinergic- and adrenergic systems, CnS agents: antipsychotics, antidepressants, CVS Agents: Antihypertensives, Antineoplastic agents, Analgesic and anti-inflammatory agents, Drug toxicity. [12]
4. **Concepts in Drug metabolism:** Basic principles and factors affecting drug metabolism, Secondary pharmacological implications of metabolism, phase i metabolic reactions, phase ii metabolic reactions, Drug metabolism and drug design, prodrugs, Metabolic pathways for common drugs. [7]
5. **Stability of Drugs and medicines:** Oxidation and stability of free-radicals, prevention of oxidative deterioration, autoxidation of fats and oils, Examples of drugs susceptible to ageing and hydrolysis, Other mechanisms of degradation. [6]
6. **Drug Development:** Clinical trials (phase-i to phase-iV), Formulation development, Quality control aspects (methods of assay). [6]

Recommended Books:

1. Thomas g. (2003) Fundamentals of Medicinal Chemistry, Wiley.
2. Cairns D. (2008) Essentials of pharmaceutical Chemistry (3rd Ed.), pharmaceutical press.
3. Block J and Beale JM. (2003) Wilson and gisvold's Textbook of Organic Medicinal and pharmaceutical Chemistry (11th Ed.), Lippincott Williams &Wilkins.
4. Rang Hp, Dale MM et al. (2007) Rang & Dale's pharmacology (6th Ed.), Churchill Livingstone.
5. Hardman Jg, Limbird LE et al. (2001) goodman & gilman's The pharmacological Basis of Therapeutics, Mcgraw-Hill professional.

L	P	T	C
3	0	1	4

C556: Advanced Bio-inorganic Chemistry

1. rinciples of bioinorganic chemistry (Justification of why certain protein/enzyme contains a particular metal ion) [3]
2. **Heme Proteins:** Types, function and mechanisms , Myoglobin, Hemoglobin, Cytochrome c, Cytochrome p450, peroxidases (Horseradish peroxidase, Chloroperoxidase), Catalase, Cytochrome c Oxidase, Synthetic porphyrins of biological relevance. [5]
3. **Iron-Sulfur Proteins:** Types, function and mechanisms , Rubredoxin, Ferredoxins, aconitase [3]
4. **Non-Heme Proteins:** Types, function and mechanisms, Mononuclear Systems (Catechol-1,2-Dioxygenases, Transferrin, Ferretin, Superoxide Dismutase, isopenicillinn- Synthase) Dinuclear Systems (Hemerythrin, Ribonucleotide Reductase, Methane Monooxygenase, purple acid phosphatases) [6]
5. **Copper Proteins (Type i, ii, and iii):** Types, function and mechanisms, Blue Copper proteins; Hemocyanin, Tyrosinase, Catechol Oxidase; Superoxide Dismutase; ascorbase Oxidase, Laccase; galactose oxidase [5]
6. **Molybdenum enzymes:** Types, function and mechanisms, Oxo-Transfer Enzymes; Xanthine Oxidase; nitrogenase. [5]
7. **Manganese:** photosynthesis (photosystem i and photosystem ii); function and mechanisms.[4]
8. **Zinc enzymes:** function and mechanisms, Hydrolytic Enzymes (Carbonic anhydrase; Carboxy peptidase a; alkaline phosphatase). [5]
9. **DNa/RNa:** Types, function and mechanisms, Dna nicking enzymes; Dna polymerase; Ribozymes. [5]
10. **Environmental & medicinal aspects:** acid-rain; green-house Effect etc. Radiopharmaceuticals; photo-Dynamic Therapy; anti-Tumor Drugs (cis-platin, Carboplatins; Bleomycins); ion-pumps. [5]

Recommended Books:

1. principles of Bioinorganic Chemistry; S. J. Lippard and J. M. Berg, panima publications, new Delhi, 1997.
2. Bioinorganic Chemistry ; inorganic Elements in the Chemistry of Life; W. Kaim, B. Schwederski Wiley, 1994
3. Biological inorganic Chemistry: Structure and Reactivity; Harry B. gray, Edward i. Stiefel, Joan Selverstone Valentine, ivano Bertini, University Science Book; 2006
4. Specific Review Articles to be collected from Internet.

L	P	T	C
3	0	1	4

C557: Nuclear Magnetic Resonance

1. **Classical NMR Spectroscopy:** nuclear magnetism, Bloch equations, chemical shift, linewidth, scalar coupling [4]
2. **Theoretical description of NMR spectroscopy:** Expectation value of magnetic moment, density matrix, pulses and rotation operator, chemical shift and coupling Hamiltonians, concept of coherence, one pulse experiment. [5]
3. **Product Operator Formalism:** Operator spaces, basis operators, free precision, pulses, single and multiple quantum coherences, application of pOF to study spin echo and standard polarization transfer protocols like inEpT. [6]
4. **Practical aspects of NMR spectroscopy:** Tuning, matching, shimming, temperature calibration, spectrum referencing, sampling theorem, quadrature detection, Fourier transformation, zero filling, apodization, phasing, signal to noise ratio, spin decoupling, pulse field gradients, water suppression, one dimensional experiments. [14]
5. **Two dimensional NMR experiments:** Two dimensional spectroscopy, coherence transfer, COSY, double quantum filtered COSY, TOCSY, NOESY, HSQC, HMQC, sensitivity enhanced HSQC. [10]
6. **Higher dimensional NmR experiments:** need for higher dimensional experiments, HNCA, HN(CO)CA, introduction to the new trend of fast multidimensional experiments: GFT, spatially spatial encoding. [3]

Recommended Books:

1. protein nMR Spectroscopy, 2nd Ed, John Cavanagh, W. J. Fairbrother, a. g. palmer iii, M. Rance and n. J. Skelton, Elsevier academic press, 2007
2. Spin dynamics 2nd Ed., Malcolm H. Levitt, John Wiley and sons Ltd., 2008

C558: Advanced Functional Materials

L	P	T	C
3	0	1	4

1. **Introduction to materials in modern Technology:** Materials as an enabling element of technological progress. Functions that materials perform. The properties - structure -processing connection. [2]
2. **Semiconductor materials:** intrinsic semiconductors, Band Structure of Semi- conductors, impurity Semiconductors, ii-V and ii-Vi compounds, Hall effect, SC devices. Charge carrier dynamics in semiconductor nanomaterials. [10]
3. **Dielectric materials:** Dielectric constant and polarizibility, insulating materials, Ferroelectrics, piezoelectrics, Measurement of Dielectric properties, applications. [6]
4. **Nanosized magnetic materials:** Basic concepts of magnetism. Types of magnetic behavior, Magnetic domains, soft and hard magnets, Classification Magnetic Nanomaterials, Ferrofluids, Single-domain particles, Physical Properties of Magnetic nanostructures, nanomagnetism for Biological applications. [6]
5. **Polymer materials and nano-composites:** Classification of Polymers, Structure- Property Correlation, Molecular weights, Conduction in polymers, natural composities, incorporation of nanomaterials into polymer Media, Organic polymer nanocomposites, Metal and Ceramic composites, Clay nanocomposite Materials, polymer- Clay nanocomposites, polymer/ graphite nanocomposites, polymer Composites with Carbonnanotubes. [10]
6. **Amorphous and Porous materials:** Crystalline vs. amorphous Solids, glass Formation, Structural Models of amosphous Materials, properties of Metglasses, Evolution and Development of porous Materials, Chemistry of Microporous Materials, Mesoporous Materials, Semiconductor nanoparticles in Zeolites, polymers and Carbon Materials in Zeolites. [10]

Recommended Books:

1. Fundamental of nanotechnology, gabor L. Hornyak, John J. Moore, Harry F. Tibbals, Joydeep Dutta, CRC press, Taylor & Francis group, 2009
2. Optical Properties and Spectroscopy of Nanomaterials, Jin Zhng Zhang, World Scientific Publishing Co. Pte. Ltd, 2008.
3. Science of Engineering Materials and Carbon nanotubes, C. M. Srivastava, C. Srinivasan, new age international pub- lishers.
4. Optimization of polymer nanocomposite properties, Edited by Vikas Mittal, WiLEY-VCH Verlag gmbH & Co. Kgaa, Weinheim, 2009.
5. Chemistry of Zeolites and Related porous Materials: Synthesis and Structure RUREn XU, WEn-Qin pang, JiHOng YU, QiSHEng HUO, JiESHEng CHEn, John Wiley & Sons(asia) pte Ltd, 2007.
6. polymer nanocomposites Handbook Rakesh K. gupta Elliot Kennel Kwang-Jea Kim, CRC press, Taylor & Francis group, 2008.

C559: Supramolecular Chemistry

P		T	C
			4

1. **Introduction:** Understanding of Supramolecular Chemistry (Multidisciplinary nature, Complementarities in biology); Selectivity; Supramolecular interactions; Chelate and Macrocyclic Effects; Characterizing Supramolecular Systems; Structural, Kinetic and Thermodynamic. [6]

2. **Molecular Self-assembly:** Non-Covalent Interactions: Electrostatic, Hydrogen Bonding, $\pi - \pi$ Stacking, Dispersion and Induction Forces, Hydrophobic or Solvophobic Effects, π-Electron Donor-Acceptor Systems, Catenanes and Rotaxanes, Tran-sition Metal Directed assemblies; Molecular Macrocycles and Boxes: Locked and Unlocked Molecular Boxes, Ladders and grids, Cages; Hydrogen Bond Directed assemblies: Rosettes and Ribbons, peptide nanotubes; Self- Replicating Molecular Systems. [12]

3. **Synthesis of macrocycles:** High Dilution Technique; Coordination Template Effects; Cation Binding and De-Metallation; porphyrins; Corrins; Crown Ethers; Cryptands; Spherands; Sepulchrates; Siderophores; Calixarenes. [4]

4. **Molecular Sensors of ions and molecules:** anions, Cations and neutral Molecules Receptor Design principles: Recognition by Electrostatic and Hydrogen Bonding, Lewis acidic Hosts interactions etc.; introduction to Fluorescence probing Techniques and applications: Fluorescent Molecular Sensors of ions and Molecules, Logic gate etc.; Expanded porphyrins, amide Functionalized Metallo Compounds, Cyclophanes, Electrostatics and Hydrophobicity, Hydrogen Bond Receptors, Chiral Recognition; Hydrophobic Effect: Recognition in Water; Solvent Effect; Cyclodextrins; Calixarenes; Metallo Receptor For nucleic acid Bases; Boronic acid Receptors for Sugars. [20]

Recommended Books:

1. D. J. Cram and J. M. Cram, Container Molecules and their guest, Monographs in Supramolecular Chemistry, Ed. J. F. Stoddart, The Royal Society of Chemistry, Cambridge, 1994.
2. J. M. Lehn, Supramolecular Chemistry: Concepts and perspectives, VCH, Weinheim, 1995.
3. Comprehensive Supramolecular Chemistry, Ed. J. L. atwood, J. E. D. Davies, D. D. Macnicol, F. Vogtle, Volumes 2 and 3, Elsevier Science, Oxford, 1996.
4. Supramolecular Chemistry ofanions, Ed. a. Bianchi, K. Bowman-James, E. garcia-Espana, John Wileyand Sons, new York, 1997.
5. Supramolecular Chemistry, p. D. Beer, p. a. gale and D. K. Smith, Oxford University press, 1999.
6. apractical guide to Supramolecular Chemistry, peter J. Cragg, John Wiley & Sons Ltd, England, 2005.

C560: Chemistry of Nanomaterials

L	P	T	C
3	0	1	4

1. **Introduction:** nano and nature, Fascination and Motivation of nanoparticle Research, Bottom-up and Top-down approaches [3]
2. **Zero and One-Dimensional Nano structures:** introduction, aqueous and non- aqueous Sol-gel Chemistry, Surfactant- assisted Synthesis, Solvent-Controlled nanoparticles, assembly: introduction, Oriented attachment and Mesocrystals, Superlattices, Core-Shell nanoparticles: introduction, Types of Systems, Characterization, properties. [10]
3. **Carbon Nanomaterials:** Fullerenes and their Derivatives, Carbon nanotubes: Structure and properties, nanocrystalline Diamond [8]
4. **Self assembled Monolayers**: introduction, Monolayers on gold, growth process, phase transitions, patterning monolyers, Mixed Monolayers Structure, Electrochemistry and applications of Self-assembled Monolayers of Thiols [4]
5. **Nano and Micro-elumsion**: Surface active agents, Micellization, Mechanism of emulsion, Characterization of Microemulsion [8]
6. **Application of nanomaterials**: Solar Energy Conversion, Molecular and nano-electronics, nanocatalyis, Biological applications and other applications. [12]

Recommended Books:

1. nanoparticles: Synthesis, Stabilization, passivation, and Functionalization, Edited by R. nagarajan, T. alan Hatton, aCS SYMpOSiUM SERiES 996.
2. Metal Oxide nanoparticles in Organic Solvents, Markus niederberger and nicola pinna, Markus niederberger and nicola pinna, Springer-Verlag London Limited 2009 .
3. Fundamental of nanotechnology, gabor L. Hornyak, John J. Moore, Harry F. Tibbals, Joydeep Dutta, CRC press, Taylor & Francis group, 2009.
4. Carbon nanomaterials, advanced Materials Series, Edited by Yury gogotsi, Taylor and Francis group, LLC, 2006.
5. Carbon Nanotubes and Related Structures, Edited by Dirk M. Guldi and Nazario Mart´ın, WILEY- VCH Verlag GmbH

& Co. Kgaa, Weinheim, 2010.

6. nano: The essential, Understanding nanoscinece and nanotechnology, T. pradeep, Tata Mcgraw- Hill publishing Company Limited.
7. applied Surfactants, Thrwat F. Tadros, WiLEY-VCH Verlag gmbH & Co. Kgaa, Weinheim, 2006.

C561: Advanced Bio-organic Chemistry

L	P	T	C
3	0	1	4

1. **Enzymology:** Mechanistic studies of enzymatic reactions. Studies of enzyme kinetic for substrate/inhibitors (reversible/ irreversible) and their future aspects in drug design. The role of cofactors and hormones in enzymatic reactions. Enzymes as Catalysts in organic chemistry reaction (group Transfer Reactions, Reduction and Oxidation; Monooxygenation; Dioxygenation Substitutions, addition/Elimination; Carboxylations; Decarboxylation; isomerizations; aldol and Claisen Reactions; and Retroreactions; Formylations, Hydroxymethylations, and Methylations; Rearrangements. [12]

   Application of enzyme Kinetics: Substrate Kinetics; Kinetics of Enzyme inhibition; Substrate inhibition; nonproductive Binding; Competing Substrates; Multi- substrate Systems; allosterism and Cooperativity. [5]

2. **Biosynthesis of secondary metabolites:** polyketide Biosynthesis; Saccharide Biosynthesis; Shikimate pathway (pDF); Shikimate pathway Flavonoids ; alkaloid Biosynthesis; alkaloid Bioynthesis: Tyrosine Derivatives; Terpene Biosynthesis with example-Taxol, vancomycine, penicillin and other recent discovered natural products. Design and synthesis of modified secondary metabolites analogues. isotope labeling (radioactive/non radioactive) and their application in biosynthetic pathways. [12]

3. **Non-natural bio-active molecules:** Synthesis and importance of these amino acids (β, γ&δ), non-ribosomal peptides and nucleotides (pna, Lna, Tna & other stable analogues).[5]

4. **Introduction of vital bio-macromolecule secondary structures:** g-Quadruplex, i-motif, Rnai (mi-Rna & si-Rna) & Collagen and their application in therapeutics. [5]

Recommended Books:

1. Organic Chemistry of Enzyme-Catalyzed Reactions, Revised Edition by Richard Silverman published: FEB-2002. iSBn 10: 0-12-643731-9. aCaDEMiC pRESS
2. Structure and Mechanism in protein Science: aguide to Enzyme Catalysis and protein Folding by alan Fersht, publisher: W. H. Freeman; 1st edition (September 15, 1998)
3. Evaluation of Enzyme inhibitors in Drug Discovery: a guide for Medicinal Chemists and pharmacologists (Methods of Biochemicalanalysis); by Robert a. Copeland, publisher: Wiley-interscience; 1 edition (March 28, 2005).
4. Dewick, paul M. Medicinal natural products: a Biosynthetic approach. 2nd ed. new York, nY: John Wiley & Sons, inc., 2001. iSBn: 9780471496410 (paperback);
5. Structural Diversity of g-Quadruplex Scaffolds; Stephen neidle and Shankar Balasubramanian, CRC press Copyright Year-2006.
6. gene Silencing by Rna interference: Technology and application, by Muhammad Sohail (Editor), CRC press; 1 edition (July 26, 2004).
7. Modified Nucleosides: in Biochemistry, Biotechnology and Medicine (ed P. Herdewijn), Wiley-VCH Verlag GmbH &Co. Kgaa, Weinheim, germany.
8. natural products: The Secondary Metabolites , James R. Hanson Copyright Year:2003. iSBn: 978-1-84755-153-5

C562: Polymer Chemistry

L	P	T	C
3	0	1	4

1. Classification of polymers, Nomenclature of polymers, Synthesis of polymers using different methods, viz chain polymerization, step polymerization, ring-opening polymerization etc. polymerization techniques, viz Bulk polymerization, Solution polymerization, Suspension polymerization, Emulsion polymerization etc. [10]
2. Polymer characterization, Molecular weight-number average, weight average; significance of molecular weight; methods of characterizing molecular masses, gpC, Viscosity, Mass analysis, end-group analysis, Thermal properties - melting point, glass transition temperature (Tg), factors influencing Tg, relation between Tg and molecular weight. Crystallinity in polymers - degree of crystallinity in polymers, structural regularity and crystallinity. [15]
3. Kinetics of polymerization, free-radical, cationic and anionic polymerization and polycondensation. [5]
4. Copolymerization, free-radical and ionic copolymerization and copolycondensation [5]
5. Steriochemistry of polymerization, types of stereoisomerism in polymers, properties of stereoregular polymers, different methods for the synthesis of steroregular polymers. Less traditional approaches: aTRp, RaFT, ROMp, Surface functionalization of polymers [5]
6. Biodegradable polymers: Synthesis and challenges [3]

Recommended Books:

1. Odian, g. principles of polymerization. 4th ed. Hoboken, nJ: Wiley-interscience, 2004.
2. allcock, H. R., Lampe, F. W. in Contemporary polymer Chemistry; prentice-Hall: Engelwood Cliffs, nJ, 1990
3. Billmeyer Jr. F. W. Textbook of polymer Science Wiley - inter Science.

C563: Molecular Reaction Dynamics

L	P	T	C
3	0	1	4

1. **Introduction:** The rate constant - History and current view. What is molecular reaction dynamics? [2]
2. **Theoretical methods i:** Transition State Thoery (TST), RRKM Theory. [5]
3. Theoretical Methods ii: Rate and cross-section, Classical scattering theory, Quantum scattering theory (reactive and non- reactive), Connection to TST and RRKM. [10]
4. **Experimental methods:** newton's diagrams, Molecular Beams, State-resolved spectroscopic techniques, imaging techniques. [8]
5. **Applications:** photoselective chemistry - photodissociation and photoisomerization dynamics, Dynamics in real time (ps, fs and attosecond regimes), Molecular energy transfer, Control of chemical reactions, Condensed phase dynamics, Dynamics of gas-surface reations.

[15]

Recommended Books:

1. R. D. Levine, Molecular Reaction Dynamics Cambridge University press, nY 2005.
2. J. I. Steinfield, J. S. Fransisco and W. L. Hase, Chemical Kinetics and Dynamics, Prentice Hall Inc., NJ,1999.
3. Journal articles.

C564: Theory of Molecular Spectroscopy

L	*P*	*T*	*C*
3	0	1	4

1. Recap: introduction and review of basic quantum mechanics, molecular symmetry [3]

2. Rovibronic Hamiltonian - Coordinates and momenta: Euler angles, axis systems, rotational and vibrational angular momentum, normal and internal coordinates, the g matrix, the gF matrix. [8]

3. Rovibronic wavefunctions: Classification of rotational, vibrational, rotation- vibration, and electronic wavefunctions, Hund's cases. [6]

4. Energy levels and interaction: Rotation-vibration interactions, vibronic and rovibronic interactions, Renner-Teller and Jahn-Teller effect, Rydberg states, spin effects. [8]

5. Transition intensities and Optical selection rules. Electric - magnetic dipole electric quadrapole transitions, multiphoton processes and Raman effect. [7]

6. Advanced topics: Spectroscopy at high energies, intramolecular vibrational energy redistribution (iVR), wave-packet approach to spectroscopy. [8]

Recommended Books:

1. p. R. Bunker and p. Jensen, Molecular Symmetry and Spectroscopy, nRC Research press, Ottawa.
2. J. D. graybeal, Molecular Spectroscopy, Mcgraw-Hill.
3. p. F. Bernath, Spectra of atoms and Molecules, Oxford University press, nY, 1995.
4. E. B. Wilson, J. C. Decius and p. C. Cross, Molecular Vibrations: The Theory of infrared and Raman Vibrational Spectra,Dover, nY, 1955.

C565: Advanced Organic Chemistry

L	P	T	C
3	0	1	4

Review of Basic Bonding Concepts; Conformational analysis; Stereochemistry; Kinetics and Thermodynamics of Organic Reactions; Reaction Mechanisms and Con- formational Effects on Reactivity; Oxidation Reactions; Reductions Reactions; Enolate Chemistry; Metalation Reactions; Key Ring Forming Reactions; Olefin Synthesis; Conjugate Additions; Synthetic analysis and Design; Total Synthesis of natural products; asymmetric Synthesis; Combinatorial Chemistry.

Recommended Books:

1. E. V.anslyn, D. a. Dougherty "Modern physical Organic Chemistry" California University Science Books, 2006.
2. E. L. Eliel, S. H. Wilen "Stereochemistry of Organic Compounds" Wiley-interscience, 1994.
3. R. Bruckner "Organic Mechanisms: Reactions, Stereochemistry and Synthesis" Springer, 2010.
4. F. a. Carey, R. J. Sundberg "advanced Organic Chemistry partsa & B: Structure and Mechanisms" 5th Edition, Spring- er, 2007.
5. M. B. Smith, J. March "Marchs advanced Organic Chemistry" 6th Edition, Wiley-VCH, 2007.
6. E. J. Corey, X.-M. Cheng "The Logic of Chemical Synthesis" Wiley-interscience, 1995.
7. T. Hudlicky, J. W. Reed "The Way of Synthesis: Evolution of Design and Methods for natural products" Wiley-VCH, 2007.
8. p. Wyatt, S. Warren "Organic Synthesis: Strategy and Control" Wiley, 2007.
9. M. Christmann, S, Br¨ase Eds "asymmetric Synthesis- The Essentials" 2nd Edition, Wiley-VCH, 2008.
10. 10. K. C. nicolaou, R. Hanko, W. Hartwig Eds. "Handbook of Combinatorial Chemistry", VCH-Wiley, Weinheim 2002.

C566: Catalysis: Reaction Mechanisms and Applications

L	P	T	C
3	0	1	4

1. Introduction to catalysis: fundamental concepts. [5]
2. Survey of ligands: Characteristics of the transition-metal in the complexes; Elementary steps. [10]
3. Reaction mechanisms and applications: Carbonylation, Hydroformylation, Hydrogenation, metathesis reactions, oxidation reactions, isomerization reactions, Cross- Coupling reactions, and C-H functionalization reactions. [20]
4. Examples of synthetic and industrial applications. [5]

Recommended Books:

11. The Organometallic Chemistry of the Transition Metals. R. H. Crabtree, John Wiley & Sons, 2005.
12. industrial Catalysis. J. Hagen, Wiely-VCH, 2006.
13. Homogeneous Catalysis. p. W. n. M. van Leeuwen, Kluwer academic publishers, 2004.

14. Homogeneous Catalysis. S. Bhaduri, D. Mukesh, John Wiley & Sons, 2000.
15. Metal-Catalyzed Cross-Coupling Reactions a. de Meijere, F. Diederich (Eds.), 2004.
16. Catalysts for Fine Chemical Synthesis. S. M. Roberts, g. poignant, John Wiley & Sons, 2002.
17. Catalysis of Organic Reactions, S.R. Schmidt, CRC press, 2007

C567: Advanced Main Group Chemistry

L	*P*	*T*	*C*
3	0	1	4

1. **(a) Direct bonds between metal atoms:** Mg and Ca compounds with metal-metal bonds (b) Multiple bonded group 13, 14 and 15 elements: Synthesis, reactivity and bonding [12]
2. NHC stabilized low oxidation state main group metal complexes [4]
3. **Low oxidation state main group metal hydrides:** synthesis and reactivity [4]
4. **NHCs analogues with low valent group 13 and 14 elements:** Synthesis, structure and reactivity studies; (a) Boron(i), aluminum(i), gallium(i), indium(i) and Thallium(i) heterocycles (b) Silicon(ii), germanium(ii), Tin(ii), and Lead(ii) hetero cylces [8]
5. Role of main group compounds in catalysis, organic synthesis and medicinal chemistry [8]
6. **inorganic New materials:** nanomaterials, polymers and chemical sensors [6]

Recommended Books:

1. inorganic Chemistry-principles of Structure and Reactivity. 4th Edn. Huheey J. E.; Keiter, E. a.; and Keiter, R. L. Harper-Collins, nY, 1993
2. Concepts and Models of inorganic Chemsitry. 3rd Edn. Douglas, B.; McDaniel, D.; and alexander, J. John Wiley, new York. 1993
3. Chemistry of the Elements. 2nd Edn. greenwood, n. n.; and Earnshaw, a. pergamon, Oxford, 1989
4. Organometallics: a Concise introduction, C. Elschenbroich and a. Salzer, 3rd Edn. 1999
5. Inorganic and Organometallic polymers. Chandrasekhar, V. Springer-Verlag, Heidelberg, 2005

C568: Advanced Fluorescence Spectroscopy

L	*P*	*T*	*C*
3	0	1	4

1. **Phenomena of Fluorescence and instrumentaion for Fluorescence Spectroscopy:** introduction. Jablonski Diagram, Characteristics of Fluorescence Emission, Fluorescence Lifetimes and Quantum Yields. Spectrofluorometers, Light Sources, Monochromators, Optical Filters, photomultiplier Tubes, polarizers. [5]
2. **Fluorophores:** intrinsic or natural Fluorophores; Fluorescence Enzyme Cofactors, Extrinsic Fluorophores; protein- Labeling Reagents, Membrane probes, Red and near-infrared (niR) Dyes, Dna probes, Chemical Sensing probes, Viscosity probes, green

Fluorescent proteins, Long-Lifetime probes. Quantum Dots. [4]

3. **Life-Time measurements:** Time-Domain and Frequency- Domain Measurements. Time-Correlated Single-photon Counting; principle and instrumentation, alternative Methods for Time-Resolved Measurements; Streak Cameras, Upconversion Methods. Data analysis. [6]

4. **Some important Photo-processes:** Dynamics of Solvent and Spectral Relaxation: Measurement of Time-Resolved Emission Spectra (TRES), Theory for Time-Dependent Solvent Relaxation, Fluorescence Quenching: Theory, Fractional Accessibility to Quenchers, Applications of Quenching to Proteins; Fluorescence Anisotropy: Origin of the Definitions of polarization and anisotropy, Measurement of Fluorescence anisotropies, Causes of Depolarization, Biochemical applications. Energy Transfer: Theory of Energy Transfer for a Donoracceptor pair, Distance Measurements Using Resonance Energy Transfer (RET), Biochemical applications of RET. [12]

5. **Multiphoton excitation:** introduction to Multiphoton Excitation, Two-photon absorption Spectra, Cross Section for Multi-photon absorption. [3]

6. **Single-molecule Detection (SmD):** Delectability of Single Molecules, instrumentation for SMD, Single-Molecule photophysics, Biochemical applications of SMD. [3]

7. **Fluorescence Correlation Spectroscopy(FCS):** principles of Fluorescence Correlation Spectroscopy, Theory of FCS, Examples of FCS Experiments. [3]

8. **Fluorescence-Lifetime imaging microscopy(FLim):** Early Methods for Fluorescence-Lifetime imaging, Laser Scanning TCSpC FLiM, Lifetime imaging of Cellular Biomolecules. [3]

9. **Radiative Decay engineering:** introduction to Radiative Decay Engineering, Review of Metal Effects on Fluorescence, Surface Plasmon-Coupled Emission(SPCE), Applications of Metal-Enhanced fluorescence, Application of SPCE. [3]

Recommended Books:

1. principles of Fluorescence Spectroscopy, Joseph R. Lakowicz, 3rd Edition, Springer, 2006
2. advanced Time-correlated Single photon Counting Techniques, W. Becker, Springer, 2005
3. Molecular Fluorescence principles and applications, B. Valeur, WiLEY-VCH, 2002
4. Single-Molecule Detection in Solution. Methods and applications, C. Zander, R. a. Keller, and J. Enderlein, WiLEY- VCH, 2001

C569: Biomacromolecules

L	*P*	*T*	*C*
3	0	1	4

1. Buffers (their use in study of biomolecules), pH, pKa of amino acids, D and L amino acid nomenclature [1]

2. Biophysical techniques to purify and study proteins: Dialysis, salting out and precipitation by organic solvents, ion exchange, gel filtration, reversed phase, affinity chromatography, ultracentrifugation, gel electrophoresis [3]

3. **Proteins:** protein sequencing by chemical and mass & nMR spectroscopic methods, Use of spectroscopic tools in studying biomolecules. primary (single letter amino acid codes), Ramachandran plot, secondary structures like helices, parallel and antiparallel -sheets, circular dichroism of secondary structures, tertiary (motifs and domains: some important motifs like Rossman fold, helix turn helix, 4 helix bundles, beta barrel), quaternary structure (Hemoglobin and Myoglobin) and Enzymes [21]

4. **Nucleic acids:** a, B and Z-Dna structures, Method of replication, sequencing of nucleic acids (Chemical, dideoxy and fluorescence), Transcription, Translation, genetic code, genomes, Genes, over expression of recombinant proteins, mutagenesis (random and site directed). polymerase chain reaction (pCR) [9]

5. Carbohydrates and glycoproteins, proteoglycans, Membranes and lipids, bacteial cell wall synthesis and mechanism of some important antibiotics like penicllin, antibiotic resistance [4]

6. **Metabolism:** photosynthesis, Calvins cycle, glycolysis, Krebs cycle, electron transport, cofactors. [4]

Recommended Books:

1. Voet, D, Voet, Jg, pratt, CW Fundamentals of biochemistry: life at the molecular level, 2nd Edition, 2006
2. Berg J.M, Tymoczko J.L. and Stryer L. Biochemistry, 6th Edition,2007
3. Creighton, TE, proteins: structure and molecular properties, 2nd edition, 1993
4. Lewin B. genes iX, 2008
5. Branden C and Tooze J., introduction to protein structure, 2nd Edition, 1999.
6. Fersht a., Structure and mechanism in protein science: a guide to enzyme catalysis and protein folding, 1999

C570: Advanced Heterocyclic Chemistry

L	*P*	*T*	*C*
3	0	1	4

1. **Introduction:** Heterocyclic Chemistry introduction to heterocycles: nomenclature, spectral characteristics, reactivity and aromaticity. [2]
2. Synthesis and reactivity of three and four membered heterocycles e.g., aziridine, azirine, azetidine, oxiranes, thiarines, oxetenes and thietanes. [4]
3. Synthesis and reactivity of five membered rings with two heteroatoms: pyrazole, imidazole, oxazole, thiazole, isothiazole and benzofused analogs; Benzofused five membered heterocycles with one heteroatom, e.g., indole, benzofuran, benzothiophene. [8]

4. Synthesis and reactivity of benzofused six membered rings with one, two and three heteroatoms: benzopyrans, quinolines, isoquinoline, quinoxazaline, acridine, phenoxazine, phenothiazine, benzotriazine, pteridines. [8]

5. Synthesis and reactivity of seven and large membered heterocycles: azepines, oxepines, thiepines; spiro heterocycles; bicyclic compounds containing one or more heteroatoms[4]

6. Recent methods of C-H functionalization/activations of heterocyclic derivatives. [16]

Recommended Books:

1. Carey, F.a. & Sundberg, R. J. advanced Organic Chemistry, parts a & B, plenum: U.S. 2004
2. Thomas. L. gilchrist, Heterocyclic chemistry, (3rd Edition) 1997
3. Joules, J. a; Mills, K.; Smith, g. F. Heterocyclic Chemistry, 3rd Ed.
4. advances in Heterocyclic Chemistry, Book series Elsevier Edited by alan Katritzky
5. Branden C and Tooze J., introduction to protein structure, 2nd Edition, 1999.
6. Journal articles

C571: Statistical Mechanics

L	*P*	*T*	*C*
3	0	1	4

1. Basic assumptions, concept of microscopic and macroscopic states, ensembles and averages. Calculation of distribution functions in canonical ensemble and the canonical partition function. Relations between the canonical partition function and thermodynamic functions. Calculations in other ensembles like micronanonical and grand canonical ensembles. [4]

2. Calculations of partition functions and thermodynamic properties for ideal systems of monatomic and diatomic molecules.
3. Calculations of fluctuations and equivalence of ensembles. [7]

4. Calculation of heat capacity of solids, Einstein and Debye theories, study of chemical equilibrium in terms of partition functions. [4]

5. **Quantum Statistics:** Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac statistics. Systems of Fermions and Bosons in weak and strong degenerate limits. [7]

6. **Classical Statistical mechanics:** partition functions as integrals over phase space coordinates, Systems of interacting particles, imperfect gases, concept of radial distribution functions of liquids and applications to ionic solutions using Debye-Huckel theory. [6]

7. **Non-equilibrium Statistical mechanics:** Onsager regression hypothesis and fluctuation-dissipation theorem, calculations of transport coefficients like diffusion, conductivity.[6]

Recommended Books:

1. Physical Chemistry: A Molecular Approach, D. A. McQuarrie and J. D. Simon, Viva Books, New Delhi, 1998.
2. Statistical Mechanics, D. A. McQuarrie, University Science Books, 2nd Edn., 2000.
3. Introduction to Modern Statistical Mechanics, D. Chandler, Oxford Univ. press, 1987.
4. Statistical Thermodynamics of non-Equilibrium processes, J. Kaizer, Springer, 1st Edn., 1987.
5. Statistical Physics II: non-Equilibrium Statistical Mechanics, R. Kubo, M. Toda and N. Hashitsume, Springer, 2003.

SCHOOL OF HUMANITIES

DETAILED COURSE STRUCTURE

FOR

INTEGRATED M.Sc. COURSE

Revised Jan 2017

National Institute of Science Education and Research (HBNI)

Humanities courses for integrated M.Sc.

Year/Semester	Course no.	Credits	Course Name
CORE COURSES			
1/Semester I	H109	2	Technical Communication I
1/Semester I	H133	2	Introduction to Sociology
1/Semester II	H110	2	Technical Communication
1/Semester II	H101	2	Introduction to Economics
ELECTIVE COURSES			
2/Semester III	H225	2	Introduction to Psychology
	H201	2	Environmental Economics and Environmental Impact Assessment
	H239	2	Introduction to Innovation System
	H238	2	Life and Community in Urban World.
2/Semester IV	H227	2	Organizational Behaviour
	H235	2	Sociology of Science and Technology
	H236	2	Perspectives on Indian Society
	H237	2	Science Communication and Citizen

SEM- I	**H 109**	+	**H 133**
SEM – II	**H 110**	+	**H 101**
SEM – III			**2 Electives**
SEM-I V			**2 Electives**

Economics

H101:Course title: Introduction to Economics

Instructor/Proposed by: Dr Amarendra Das
Prerequisite: None

Course Content:

1. Role of Government in Organised Society [1 class]
2. Expenditure Obligation of Union, State and Local Government [2 classes]
3. Sources of Revenue for Union, State and Local Governments [4 Classes]
4. Concepts of Budget, and Different deficits [1 class]
5. Channels of Resource Transfer from Union to State Governments [2, classes]
6. Balance of Payment [3 classes]
7. Laws of Demand and Supply [3 classes]
8. Equilibrium Price Determination [1 class]
9. Exchange rate Determination [2 classes]
10. Consumer's Equilibrium [2 classes]
11. Producer's Equilibrium [2 classes]
12. Current Economic events [3 classes]

References:

E.Case and R.C.Fair (2006) Principles of Economics, Prentice Hall, USA,

Samuelson, Paul and William D. Nordhaus (1948) Economics, 19th Edition, Mc Graw Hill

Government of India (2017) Union Budget 2017-18

Government of India (2017) Economic Survey-2016-17

H201: Environmental Economics and Environmental Impact Assessment
Instructor/Proposed by: Dr Amarendra Das
Prerequisite: None

Course Content:

12. Definition of Environmental Economics, Ecological Economics and Natural Resource Economics [1 class]
13. Key environmental problems faced by humanity [2 classes]
14. Limits to Growth [2 classes]
15. Sustainable Development: Strong and weak sustainability [2 classes]
16. Indicators of sustainability [1 class]
17. Market Failure: Causes and Remedies [3 classes]
18. Perspective on Environmental Policy/Regulation [2 classes]
19. Informal Regulation [1 class]
20. Population, Poverty and Economic Growth [1 class]
21. Climate Change, Causes and Consequences [2 classes]
22. Principles of using Renewable resources [2 classes]
23. Principles of using Non-renewable resources [2 classes]
24. Environmental Kuznets Curve [2 classes]
25. Mainstreaming of Environment [2 classes}
26. Environmental Impact Assessment [2 classes}
27. Environmental Regulations in India [1 class]
28. Green Accounting, Concepts, Integrated Economic and Environmental
29. Accounting [2 classes]

References:

Report of the World Commission on Environment and Development: Our Common Future

Baumol, W.J. & Oates, W.E. (1975), "The Theory of Environmental Policy: Externalities, Public Outlays and the Quality of Life", Prentice Hall Inc.

Bromley, Daniel W. (1995), "The Handbook of Environmental Economics", Blackwell Publications Ltd.

Pearce, D.W. (1976), "Environmental Economics", Orient Longman Ltd.

World Bank, (1992). "World Development Report, 1992: Development and the Environment", Oxford University Press

Bhatacharya R N (2002) Environemntal Ecconomics: An Indian Perspective, Oxford University Press, New Delhi

English

H109: Technical Communication I

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **Ideations of Science** (4 classes)
   Categorization and social perspective.

2. **Inscription and the material arts** (4 classes)
   Scientific representation and the figural social.

3. **Mechanics of Writing** (6 classes)
   Structure and compositional logic

4. **The Rhetorical Process** (6 classes)
   Building the argument

5. **Cultural Context and the Sciences** (4 classes)
   Literature and the aesthetic of science.

References

Barrass, Robert (2002). *Scientists Must Write: A Guide to Better Writing for Scientists, Engineers and Students*. London: Routledge.

Booth, Vernon (1993). *Communicating in Science: Writing a Scientific Paper and Speaking at Scientific Meetings*. Cambridge: Cambridge UP.

Cottrell, Stella (2011). *Critical Thinking Skills: Developing Effective Analysis and Argument*. London: Palgrave Macmillan.

Lynn, Steven (2010). *Rhetoric and Composition: An Introduction*. Cambridge: Cambridge UP.

Ranciere, Jacques (1991). *The Ignorant Schoolmaster*.Redwood:Stanford UP.

Ehrlich, Eugene (2011). *Schaum's Outline of English Grammar*, Third Edition. NY: Schaum's.

H110: Technical Communication II

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **The logic of Critique** (4 classes)
   Notions of evidence, proof and fact.

2. **Humanities and empiricism** (4 classes)
   Empirical fallacy and social intervention.

3. **Mechanics of Writing II** (6 classes)
   The forms of knowledge production. Understanding readership.

4. **The Rhetorical Process II** (6 classes)
   Staging the argument. Perspective and Institutional / Disciplinary norms.

5. **Narrativizing the Sciences** (4 classes)
   Scientific correspondence and reflections. Popular science and Science fiction.

References

Baudrillard, Jean (2012). *The Ecstasy of Communication*. Cambridge: MIT Press.

Fogelin, Robert (2014). *Cengage Advantage Books: Understanding Arguments*. London: Wadsworth.

Heidegger, Martin (2008). *"The question concerning technology," Basic Writings.* New York: Harper Collins.

Poovey, Mary (1998). *A History of the Modern Fact*. Chicago: University of Chicago press.

Strunk Jr, William (1767). *The Elements of Style: TheOriginal Edition* (2014). London: Dover.

Psychology

H 225: Introduction to Psychology
Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1.	Introduction: perspectives, methods, issues.	(3 classes)
2.	Perceptual Process.	(4 classes)
3.	Learning Process	(3 classes)
4.	Memory	(2 classes)
5.	Intelligence	(2 classes)
6.	Emotion	(2 classes)
7.	Personality	(4 classes)
8.	Motivation	(4 classes)
9.	Attitude	(3 classes)

References:

Morgan, C.T., King, R.A., Weisz, J.R., Scopler, J. **Introduction to Psychology** (7th ed). Tata McGraw-Hill.

Baron, R.A. **Psychology** (5th ed) PHI New Delhi

Feldman, R.S. **Introduction to Psychology** (6th ed) Tata McGraw-Hill.

H 226: Applied Behavioural Science
Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1.	Introduction: Personality	(1 class)
2.	Interpersonal Relationship and Personal Effectiveness	(5 classes)
3.	Social Perception: errors, biases, impression management	(3 classes)
4.	Emotional Intelligence: managing emotions.	(3 classes)
5.	Group and Team Dynamics.	(5 classes)
6.	Effective Communication.	(4 classes)
7.	Values and Value System	(3 lectures)
8.	Stress: coping and managing stress	(4 classes)

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Handouts will be given as and when required.

H 227: Organizational Behaviour

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. **Introduction to Organizational Behaviour** (2 classes)
   Nature of Organizations, what is OB, contributing disciplines, Functions, role and skills of a manager, environmental challenges.
2. **Individual Decision-making process** (3classes)
   Rational decision-making, creativity, bounded rationality, errors and biases, constraints, ethics in decision-making.
3. **Work attitudes** (2 classes)
   Job satisfaction, job involvement, organizational commitment, cognitive dissonance theory.
4. **Motivation** (3 classes)
   Hierarchy of needs theory, two factor theory, ERG theory, equity theory, goal setting and expectancy theory, MBO in practice, other applications.
5. **Power and Politics** (3 classes)
   Bases of power, the general dependency postulate.
6. **Leadership** (3 classes)
   Behavioural theories, contingency theories, contemporary theories, issues in leadership studies.
7. **Groups and team dynamics** (3 classes)
   Stages of group development, group structure, group decision-making, Types of teams, creating effective teams.
8. **Conflict and conflict resolution** (2 classes)
   Functional and dysfunctional conflict, the conflict process, negotiation.
9. **Organizational Structure** (2 classes)
   Elements of organizational structure, common organizational designs, why do structures differ?
10. **Organizational Culture** (2 classes)
    Functions of culture, creating and sustaining culture.
11. **Organizational Change** (3 classes)
    Forces for change, resistance to change, approaches to managing planned change.

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Organizational Behaviour by Steven Mcshane and Mary Von Gilnow, Tata McGraw - Hill

Sociology

H 237: Science Communication & the Citizenship

Instructor/Proposed by: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course content:

1. Introduction, citizenship and Science (4 classes)
2. Science in public, the public understanding of science (4 classes)
3. Public engagement with science (5 classes)
4. Science, communication, ethical codes & scientific norms (4 classes)
5. Patents and dissemination of scientific knowledge (4 classes)
6. Science communication in age of innovation (4 classes)

References

Jane Gregory, J., and Miller, S. *Science in Public: Communication, Culture and Credibility*, New York: Plenum, 2000.

Collins, H., and Trevor Pinch, T. *The Golem: What Everyone should Know about Science*, Cambridge: Cambridge University Press, 1993.

Leach, M., Scoones, I., and Wynne, B. *Science and Citizens: Globalization and the Challenge of Engagement*, London: Zed, 2005.

Irwin, A. *Citizen Science*, London: Routledge, 1995.

Nowotny, H., Scott, P. and Gibbsons, M. *Rethinking Science: Knowledge and the Public in an Age of Uncertainty*, Cambridge: Polity, 2001.

H 238: Life &Community in Urban world

Proposed by: Debashis Pattanaik

Prerequisite: None

Course content:

1. Introduction, urban space and urban thought, urbanization (4 classes)
2. Emergence and evolution of cities (4 classes)
3. Urban life, urban communities (online and offline) (4 classes)
4. The city in context, migration, sorting and niches (4 classes)
5. Markets and networks (5 classes)
6. Urban ecology, suburbia, urban design, policy and planning (4 classes)

References

B. Wellman, *Networks in the Global Village*, Westview Press, Boulder, CO: 1999.

C.S. Fischer, and R.K. Merton, *The Urban Experience,* Houghton Mifflin Harcourt P, Boston: 1984.

E. Ben-Joseph and T. Szold (eds.), *Regulating Place: Standards and the Shaping of Urban America,* Routledge: New York: 2005.

J. Logan and H. Molotch. *Urban Fortunes: Toward a Political Economy of Place,* University of California Press, California: 2007.

R.W. Park, E.W. Burgess and M. Janowitz (eds.), *The City*, University of Chicago Press, Chicago: 1984.

S. Sassen, *Cities in a World Economy*, Pine Forge Press, California: 2011.

S. Zukin, *The Culture of Cities*, Blackwell, New York: 1995.

W.G. Flanagan, *Urban Sociology: Images and Structure,* Rawat Publications, New Delhi: 2011.

H239: Introduction to Innovation System

By: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course Content:

1.	Nature of innovation	(4 classes)
2.	The innovative firm	(2 classes)
3.	Innovation processes	(4 classes)
4.	Regional innovation system	(3 classes)
5.	Innovation and IPR	(4 classes)
6.	Education, universities and national innovation system	(2 classes)
7.	Multinational enterprises and innovation processes	(2 classes)
8.	Science and innovation policy	(4 classes)

References

B. Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* Pinter, London: 1992.

C. Christensen, *The Innovators Dilemma,* Harvard University Press, Boston: 1997.

E. Dundon, *The Seeds of Innovation: Cultivating the Synergy that Fosters New Ideas,* Amacom Books, New York: 2002.

H. Braczyk, et.al, *Regional Innovation Systems*, UCL Press, London: 1998.

K. Pavitt, *Technology Management and Systems of Innovation,* Cheltenham: 1999.

M. Gibbons et.al, *The New Production of Knowledge – the Dynamics of Science and Research in Contemporary Societies,* Sage, London: 1994.

P. Drucker, *Innovation and Entrepreneurship,* Harper Collins Publishers, New York: 1993.

R. Katz, *The Human Side of Managing Technological Innovation*, Oxford University Press, New York: 2004.

S. Borras, *The Innovation Policy of the EU,* Edward Elgar, Cheltenham: 2003.

H 133: Introduction to Sociology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Origin and Growth of Sociology (2 Lectures)
   Origin and development of sociology as a separate discipline,
   Nature and Scope of Sociology,
   Sociology as a Scientific Discipline.

2. Sociological Perspectives (2 Lectures)
   Conflict, Functionalism and Interactionsim

3. Basic Sociological Concepts (6 Lectures)

Society, Community, Association, Institution, Status and Role, Types of Society: From early hunting gathering to industrial development and globalization, Culture: Components of culture; Norms, values, folkways, mores, Cultural unity and diversity.

Socialization: Agents of Socialization, Early development of infant, stages of socialization

4. Social Groups (4 Lectures)

Meaning of Social Groups and Types: Primary Group, Secondary Group, In-Groups, Out- Group, Quasi- Group, Reference Group

5. Structure and Stratification (4 Lectures)

Structure, System and Function, caste and class and Racial and Ethnic group inequalities Social Stratification: Meaning and Types, Functionalist and Conflict Perspectives of Stratification, Social mobility: Meaning, horizontal and vertical mobility

6. Social Institutions (4 Lectures)

Family, marriage and kinship, religion, economy, polity and education. Functionalist and Conflict Perspectives of institutions.

7. Social processes and Change (4 Lectures)

Social Processes: Co-operation, accommodation, integration, competition and conflict;

Social Change: Meaning and Definition, Factors of change.

8. Social Problems and Social Control (2 Lectures)

Social Problems and Social disorganization

Social control : Meaning and Types

References

Harlambous, M. (1980) Sociology, Oxford University Press, New Delhi.

Inkeles, A. (1982). What is Sociology, Eastern Economic Edition, New Delhi

Johnson, H.M. (1991). Sociology – A Systematic Introduction, Allied Publishers, New Delhi

Bottomore, T.B. (2000). Sociology: A Guide to Problems and Literature, S Chand Publisher, Dehradun

Gisbert, P. (2004, 3rd edition). Fundamentals of Sociology, Orient Longman

Rao, C.N.(2001) Sociology, Rawat Publication, Jaipur

Giddens, A. (2001). Sociology, Polity Press, UK.

H 235: Sociology of Science and Technology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Social significance of science and technology (4 Lectures)
   a. Contextual nature of science
   b. Scientist as Indexical and Analogical reasoner
2. Robert Merton's approach to science (3 Lectures)
   a. Ethos of science;
   b. Thomas Theorem and Matthew Effect
3. Perspectives on scientific knowledge (8 Lectures)
   a. Karl Marx, Emile Durkheim, Karl Manheim's sociology of knowledge,
   b. Thomas Kuhn's structures of scientific revolutions
   c. Karl Popper's theory of falsification
4. Recent trends in Sociology of Science (8 Lectures)
   a. Science and technology in developing and developed countries,
   b. Indian context,
   c. Information Technology and globalization,
   d. Manuel Castell's network society, internet and social inequality
5. Case Study Discussions (4 Lectures)

References

"The Historian and the History of Science" – Harry Elmer Barnes, *The Scientific Monthly*, Vol 11, No. 2(August 1920!!!), pp. 112-126.

"What is the History of Science?"- *History Today*, pp. 32-53. April 1985. (This article is an interview of six scientists/practitioners of science)

The Structure of Scientific Revolutions, Thomas Kuhn, Chicago: Chicago University Press, 1970. (First Edition 1962). Preface, Chapter, 12,3.

The Sociology of Science – Robert Merton, Chapters, 13,14,20, 21.

"The Scientist as a Practical Reasoner: Introduction to a Constructivist and Contextual Theory of knowledge"-. K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981.

(Chapter I) **A must read, highly recommended.**

"The Scientist as an Indexical Reasoner: The Contextuality and the Opportunism of Research" – K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981. (Chapter II) **A must read, highly recommended.**

"Is Science Losing its Objectivity?" – John Ziman, Nature, Vol.382, pp. 751-756, 1996

Kuhn, Thomas, "Structure of Scientific Revolutions", Chicago University Press. 1996

Merton, Robert K., Social Theory and Social Structure, Amerind. 1981

H 236: Perspectives on Indian Society

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content:

1. Indian Social Structure (2 Lectures)
    - a- Traditional Social Organizations
    - b- Culture and Tradition
2. Caste System and Class Structure (7 Lectures)
    - a- Cultural and Structural Views about Caste System
    - b- Inequality, Differentiation and Hierarchy
    - c- Dominant Caste, Sanskritization
    - d- Change and Persistence of Caste system in Modern India
    - e- Caste in Indian Politics
    - f- Backward Caste Movements
    - g- Social Backwardness and Social Justice
3. Class Structure (3 Lectures)
    - a- Class Structure in India
    - b- Agrarian and Industrial Class Structure
    - c- Emergence of Middle Class and Elites

4. Social Institutions: Marriage, Kinship and Family (2 Lectures)

5. Rural and Urban Social Structure: Poverty, Unemployment, etc. (2 Lectures)

6. Changing faces of Rural society/economy/market, Green revolution (2 Lectures)

6. Political processes: Political system and Governance (2 Lectures)

7. Education (2 Lectures)

8. Religion and Society (2 Lectures)

9. Social Change and Development Sustainable and Inclusive (2 Lectures)
   Development, Basic developmental issues: Health, Education and Livelihood

10. Contemporary Social Issues (2 Lectures)

References:

Mandelbam, D. : Society in India (Part I & II), Popular Prakashan, Bombay, 1970
Srinivas, M.N. : Caste in Modern India and Other Essays, Asia Publishing House, Bombay,1964
Kapadia, K,M, : Marriage and Family in India, Oxford University Press, Calcutta,1981
Srinivas, M.N. : Social Change in Modern India, Orient Longman, New Delhi, 1995
Rao, M.S.A. (ed): Urban Sociology in India, Orient Longman, New Delhi, 1974
Ahuja, Ram : Social Problems in India, Rawat Publications, Jaipur, 1992
Kosambi, D.D. : The Culture & Civilization of Ancient India in Historical Perspective, New Delhi, 1982
Uberoi Patrcia (ed), Family, Kinship And Marriages in India, Oxford University Press, New Delhi.
Omen, T.K. and Mukharjee, P.N. (ed),: Indian Sociology : Reflection and Introspection, Popular Prakashan, Bombay, 1986

SCHOOL OF COMPUTER SCIENCES

A proposal for minor in Computer Science

1 Structure of the curriculum

The curriculum is divided in two category of courses, core courses and optional courses.

1.1 Core Courses

The following courses have been recommended by the steering committee as core courses. The Programming and Data Structure course are proposed to be two lab courses (2 credit each).

1. CS141 and CS142: Programming and Data Structures Lab
2. CS201: Theory of Computation
3. CS202: Discrete Structures and Computation[1]
4. CS301: Design and Analysis of Algorithms

1.2 Elective Courses

For the initial years, we shall offer the following optional courses. A student has to do three courses from the following list to obtain minor.

- CS451: Modern Cryptology
- CS452: Algorithmic Coding Theory
- CS453: Complexity Theory
- CS454: Linear Programming and Combinatorial Optimization
- CS455: Distributed Network Algorithms

In future, more elective courses will be offered based on the interests of the faculties.

1.3 Similarity with other courses

School of Mathematical Sciences offer some courses which are similar to the courses listed above. We make the following observations regarding this.

- Programming and Data Structure course can be merged with the existing Computational Laboratory courses (M141 and M142). I141 and I142 are the two lab courses, which may be offered instead of M141 and M142. The major difference in syllabus is the inclusion of different data structures which are core concepts in Computer Science.

[1] This course was originally titled Discrete Mathematics for Computer Science. We have renamed the course to capture the spectrum of the topics covered, and to avoid any confusion.

- School of Mathematical Sciences also offer Algorithms, Theory of Computation, Cryptology, Information and Coding Theory as PG optional courses. However, in Computer Science, Algorithms and Theory of Computation are fundamental courses, and need to be offered to the undergraduate students. The syllabus of Modern Cryptology, as well as Algorithmic Coding Theory has been designed from Computer Science point of view and significantly different from the SMS courses.

  However, to avoid repetition, we propose, students who take M462 (Cryptology) and M464 (Information and Coding Theory) will not be allowed to take CS451 (Modern Cryptology), and CS452 (Algorithmic Coding Theory) respectively.

2 Syllabi

Syllabi of the courses are given in the following pages. For each subject, the syllabus is organized as follows

1. prerequisite
2. topics
3. references

3 Core Courses

3.1 CS141: Programming and Data Structures Lab-I

Credit : 2

Prerequisite: None

Classes per week: 3P+1L.

Topics Module 0: (6P+2L): Introduction to Computers, Notion of Algorithm, Linux Bash Shell, Simple Shell Programs.
Module 1 (12P+4L): Introduction to Programming: Variables, operators and expressions, input and output statements, Conditions and loops. Functions and recursions.
Module 2 (12P+4L): Arrays, Pointers, Structures, Classes and Objects.
Module 3 (9P+3L): File i/o, command line arguments.
Module 4 (6P+2L). Abstract data type. Linked lists.

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

3.2 CS142: Programming and Data Structures Lab-II

Credit : 2

Prerequisite: CS141 **Classes per week**: 3P+1L. **Topics**

Module 0 (9P+3L): Review of programming, Arrays and Linked List. Bubble Sort and Quick Sort. Binary Search.
Module 1 (12P+4L): Circular Linked Lists, Doubly Linked Lists, Stacks, Queues.
Module 2 (12P+4L): Trees. Binary Search Trees, Tree traversal, Balanced Binary trees. Module 3 (6P+2L): Heap, Priority Queues.

Module 4 (3P+1L). Strings and Searching for Phrases.
Module 6:(Optional) (3P+1L) Dictionaries: universal, k-wise independent, simple tabulation hashing; chaining, dynamic perfect hashing, linear probing, cuckoo hashing

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973
- E. Horowitz,S . Sahni, Fundamentals of Data Structures in C++, Universities Press, 2008.

3.3 CS201: Theory of Computation

Credit : 4

Prerequisite: None **Classes per week**: 3L+1T. **Topics**

Module 1 (12L+4T): Introduction to Finite State Automata; DFA,NFA, and their equivalence, Regular Ex- pressions and equivalence with finite state automata.Regular Languages and Properties, Pumping Lemma and applications, Myhill-Nerode Theorem, State Minimization.
Module 2 (12L+4T): Context Free Languages (CFL) and grammars, parse trees, Chomsky Normal Form. Pushdown Automata (PDA), Equivalence of acceptance by final state and empty stack. Equivalence of CFL and PDA, Pumping Lemma for CFL.
Module 3 (12L+4T): Turing Machines and equivalence of different models. Universality. Decidability, Recog- nizability, Enumeration, and Undecidability. Reductions. Rice’s Theorem, recursion theorem.
Module 4 (9L+3T): Notions of P,NP,co-NP, hierarchy theorem, NP completeness, Cook-Levin Theorem, NP completeness proofs of some NP complete problems.

References

- J. Hopcroft, JD Ulman. Introduction to Automata Theory, Languages and Computations. Narosa Publishing 2002. (Indian Edition)
- M. Sipser. Introduction to the Theory of Computation. Cengage, 3rd Edition, 2014.
- H. R. Lewis and C. H. Papadimitriou: Elements of The Theory of Computation, Prentice Hall, Englewood Cliffs, 1981
- M. R. Garey and D. S. Johnson: Computers and Intractability: A Guide to The Theory of NP Completeness, Freeman, New York, 1979.

3.4 CS202: Discrete Structures and Computation

Credit 4
Prerequisite: none **Classes per week**:
3L+1T. **Topics**

Module 1 (6L+2T): Review of Sets, Operations, Principles of Inclusion and Exclusion. Functions, relations, Equivalence relations. Countable and uncountable sets. Review of Pigeonhole principle.

Module 2 (6L+2T): Introduction to Propositional Logic, Equivalence and Implications. Truth tables, De Mor- gan's Law, Quantifiers, Inference and Proofs. Introduction to First Order Logic, Syntax and Semantics, Soundeness and Completeness.

Module 3 (6L+2T): Mathematical Induction, Recursions, First order linear recurrence, Geometric series, Re- cursion trees and growth rates of solutions to recurrences, Master Theorem. Generating Functions.

Module 4 (6L+2T): Introduction to counting, sum and product principles, counting subsets. Binomial coefficients and Pascal's triangles. Polya's theory of counting (optional).

Module 5 (3L+1T): Arithmetic Algorithms: Computing GCD, primality testing, RSA.

Module 6 (12L+4T): Graph Theory: Graphs, representations, connectivity, cycles, trees, Spanning tree of a graph, Algorithms to find minimum spanning trees. Eulerian Cycle and Hamiltonian paths, independence number and clique number, chromatic number, Dominating Sets, and Covering Sets. Planar Graphs. Directed Graphs and tournaments.

Module 7(3L+1T) Probabilistic tools, Tail Bounds and Applications.
Module 8 (3L+1T)(optional): Linear Algebraic tools in Combinatorics.

References

- J. Gallier, Logic for Computer Science: Foundations of Automatic Theorem Proving, Wiley.
- Kenneth Rosen. Discrete Mathematics and Its Applications, 7th Edition , McGraw Hill Publishing Co., 2012.
- Ken Bogart. Discrete Mathematics for Computer Science. available at https://www.kth.se/social/files/557ec6b0f27654
- J. L. Mott, A. Kandel and T. P. Baker: Discrete Mathematics for Computer Scientists, Reston, Virginia, 1983
- J. A. Bondy and U. S. R. Murty: Graph Theory with Applications, Macmillan Press, London, 1976.
- F. S. Roberts: Applied Combinatorics, Prentice Hall, Englewood Cliffs, NJ, 1984

3.5 CS301: Design and Analysis of Algorithms

Credit 4

Prerequisite: CS201, CS202
Classes per week: 3L+1T.
Topics

Module 1 (4L+1T). Introduction and basic concepts - mathematics of algorithm analysis, asymptotic notations, worst case and average case complexity. Review of Searching and Union Find.

Module 2 (8L+3T): Divide and conquer- Motivating algorithms that leads into recurrences, solving recurrences, merge sort and its recurrence, Median computation. Analysis of quicksort.

Module 3 (9L+3T). Greedy algorithms- Greedy choice, optimal structure property, minimum spanning tree, knapsack

Module 4 (8L+2T). Dynamic programming- Integral knapsack, longest increasing subsequence, edit distance, independent sets in trees

Module 5 (8L+3T). Graph algorithms- Recall of representation of graphs, BFS, DFS, shortest path, connected components, topological sort of DAGs, biconnected components and strongly connected components in directed graphs

Module 6. (Optional)(3L+1T) Randomization- Median, randomized quicksort, probabilistic primality testing.

Algebraic Algorithms. Karatsuba's algorithm and the Fast Fourier transform

References

- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- S. Dasgupta, C. Papadimitrou, U. Vazirani, Algorithms, McGraw-Hill Education, 2006.
- A. Levitin, Introduction to Design and Analysis of Algorithms, Pearson 2007 (Lev)
- J. Kleinberg and E. Tardos, Algorithm Design, Pearson, 2005 (KT)
- E. Horowitz, S. Sahni, and S. Rajasekaran, Computer Algorithms, Silicon Press, 2007
- M. Goodrich, R. Tamassia, Algorithm Design, Wiley, 2001.
- D. Knuth: The Art of Computer Programming. Vol. 1 and Vol 3. , 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

4 Optional Courses

4.1 CS451: Modern Cryptology

Credit 4

Prerequisite: CS202, CS301.

Classes per week: 3L+1T.

Topics

Module 1: (3L+1T) Introduction and Classical Cryptography, Perfect Secrecy, One Time Pad.

Module 2: (9L+3T) Symmetric Key Encryption. Computational Security, Concrete vs Asymptotic Approach. Semantic Security. Pseudorandom generators and Stream ciphers, Pseudorandom Functions and Block Ciphers. Practical Constructions.

Module 3: (6L+2T) Hash Functions and Message Authentication Codes. Notions of Security, Generic Attacks, Domain Extension techniques, CBC MAC, HMAC, PMAC, Idea of Authenticated Encryption.

Module 4: (6L+2T) Review of Basic Number Theory. Hardness Assumptions. One-way functions, Trapdoor Permutations, RSA assumptions, Discrete Log and Diffie Hellman Assumptions, SIS and LWE Assumptions. Introduction to Elliptic Curves (Optional)

Module 5. (3L+1T) Key Exchange Protocols and Key Management.

Module 6. (6L+2T) Public Key Encryption, Semantic Security, El Gamal Encryption, Padded RSA PKCS#1 v1.5. Random Oracle Technique, OAEP.

Module 7. (6L+2T) Digital Signatures, Hash and Sign paradigm, Schnorr Signature, Forking Lemma, DSA. SSL/TLS.

Module 8. (6L+2T) (Optional) Idea of some of the following notions, Protocols and Zero Knowledge Proofs, Multiparty Computations and Oblivious Transfers, Secret Sharing. Algorithms for factoring and computing discrete logarithms, Linear and Differential Cryptanalysis, Crypto Currencies.

References

- J. Katz and Y. Lindell, Introduction to Modern Cryptography. CRC, 2014.

Possible Instructor: Rishiraj Bhattacharyya.

4.2 CS452: Agorithmic Coding Theory

Credit 4

Prerequisite: CS202

Classes per week: 3L+1T.

Topics Module 1: (9L+3T) Entropy, Characterization and Properties. Application to Combinatorics. Mutual Information and KL Divergence.

Module 2: (6L+2T) Source coding theorem, lossless compression of data, Lempel-Ziv Algorithm, Optimal lossless coding.

Module 3 (6L+2T) Communication channels (binary symmetric, erasure) and channel capacity, channel coding theorem.

Module 3: (6L+2T) Introduction to Error Correcting Codes. Hamming Codes and Hamming Bounds. BCH Codes, Maximum likelihood decoding and syndrome decoding; coding theory bounds.

Module 4: (9L+3T) Reed-Solomon codes and the Berlekamp-Welch decoding algorithm with Analysis. List Decoding of Reed-Solomon Codes.

Module 5. (6L+2T)Reed-Muller Code and Local decoding. Module 6.

(3L+1T) (Optional) Lovasz Local lemma and proof.

References

- T. M. Cover and J. A. Thomas, "Elements of Information Theory" (Second Edition, Wiley).
- S. Ling C. Xing, "Coding Theory: A First Course", Cambridge University Press.
- J. Radhakrishnan, "Entropy and Counting", http://www.tcs.tifr.res.in/ jaikumar/Papers/EntropyAndCounting.pdf
- V. Guruswami, A. Rudra and M. Sudan, "Essential Coding Theory (Draft of a new book)" available at http://www.cse.buffalo.edu/faculty/atri/courses/coding-theory/book/
- F.J. MacWilliams and N.J.A. Sloane, The Theory of Error-Correcting Codes, North-Holland ML, 1983.

Possible Instructor: Rishiraj Bhattacharyya.

4.3 CS453: Complexity Theory

Credit 4

Prerequisite: CS201, CS202, CS301

Classes per week: 3L+1T.

Topics

Module 1 (9L+3T): Introduction, P and NP - Review of Turing machines, universal Turing machines, and uncomputable functions, P vs. NP, NP vs. co-NP, and NP-completeness, EXP, NEXP

Module 2: (3L) Cook Levin's Theorem

Module 3 (12L+4T): Diagonalization, Space complexity, Polynomial Hierarchy

Module 4 (9L+3T): Interactive Proofs - PCP theorem and its application to approximability Module 5 (4L+1T): Circuit complexity and lower bounds

Module 6 (6L+2T): Hardness vs. Randomness - Randomized Computation, derandomization, Pseudo-random generators

Module 7 (3L+1T): Polynomial identity testing vs Lower bounds for arithmetic circuits

References:

- S. Arora and B. Barak, "Computational Complexity: A Modern Approach", Cambridge University Press.
- O. Goldreich, "Computational Complexity: A conceptual perspective", Cambridge University Press.
- J. Hopcroft, R. Motwani, J. D. Ullman. Introduction to Automata Theory, Languages, and Computation. Pearson Education.
- J. Raddhakrishnan, Graduate course on Computational Complexity, http://www.tcs.tifr.res.in/ jaikumar/Courses/Com

Possible Instructor: Anisur Rahaman Molla.

4.4 CS454: Linear Programming and Combinatorial Optimization

Credit 4

Prerequisite: CS202, CS301
Classes per week: 3L+1T.

Topics

Module 1: (10L+3T) Basic geoemetry and linear algebra related to Linear Programming. Simplex-method and Duality theorem (leading to Von Neumann's minmax principle) and complimentary slackness.

Module 2: (8L+3T) Ellipsoid algorithm. separation oracles.

Module 3: (9L+3T) Semidefinite programming as an extension of linear programming.

Module 4: (9L+3T) LP relaxation. Examples of problems where LP relaxation achieves optimum. Examples where LP/SDP relaxation achieves approximate solution. Integrality gaps.

Module 5: (6L+2T) Rounding, probabilistic roundings, iterative rounding, primal dual methods.

Module 6 (Optional): (3L+1T) Gale-Shapley algorithm, Connection of LP to Cooperative Game Theory core, nucleolus, combinatorial optimization games.

References

- A. Schrijver, "Theory of Linear and Integer Programming", Wiley.
- A. Schrijver, "Combinatorial Algorithm: Polyhedra and Efficiency, Volume A", Springer.
- V. Vazirani, "Approximation Algorithm", Springer.
- S. Chakraborty, M. Mitra, P. Sarkar, "A Course on Cooperative Game Theory", Cambridge University Press.

Possible Instructor: Rishiraj Bhattacharyya, Anisur Rahaman Molla.

4.5 CS455: Distributed Network Algorithms

Credit 4

Prerequisite: CS202, CS301

Classes per week: 3L+1T. **Topics** Module 1: (9L+3T) Foundations of distributed network algorithms - Broad- cast, converge-cast, maximal independent set, coloring, leader election, spanning tree algorithms, shortest paths, and routing.

Module 2:(9L+3T) Fundamental concepts in distributed algorithms - Symmetry breaking, locality, synchronizers Module 3:(9L+3T) Basics of distributed network systems - Communication, synchronization, fault-tolerance,

and resource allocation

Module 4:(9L+3T) Applications to real-world networks - Internet, peer-to-peer networks, wireless networks, sensor networks and dynamic networks

Module 5:(9L+3T) Lower bounds using communication complexity, distributed computation of large-scale data, dynamic network algorithms.

References

- D. Peleg, "Distributed Computing: A Locality-Sensitive Approach", SIAM 2000.
- Distributed Computing: Fundamentals, Simulations and Advanced Topics, by Hagit Attiya, Jennifer Welch, McGraw-Hill Publishing, 1998.
- N. Lynch, "Distributed Algorithms", Morgan Kaufmann 1996.
- G. Tel, Introduction to Distributed Algorithms, Cambridge University Press 2000.
- G. Pandurangan, "Distributed Network Algorithms, a monograph", Department of CS, University of Houston.

Possible Instructor: Anisur Rahaman Molla.

NISER

SCHOOL OF BIOLOGICAL SCIENCES

INTEGRATED M.Sc LIFE SCIENCES (PROGRAM CODE: LIFE13)

DETAILED COURSE STRUCTURE FOR

INTEGRATED M.Sc. COURSE

Syllabus Revised Jan 2017

Approved and Implemented August 2017 Course Structure

Modified September 2019

Table 1.Course structure for Integrated M.Sc. in School of Biological Sciences

Year/Semester	New Course No	Credits	Course Name
1/Semester-I	B101	3	Biology I: Science of Life
	B141	2	Biology Laboratory-1
1/Semester-II	B102	3	Biology II: Cellular and Genetic basis of life
	B142	2	Biology Laboratory-2
2/Semester-III	B201	4	Microbiology
	B202	4	Biochemistry
	B203	4	Biophysics and Biostatistics
	B241	2	Laboratory-3 (Microbiology)
	B242	2	Laboratory-4 (Biochemistry)
2/Semester-IV	B204	4	Cell Biology
	B205	4	Genetics
	B251-255	4	Elective-1
	B243	2	Laboratory-5 (Cell Biology)
	B244	2	Laboratory-6 (Genetics)
3/Semester-V	B301	4	Physiology-I (Animal)
	B302	4	Physiology-II (Plant)
	B303	4	Ecology
	B342	2	Laboratory-7 (Plant physiology)
	B351-355	4	Elective-2
3/Semester-VI	B304	4	Molecular Biology
	B305	4	Immunology
	B306	4	Evolutionary Biology
	B343	2	Laboratory-8 (Molecular Biology)
	B344	2	Laboratory-9 (Immunology)
	B351-355	4	Elective-3
4/Semester-VII	B403	4	Bioinformatics
	B402	4	Developmental Biology
	B498	4	Biology Project
	B451-460	4	Elective-4
	B451-460	4	Elective-5
4/Semester-VIII	B405	4	Bio-techniques
	B551-B562	4	Elective-6
	B551-B562	4	Elective-7
	B499	8	Biology Project
5/Semester-IX	B598	24	Biology Project /Dissertation
5/Semester-X	B599	24	Biology Project /Dissertation

Table 2. List of compulsory courses

Year/Semester	Course No	Credits	Course Name
1/Semester-I	B101	3	Biology I: Science of Life
	B141	2	Biology Laboratory-1
1/Semester-II	B102	3	Biology II: Cellular and Genetic basis of life
	B142	2	Biology Laboratory-2
2/Semester-III	B201	4	Microbiology
	B202	4	Biochemistry
	B203	4	Biophysics and Biostatistics
	B241	2	Laboratory-3 (Microbiology)
	B242	2	Laboratory-4 (Biochemistry)
2/Semester-IV	B204	4	Cell Biology
	B205	4	Genetics
	B243	2	Laboratory-5 (Cell Biology)
	B244	2	Laboratory-6 (Genetics)
3/Semester-V	B301	4	Physiology (Animal)
	B302	4	Physiology (Plant)
	B303	4	Ecology
	B342	2	Laboratory-7 (Plant physiology)
3/Semester-VI	B304	4	Molecular Biology
	B305	4	Immunology
	B306	4	Evolutionary Biology
	B343	2	Laboratory-8 (Molecular Biology)
	B344	2	Laboratory-9 (Immunology)
4/Semester-VII	B403	4	Bioinformatics
	B402	4	Developmental Biology
	B498	4	Biology Project
4/Semester-VIII	B405	4	Bio-techniques
	B499	8	Biology Project
5/Semester-IX	B598	24	Biology Project /Dissertation
5/Semester-X	B599	24	Biology Project /Dissertation

Table 3. List of elective courses

Year/Semester	Course No	Credits	Course Name
2nd and 3rd year			
	B351	4	Principles of Drug Design
	B352	4	Endocrinology
	B353	4	Plant Developmental Biology
	B354	4	Neurobiology
	B355	4	Structural Biology
4th year	B451	4	Advanced Cell Biology
	B452	4	Genetic engineering
	B453	4	Advance Biochemistry
	B454	4	Advance Microbiology
	B455	4	Enzymology
	B456	4	Advance Neurobiology
	B457	4	Chemical Biology
	B460	4	Virology
5th year	B551	4	Advanced Molecular Biology

	B552	4	Advanced Immunology
	B553	4	Infectious Disease Biology
	B554	4	Cancer Biology
	B555	4	Advanced Genetics
	B556	4	Immune regulation and Infection immunity
	B557	4	Macromolecular crystallography
	B558	4	Quantitative Biology
	B559	4	Ion Channels
	B561	4	Concepts in Mechanobiology
	B562	4	Molecular errors in disease pathogenesis

Table 4. Course for integrated MSc minor degree in Biology

Sr No.	**Course No**	**Credits**	**Course Name**
1	B101	3	Biology I: Science of Life
2	B141	2	Biology Laboratory-1
3	B102	3	Biology II: Cellular and Genetic basis of life
4	B142	2	Biology Laboratory-2
5	B202	4	Biochemistry
6	B204	4	Cell Biology
7	B205	4	Genetics
8	B304	4	Molecular Biology
9	B306	4	Evolutionary Biology
10	Bx5x	4	**Any one course from biology subjected to qualified prerequisite**
Total		**34**	

DETAILED SYLLABUS – COMPULSORY COURSES

1st Year, Semester I

Science of Life (B101)

Course Title : Science of Life
Course Code : B101
Credits : 3 Credits
Course Category : Core
Course Prerequisites : No prerequisites
Contact Hours (28/42/56) : 42 (including tutorials)

Outcome of the Course:

- Understanding the origin and evolution of life.
- Fundamental understanding of the structure and function of the molecules of life.
- Fundamental understanding of the structure & function of cellular organelles.

Course Contents:

1) Origin of life: Bioenergetics and concepts of evolution (10 Lectures + 5 Tutorials)
- What is life?
- Origin(s) of life on planet earth.
- First cellular forms to current day view of 'Tree of life'.
- Basics of evolution – natural selection, adaptive evolution, genetic drift, neutral evolution, molecular clock and molecular systematics.

2) Molecules of life: (11 Lectures + 5 Tutorials)
- Nucleic acids – architecture (structure), physico-chemical properties and importance in biology.
- Proteins – structure, biochemical properties, functions as major biological workhorses.
- Lipids – membrane architecture, composition and lipid constituents of membranes, importance of membrane lipids and proteins in cellular function.
- Brief introduction to metabolism and energy cycles in cellular forms.

3) Unit of life: (7 Lectures + 4 Tutorials)
- Basic unit of life (introduction to architecture and composition).
- Structure & function of organelles.
- Cytoskeleton
- Extracellular matrix

Recommended Books:

a) Biology by Campbell and Reece, Eighth Edition.
b) Lehninger Principles of Biochemistry, by DL Nelson and Michael M Cox., Sixth Edition.
c) Molecular biology of the Cell by Albert et.al, Sixth Edition.

Suggested References:
Class notes, handouts and other reading relevant to contemporary research problems and recent findings in the context of the course will be provided from time to time whenever necessary.

1st Year, Semester II

Biology II - Cellular and Genetic basis of life (B102)

Course Title : Biology II - Cellular and Genetic basis of life
Course Code : B102
Credits : 3 Credits
Course Category : Core
Course Prerequisites : B101
Contact Hours (28/42/56) : 42
(including tutorials)

Outcome of the Course:

- Understanding the principles of cellular mechanisms driving development of an organism
- Key evolutionary concepts in Lamarckism, Darwinism and Speciation
- Understanding the genetic basis of inheritance
- Fundamental understanding of molecular Biology

Course Contents:

1. Cellular Mechanisms of Development (7 Lectures + 3 Tutorials)
   - Cell Cycle
   - Cell-Cell communication
   - Cell differentiation

2. Evolutionary concepts (6 Lectures + 3 Tutorials)
   - Lamarckism
   - Darwinism
   - Speciation

3. Basis of Inheritance (9 Lectures + 3 Tutorials)
   - Chromosomal patterns of inheritance
   - Molecular patterns of inheritance

4. Molecular Biology (8 Lectures + 3 Tutorials)
   - Basics of Replication
   - Basics of Transcription
   - Basics of Translation
   - Basics of DNA manipulation

Recommended Books:

a) Biology by Campbell and Reece

Suggested References:

Class notes, handouts and other reading as suggested during the class.

2nd Year, Semester III

Microbiology (B201)

Course Title : Microbiology
Course Code : B201
Credits : 4 Credits
Course Category : Core
Course Prerequisites : None
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Microbiology as a science.
- Key concepts in Microbes in health & disease.
- Overview of role of microbes in nutrient cycling
- Implications in Evolution, Health and disease.

Course Contents:

1. Development Microbiology as a science and Microbial world (6 Lectures + 2 Tutorials)
   - Microbial diversity: Microbial evolution and systematic, Eukaryotic microorganisms – Protists, Fungi, Unicellular red & green algae. Overview of viruses and their classification, overview of viral replication, Prions – non-microbial infectious agent
   - Cell structure and function of bacteria, archaea and eukaryotic microorganisms
   - Role of microorganisms in understanding biological systems
2. Microbial nutrition and physiology: (7 Lectures + 2 Tutorials)
   - Metabolic diversity – Phototrophy, Autotrophy, Chemolithotrophy and Nitrogen fixation
   - Catabolism of organic compounds – fermentations, anaerobic respiration & aerobic chemorganotrophic processes.
   - Microbial growth
3. Microbial genetics: Overview (6 Lectures + 2 Tutorials)
   - Bacterial genetics – chromosomes, plasmids & incompatibility, mutation, genetic exchange in prokaryotes – transformation, conjugation, transduction
4. Microbes in health & disease: (8 Lectures + 2 Tutorials)
   - Beneficial microbial interactions with humans,
   - Harmful microbial interactions with humans: host-parasite interactions, overview of host defense system, pathogenesis & infection establishment, Virulence factors & toxins.
   - Brief overview of antibiotics, antibiotic resistance & their mechanism of action
5. Microbes in agriculture: Overview (5 Lectures + 2 Tutorials)
   - Microbial diseases of economically important plants
   - Agrobacterium and crown gall disease, Transformation
6. Microbes in environment: (6 Lectures + 2 Tutorials)
   - Brief overview of role of microbes in nutrient cycling
   - Microbial bioremediation: leaching of ores, mercury & heavy metal transformation, petroleum degradation, biodegradation of xenobiotics
   - Animal-microbial symbiosis: rumen and ruminant animals,

- Plant-microbial symbiosis: Lichens- mycorrhizae, Agrobacterium and crown gall disease, Legume-root nodule symbiosis

7. Microbes in industry: Brief over view of their roles in: (4 Lectures + 2 Tutorials)

- Food, health and fermentation sectors

Recommended Books:-

a) Brock's Biology of Microorganisms by Madigan et al.
b) Microbiology by Prescott et al.
c) Class notes, handouts and other reading as suggested during the class.

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Biochemistry (B202)

Course Title : Biochemistry
Course Code : B202
Credits : 4 Credits
Course Category : Core
Course Prerequisites : None
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding the principles governing Protein structure & function
- Basic concepts on metabolism and their implications in living organisms
- Concept on signal transduction
- Implications in Evolution, Health and disease.

Course Contents:

1. Overview of Biochemistry (1 lecture)
2. Protein structure & function, Protein Folding, Protein Degradation (3 lectures + 1 tutorial)
3. Enzymes: Classification, Mode of action, kinetics, regulation and inhibition, examples of enzymatic reactions and regulatory enzymes (2 lectures + 1 tutorial)
4. Lipids: Transmembrane lipids, receptors, lipids as signals, co-factors and pigments (3 lectures + 1 tutorial)
5. Membrane (3 lectures + 1 tutorial)
6. Intermediary Metabolism and Energetics: (3 lectures + 1 tutorial)
7. CarbohydrateMetabolism: Glycolysis, TCA cycle, Gluconeogensis, Pentose phosphate pathway, Glycogenesis and Glycogenolysis, co-ordianted regulation of glycolysis and gluconeogensis, Phosphorylation and bioenergetics of above processes. (6 lectures + 2 tutorials)
8. Electron Transport Chain and Oxidative Phosphorylation (3 lectures + 1 tutorial)
9. Fatty acid biosynthesis and degradation, Synthesis of Cholesterol, Steroid Hormones and Eicosanoids (3 lectures + 1 tutorial)
10. Amino acid biosynthesis and degradation (3 lectures + 1 tutorial)
11. Nucleotide biosynthesis and degradation (3 lectures + 1 tutorial)
12. Hormones: Mechanism of action, regulation and integration in mammalian metabolism (3 lectures + 1 tutorial)
13. Biochemistry of signal Transduction (3 lectures + 1 tutorial)

Recommended Books:
a) Lehninger Principles of Biochemistry, Fourth Edition by David L. Nelson, Michael M. Cox
b) Biochemistry by Berg and Stryer
c) Biochemistry by Voet and Voet
d) Harper’s book of Biochemistry

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

B203: Biophysics & Biostatistics

Course Title : Biophysics and Biostatistics
Course Code : B203
Credits : 4 Credits
Course Category : Core
Course Prerequisites : None
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Introducing the concepts of Biophysics and Biostatistics
- Understanding the laws and tools of physics that are applied to understand biology
- How is statistics required and applied in the field of biology
- Evolution of the subject Biophysics and its application
- Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of biophysics and biostatistics
- Understanding Biophysics to do new and more insightful biology
- Understanding details of biostatistics to understand a) the quality of the data, b) the validity of comparative biological analysis, and classification and grouping of data for better insight of the underlying biological principles

Course Contents:

Biostatistics

1. Simple Statistics & Effect Statistics (2 Lectures)
2. Precision of Measurement (1 Lecture + 1 Tutorial)
3. Generalizing to a Population (2 Lectures)
    a. Confidence Limits, Statistical Models
4. Models: Important Details (2 Lectures +1 Tutorial)
    a. Complex Models
5. Repeated-Measures ANOVA (2 Lectures +1 Tutorial)
6. Dimension Reduction (2 Lectures + 1 Tutorial)
    a. Principal Components · Factor Analysis · Cluster Analysis
7. Estimating Sample Size (2 Lectures +1 Tutorial)
8. On the Fly: Miscellaneous (1 Lecture)
9. Simulation for Sample Size (2 Lectures)

Biophysics

1. Introduction: What is biophysics (3 Lectures +1 Tutorial)
2. Basic techniques in life sciences (6 Lectures + 2 Tutorials)
3. Energetics and Thermodynamics (6 Lectures + 2 Tutorials)
    a. reversible and irreversible (6 Lectures + 2 Tutorials)
4. Kinetics & Catalysis mechanisms
    a. (emphasis on enzymes)
5. Structure-function relationship (2 Lectures +1 Tutorial)
6. Models in evolution and agricultural sciences (2 Lectures +1 Tutorial)
7. Recent advances in biophysics (2 Lectures + 1 Tutorial)

a. an overview of Omics and systems biology

Recommended Books:

a) Class notes, handouts
b) Statistics at the Bench: A Step-by-Step Handbook for Biologists by Martina Bremer
c) Introductory Biophysics by V. Pattabhi & N. Gautham
d) Biophysical Chemistry, Part 1, 2, 3. by Cantor & Schimmel
e) Principles of Fluorescence Spectroscopy by J. R. Lacowicz
f) Physical Biochemistry by David Freifelder.
g) Biological Spectroscopy by Iain D. Campbell, Raymond A. Dwek

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

2nd Year, Semester IV

Cell Biology (B204)

Course Title	:	Cell Biology
Course Code	:	B204
Credits	:	Credits – 4
Course Category	:	Core/
Course Prerequisite	:	Successful completion of All 1st year courses B201 (Microbiology), B202 (Biochemistry), B203 (Biophysics and Biostatistics)
Contact Hours (28/42/56) (including tutorials)	:	56

Outcome of the Course:
* Understanding the basic principles governing cell structure and functions
* Biochemcial, biophysical, genetical basis of cell and its response
* Key concepts in maintenance of cell structure
* Evolution of cell organelles, importance in health and disease.

Course Contents:

1. Overview of Cell biology (1 lecture)
2. Universal features of cells (2 lectures + 1 Tutorial)
5. Basic microscopy, Visualization of cell, its fine structure, molecules and different functions (3 lectures)
6. The cell membrane, its structure and its dynamics (2 lectures + 1 Tutorial)
7. Transport across membrane (3 lectures)
8. Ion channels (2 lectures + 1 Tutorial)
9. Cellular compartments and function, protein sorting (3 lectures)
10. Vesicular traffic inside the cells (2 lectures + 1 Tutorial)
11. Mitochondria and chloroplast and their genetic system, fission and fusion of mitochondria

12. Cellular communication and cell signaling (2 lectures + 1 Tutorial)
13. Cytoskeleton of cells, cytoskeleton filaments, molecular motors, cell junction, extra cellular matrix, cell adhesion (5 lectures + 2 Tutorials)
14. Cell cycle, Cell division- Mitosis, meiosis and the mechanism of cell division (2 lectures)
15. Cell biology of nucleus and chromatin (2 lectures + 1 Tutorial)
16. Cell biology of Germ cells, neuronal cells, stem cells, gametes, immune cells (2 lectures + 1 Tutorial)
17. Cell biology of cancer cells (2 lectures + 1 Tutorial)
18. Cell survival and cell death (2 lectures + 1 Tutorial)
19. Cell biology of model organisms and plant cells (2 lectures + 1 Tutorial)
20. Advancement in microscopic techniques (3 lectures + 1 Tutorial)

Recommended Books:
"Molecular biology of the Cell" by Albert et.al

Suggested References:
Important research articles and reviews as suggested in the class by the instructor

Genetics (B205)

Course Title : Genetics
Course Code : B205
Credits : 4 Credits
Course Category : Core
Course Prerequisites : Successful completion of 1st year courses
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding the basic principles of inheritance
- Knowledge of genetic disease mechanism
- Comprehension of monogenic, polygenic and multifactorial diseases
- Application in health and diseases

Course Contents:

1. Overview of Genetics and terminology (1 Lecture)
2. Model Genetic systems (1 Lecture)
3. Mendelian Inheritance (1 Lectures + 1 Tutorial)
4. Deviations from Mendelian Inheritance- Linkage and Sex linked Inheritance, Gene Interactions, Maternal and Extranuclear Inheritance (6 Lectures + 2 Tutorials)
5. Recombination, Recombination mapping and mechanism of recombination (3 lectures + 1 Tutorial)
6. Transposable Elements (3 lectures + 1 Tutorial)
7. Mechanisms of Genetic Diseases- Chromosome number variation, changes in chromosome structure, Gene mutation, mutagenesis and mutant selection, X-chromosome inactivation, Genetic imprinting (6 lectures + 2 Tutorials)
8. Elements of human genetics-genetic disorders, patterns of inheritance, molecular diagnosis (3 lectures + 1 Tutorial)
9. Cytogenetics (2 lectures + 1 Tutorial)
10. Prenatal Diagnosis and Genetic Counseling (3 lectures + 1 Tutorial)
11. Epigenetics (3 lectures + 1 Tutorial)
12. Cancer Genetics (1 lecture)
13. Population Genetics (6 lectures + 2 Tutorials)
14. Developmental Genetics (1 lecture)
15. Immunogenetics (1 lecture)
16. Genes and Evolution (1 lecture + 1 Tutorial)

Recommended Books:
a) “Genetics” by M. W. Strickberger
b) “Principles of Genetics” by E. J. Gardner, M. J. Simmons, D. P. Snudstad
c) “Human Genetics” by A. Gardner, R.T. Howell, and T. Davis

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor.

3rd Year, Semester V

Physiology I (Animal) (B301)

Course Title : Animal Physiology
Course Code : B301
Credits : 4 Credits
Course Category : Core
Course Prerequisites : Cell Biology, Biochemistry
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Learning molecular, chemical and physical principles of animal body plan.
- Understanding structure-function relationships and how various physiological systems work.
- Integrating knowledge to understand health and disease.

Course Contents:

1. Overview of animal anatomy and body plan (3 Lectures + 1 Tutorial)
   - Animal kingdom and classification
   - Relationships between phyla
   - Body plan, symmetry and cavities

2. Fundamentals of animal physiology (3 Lectures + 1 Tutorial)
   - Adaptation
   - Acclimatization, acclimation
   - Conformity and regulation

3. Homeostasis (3 Lectures)
   - *Milieu internae*, Feedback and control systems
   - Feedforward systems
   - Nonpysiological homeostasis

4. Biomembranes & transport across membrane (2 Lectures + 1 Tutorial)
   - Membrane composition, models
   - Transmembrane movement of ions, diffusion, osmosis

5. Membrane potential (2 Lectures + 1 Tutorial)
   - Electrical properties of membrane and resting membrane potential
   - Action potential

6. Neurophysiology (2 Lectures + 1 Tutorial)
   - Neurons and synapses
   - Neurotransmitters: classification and receptors

7. Sensory physiology (3 Lectures + 1 Tutorial)
   - Photoreception, olfaction
   - Taste, hearing

- Mecahnoreception and heat reception

8. Physiology of muscle (4 Lectures + 1 Tutorial)
   - Skeletal muscle and mechanism of contraction
   - Cardiac muscle and mechanism of contraction
   - Smooth muscle and mechanism of contraction

9. Cardiovascular systems or cardiac physiology (2 Lectures + 1 Tutorial)
   - Open and closed circulation
   - Heart: electrical and mechanical properties
   - Regulation of the cardiovascular system

10. Respiratory system across animal phyla & gas exchange (2 Lectures)
    - Lungs and other systems, lung volumes and capacities
    - Regulation of respiration

11. Excretory systems (2 Lectures + 1 Tutorial)
    - Excretory organs in aquatic and terrestrial animals
    - Urine-concentrating mechanisms, countercurrent mechanism

12. Osmoregulation (2 Lectures)
    - Osmotic responses of animals
    - Vertebrate and invertebrate osmoregulation

13. Fluid and acid base balance (3 Lectures + 1 Tutorial)
    - Regulation of acid-base balance by blood buffers, lungs and kidneys.
    - Hormonal and renal regulation of body fluids and electrolyte balance.

14. Digestive system (2 Lectures + 1 Tutorial)
    - Anatomy of the digestive system, variations
    - Digestion and absorption
    - Gastric hormones and reflexes

15. Endocrine system (3 Lectures + 1 Tutorial)
    - Glands, hormones and classification
    - Regulation of endocrine secretion
    - Mechanisms of hormonal action, receptors

16. Reproductive system (2 Lectures + 1 Tutorial)
    - Male and female reproductive systems
    - Fertilization and embryogenesis

17. Lymphatics and immune system (2 Lectures + 1 Tutorial)
    - Lymphatic system: organization and function
    - Organization of immune system

Recommended Books:
"Animal Physiology", Hill R, Wise G A & Anderson M Sinauer.

Suggested References:
Relevant articles from journals.

Physiology II (Plant) (B302)

Course Title : Physiology II (Plant)
Course Code : B302
Credits : 4 Credits
Course Category : Core
Course Prerequisites : Genetics, Cell Biology, Biochemistry
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Entrain the students with different hormone physiology and it's interaction.
- Learning light physiology, transformation and photosynthesis.

Course Contents:

1. Gross anatomy of plants and Plant Cell architecture (3 Lectures + 1 Tutorials)
2. Transpiration (1 Lecture)
3. Mendelian Genetics (1 Lecture)
4. Plant transformation (1 Lectures + 1 Tutorials)
5. Photosynthesis (2 Lectures + 1 Tutorials)
6. Respiration (2 Lectures + 1 Tutorial)
7. Protein trafficking in plants, (1 Lecture)
8. Macromolecular complexes in plants (1 Lecture)
9. Gene expression and transgene Silencing mechanisms in plant (3 Lectures + 1 Tutorial)
10. Phytochrome, Photomorphogenesis (3 Lectures + 2 Tutorials)
11. Cryptochromes, Phtotrophins and UV light responses (3 Lectures + 1 Tutorial)
12. Plant growth regulators: auxins, gibberellins, cytokinins, ethylene abscisic acid (7 Lectures + 2 Tutorials)
13. Plant photoreceptors and light signaling in plants (4 Lectures + 1 Tutorial)
14. Control of flowering time (4 Lectures + 2 Tutorials)
15. Ethylene signaling and fruit ripening (2 Lectures + 1 Tutorial)
16. Stress response in plants (1 Lecture)
17. Plant pathogen interaction, Symbiosis vs. Parasitic (1 Lecture)

18. Leaf Senescence (1 Lecture)

19. Medicinal plants and its importance (1 Lecture)

Recommended Books:

a) “Plant Physiology” by Taiz & Zeiger Sinaue,

b) “Plant Physiology” by Salisbury and Ross

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

<u>Ecology (B303)</u>

Course Title **: Ecology**
Course Code **: B303**
Credits **: 4 credits**
Course Category **: Core**
Course Prerequisite **: Introductory Biology**
Contact Hours (28/42/56) **: 56**
(including tutorials)

Outcomes of the Course:

- Understanding biotic and biotic factors governing the distributions of organisms
- Understanding the biosphere from the viewpoint of organism, population, community and ecosystem
- Understand organismal diversity and functional diversity of organisms in a landscape or ecosystem

Course Contents (with both Lectures + Tutorials marked:

1. General principles (4 Lectures +1 tutorial)
    - Geographical variation in climate on Earth
    - Major ecological patterns in relation to climate
    - Major biomes and their geographic distributions
2. Ecology and Society (3 Lectures +2 tutorials)
    - Human society and environment: past and present
    - History of ecology as a science
    - Relevance of ecology in the modern world
3. Ecology as a quantitative science (4 Lectures +1 tutorial)
    - What are data?
    - How are data collected, summarized and interpreted?
    - Basic statistical techniques used for making inference
    - Computer applications
4. Ecology of populations (3 Lectures + 2 tutorials)
    - Single-species population dynamics under unrestricted resources
    - Single-species population dynamics under limited resources
5. Species interactions (4 Lectures + 1 tutorial)
    - Various types of species interactions
    - Dynamics of two-species competition
    - Multi-species coexistence and the ‘niche’ concept
    - Succession
    - Dynamics of predator-prey interaction
6. Food-webs (3 Lectures + 2 tutorials)
    - Trophic dynamics and energy transfer
    - Interaction between competition and predation

- Trophic cascades

7. Behavioural Ecology (4 Lectures + 1 tutorial)
    - Behaviour and natural selection
    - Behaviour and sexual selection
    - Co-evolution
8. Ecosystems (3 Lectures + 2 tutorials)
    - Material and energy flow
    - Biogeochemical cycles
    - Case study of a grazing ecosystem
9. Biodiversity (4 Lectures +1 tutorial)
    - Different levels of biological diversity
    - How to measure species diversity
    - Threats to biodiversity
    - Principles of Conservation
    - Conservation in practice
10. Global change (4 Lectures +1 tutorial)
    - Various aspects of global change
    - Climate and the earth's geological history
    - Mitigating the effects of ongoing global change: science and policy

11. Field Methods and Field trips (*tentative*) (6 Lectures)

Recommended Books:

a) Ecology-Principles and Applications by *Chapman and Reiss Cambridge*
b) Essentials of Ecology by Townsend C, Begun M and Harper
c) Fundamentals of Ecology *by M. C. Dash*

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

3^{rd} Year, Semester VI

Molecular Biology (B304)

Course Title : Molecular Biology
Course Code : B304
Credits : 4 Credits
Course Category : Core
Course Prerequisites : B101, B102
Contact Hours (28/42/56) : 56

Outcome of the Course:

- Understanding the key components of cell involved in central dogma of molecular biology.
- Understanding of structure-function of genetic material, replication, repair, transcription and translation.

Course Contents:

1. Molecular biology an overview, discovery of DNA as genetic material (2 Lectures)
    - Genes, proteins and function
    - Historic perspectives and identification of DNA as genetic material
    - Central Dogma of Molecular Biology

2. Model organism used in molecular biology (2 Lectures)
    - *Escherichia coli*, *Saccharomyces cerevisiae*, *Caenorhabdits elegans*, *Drosophila melanogaster*, *Danio rerio*, *Arabdiopsis thaliana*, *Mus musculus*,
    - Virus and Tissue culture.

3. Nucleic acid structure and function (4 lectures + 1 tutorial)
    - Structure and components of nucleic acids
    - Chemical and physical properties of nucleic acids
    - Enzymes in DNA topology

4. Chromosome, chromatin structure and function (3 lectures + 1 tutorial)
    - Nucleosome structure
    - Chromatin remodeling complexes
    - Histone code
    - Structural maintenance of chromosome

5. DNA replication (4 lectures + 1 tutorial)
    - Components of DNA replication
    - Regulation of DNA replication
    - End replication problem, teleomere and telomerase

6. Mutations and DNA repair (3 lectures + 1 tutorial)

- Different types of mutations
- Chemical and physical agents of mutation
- Mechanism of mutations
- Repair system, components and their mechanism

7. Recombination and Transposons (4 lectures + 1 tutorial)

- Homologous recombination: Holliday junction and its resolution
- Components of homologous recombination system
- Cre recombinase and its mechanism
- Gene conversion
- Transposable elements
- LINEs and SINEs

8. Transcription and Gene Regulation (8 lectures + 2 tutorial)

- Historic perspective of gene regulation: PaJaMo experiment
- Lac and Trp Operon
- Techniques used in studying transcription: ChIP, foot-printing, yeast two hybrid system
- Architecture of eukaryotic gene regulation machinery
- Transcription factors, activators and repressors
- RNA polymerase in prokaryote and eukaryotes: initiation and elongation
- Transcription termination Rho dependent and Rho independent
- Post transcription RNA processes in eukaryotes Capping; RNA binding proteins; Poly-adenylation; mRNA splicing; Spliceosome complex; regulation at splicing level drosophila sex determination; RNAi; siRNA, miRNA; RISC complexes; RNA degradation and P-body; stress granules

9. Genetic code (4 lectures + 1 tutorial)

- The information problem
- Experimental evidence that genetic code is triplet, identification of different codons, start and stop codon, genetic code table and AA classification,
- The decoding system, necessity of adaptor molecule in translation
- tRNA structure, aminoacyl synthetase mechanism of tRNA charging

10. Protein translation (9 lectures + 3 tutorial)

- Introduction to protein translation apparatus
- Difference between prokaryote and eukaryotic translation initiation
- Cap binding complex, 43S, 48S scanning complex, Kozak consensus sequence and its importance in scanning
- Mechanism of ORF selection, structure-function studies
- Ribonucloproteins involved in translation process, factors involved in and mechanism of elongation cycle, peptidyl transferase reaction,
- Factors involved in and mechanism of translation termination
- Ribosome recycling

- Quality control mechanism in translation: breakage mRNA (tmRNA rescue), nonstop mediated decay, Nonsense mediated decay, antibiotics and toxins useful in translation study.

11. Gene Family and Developmental regulation (2 lectures)

- Evolution of concept of gene, gene families, simple and complex multigene family, gene alteration, gene evolution, regulatory sequences in developmental decisions.

Recommended Books:

1) Molecular Biology of Gene by Watson et.al *Pearson*.

2) Biochemistry, by Voet and Voet.

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Immunology (B305)

Course Title **: Immunology**
Course Code **: B305**
Credits **: 04**
Course Category **: Core**
Course Prerequisite **: Cell Biology, Biochemistry, Animal Physiology, Microbiology, Molecular Biology**
Contact Hours (28/42/56) **: 56**
(including tutorials)

Outcome of the Course:

Understating the basics of the immune system and the immunological processes during infection, tumor progression, inflammation and immunogenic responses of various cases of altered host physiological functions and phenotypes

Course Contents (with both Lectures + Tutorials marked:

1. Overview of the Immune system (3 Lectures + 1 Tutorial)
2. Cells and organs of the immune system (6 Lectures + 2 Tutorials)
3. Innate immunity (3 Lectures + 1 Tutorial)
4. Adaptive immunity (3 Lectures + 1 Tutorial)
5. MHC, Antigen processing & presentation (3 Lectures + 1 Tutorial)
6. Cell mediated Immunity: T cell response and its diversity. (6 Lectures + 2 Tutorials)
7. Humoral Immunity: B cell response and its diversity . (4 Lectures + 2 Tutorials)
8. Cytokines and Chemokines (4 Lectures + 1 Tutorial)
9. Self Non-self immune response (3 Lectures + 1 Tutorial)
10. Altered Immune response and disease pathology: Autoimmunity, Transplantation Immunity, Tumor Immunity, Infection Immunity. (4 Lectures + 2 Tutorials)
11. Translational Immunology: Animal models, Vaccine and Immunotherapy (3 Lectures + 2 Tutorials)

Recommended Books:

Kuby IMMUNOLGY 6th Edition by Richard A. Goldsby, Barbara Anne Osborne, Janis Kuby. Publisher: W.H. Freeman

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor

Evolutionary Biology (B306)

Course Title : **Evolutionary Biology**
Course Code : **B306**
Credits : **4 credits**
Course Category : **Core**
Course Prerequisite : **Introductory Biology, Genetics, Molecular Biology**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcomes of the Course:

- Understanding how life originated on the planet
- Understanding the formation of species and underlying genetic diversity
- Understanding biology from an organismal point of view and why some species evolve slowly while others evolve rapidly
- Understanding systematic relationships between organisms using phylogenetic tools

Course Contents (with both Lectures + Tutorials marked:

1. Introduction to evolutionary Biology	(2 Lectures)
2. Classification, Phylogeny & the tree of life	(2 lectures + 1 Tutorial)
3. Patterns of evolution	(2 lectures + 1 Tutorial)
4. Evolution & fossil record	(2 lectures + 1 Tutorial)
5. History of life on earth	(2 lectures)
6. Geography of evolution	(2 lectures + 1 Tutorial)
7. Evolution of biodiversity	(2 lectures)
8. Genetic variation	(2 lectures + 1 Tutorial)
9. Phenotypic variation	(2 lectures)
10. Genetic drift	(2 lectures + 1 Tutorial)
11. Natural selection and adaptation	(2 lectures)
12. Genetic theory of natural selection	(2 lectures + 1 Tutorial)
13. Evolution of phenotypic traits	(2 lectures)
14. Conflict and cooperation	(2 lectures + 1 Tutorial)
15. Species and speciation	(2 lectures)
16. Reproductive success	(2 lectures + 1 Tutorial)
17. Co-evolution- interactions amongst species	(2 lectures)
18. Evolution of genes and genomics	(2 lectures + 1 Tutorial)
19. Evolution and development	(2 lectures)
20. Macroevolution	(2 lectures + 1 Tutorial)
21. Evolution & society	(2 lectures)
22. Human evolution	(2 lectures + 1 Tutorial)

Recommended Books:
a) "Evolution" by *D. J. Futuyma*.

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor.

4^{th} Year, Semester VII

Developmental Biology (B402)

Course Title : Developmental Biology
Course Code : B402
Credits : 4 Credits
Course Category : Core
Course Prerequisites : Genetics, Cell Biology, Molecular Biology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding the principles governing development of an organism from conception to birth.
- Key concepts in maintenance of growth of an organism and aging.
- Implications in Evolution, Health and disease.

Course Contents:

1. Key concepts and techniques (6 Lectures + 2 Tutorials)
    - Principles and excitements of Developmental biology
    - Developmental events and differential gene expression
    - Developmental Genetics - approaches & techniques
    - Cell fate determination in *C. elegans*

2. Early embryonic development (9 Lectures + 3 Tutorials)
    - Gametogenesis
    - Fertilization
    - Cleavage
    - Gastrulation

3. Axial patterning (9 Lectures + 3 Tutorials)
    - Axis formation in Amphibian
    - Anterior posterior patterning in Amphibians
    - Anterior posterior patterning in Drosophila
    - Homeotic gene regulation
    - Early mammalian development
    - Left right patterning

4. Later embryonic development (9 Lectures + 3 Tutorials)
    - Patterning in Central nervous system
    - Ectoderm
    - Mesoderm
    - Endoderm

5. Post embryonic development (6 Lectures + 2 Tutorials)
    - Sex determination in Drosophila, mammals and other species

- Regeneration
- Aging & Senescence

6. Implications of Developmental Biology (3 Lectures + 1 Tutorial)
   - Medical implications
   - Cancer as a developmental disease
   - Environmental regulation and development
   - Developmental mechanisms and evolutionary change

Recommended Books:

a) “Developmental biology” by *Scott Gilbert*
b) “Principles of Development” by *Lewis Wolpert*

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

<u>Bioinformatics (B403)</u>

Course Title : Bioinformatics
Course Code : B403
Credits : 4 Credits
Course Category : Core
Course Prerequisites : Biochemistry, Molecular Biology, Genetics, Biostatistics
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Application of bioinformatics knowledge in understanding relationships at sequence, structure and network-level.
- Demonstration of popularly used bioinformatics tools for research work
- Help understand the patterns of life and rhythms

Course Contents:

1. Introduction to bio-informatics (2 Lectures)
   - Introduction,
   - History and importance
   - Field and scope

2. Databases and Database searching (2 Lecture + 1 demo)
   - Importance, classification
   - Annotation and File formats
   - Demo : NCBI, SWISS-PROT, PDB

3. Locating Coding regions and Gene prediction (3 Lecture)
   - 6-frame translation,
   - parameters governing prokaryotic and eukaryotic translation,
   - Concept, neural networks and its importance in gene prediction as example

4. Alignments (2 Lectures)
   - Significance and importance, types, classification
   - Dot-plot matrix

5. Substitution Matrices (3 Lectures + tutorial)
   - Significance, types,
   - derivation of BLOSUM and PAM
   - Application of Substitution Matrices

6. Algorithms behind pairwise sequence alignments (6 Lecture + 1 demo + 1 tutorial)
   - Dynamic programming,
   - Smith-Watermann,
   - Needleman-Wunsch,
   - Heuristic, BLAST, FastA
   - applications, statistical parameters governing BLAST results

- Demo : database searching using BLAST

7. Multiple sequence alignments (1 Lecture + 1 demo)
   - Importance, progressive sequence alignment, ClustalW, statistical parameters governing clustalW, applications
   - Demo : ClustalW

8. Phylogenetic tree construction and different approaches (5 Lecture + 1 demo)
   - Introduction, importance, classification and parts of tree,
   - predicting number of root and unrooted trees, orthologs and paralogs, transitions and transversions, susbstitutions matrices,
   - different methods to construct phylogenetic tree,
   - Neighbour-Joining (star decomposition method),
   - Bootstrapping
   - Demo : MEGA software

9. Pattern matching/position specific scoring matrices (1 Lecture + 1 demo)
   - Importance of patterns, motifs, deriving PSSM, sequence logo
   - Demo : Prosite, Pfam

10. Structural Bioinformatics (5 Lecture + 2 demo)
   - Introduction to structural bioinformatics and protein structure, Ramachandrean plot
   - Secondary structure prediction and methods
   - Hydropathy plot, helical wheel, signal peptide prediction, transmembrane prediction,
   - Demo :
   - Tertiary structure prediction : RMSD and Homology modelling
   - Demo : Swiss Model and evaluation
   - Concepts related to Drug design : Lipinski Rule of 5 and Molecular docking

11. Systems Biology (4 Lecture + 1 demo)
   - Introduction, need for computers in system biology
   - High-throughput and *omic* approaches, difference and application
   - Graph theory
   - Gene Ontology
   - Demo: KEGG and gene ontology

Text Books (if any):

a) Introduction to bioinformatics – Arthur M. Lesk
b) Bioinformatics – David Mount
c) Essential bioinformatics – Jin Xiong

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

4th Year, Semester – VIII

Biotechniques (B405)

Course Title : **Biotechniques**
Course Code : **B405**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **NIL**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

Basic principle behind the biophysical, and biochemical experiments. Troubleshoot the experiments, interpretation of results, plotting of graphs, design the experiments.

Course Contents (with both Lectures + Tutorials marked:

1. Techniques use in DNA characterization: Construction of genomic & cDNA library; Agarose gel electrophoresis; Northern blotting; Southern blotting; RFLP; AFLP; microarray. (6 Lectures + 2 Tutorials)
2. Techniques use in DNA manipulations: PCR and its application; Restriction digestion; Ligation; Site directed mutagenesis. (3 Lectures + 1 Tutorial)
3. Enzymes used in genetic engineering experiments: DNA polymerases; Ligase; Reverse transcriptase; Restriction endonucleases and other enzymes. (3 Lectures + 1 Tutorial)
4. Techniques use in protein characterization: SDS-Gel electrophoresis; Western blotting; IEF-2D gel electrophoresis; FRET; Co-Immunoprecipitation; CHIP; Protein-ligand interactions and affinity studies by Surface Plasmon resonance; Density gradient separation. (3 Lectures + 1 Tutorial)
5. Spectrophotometry (UV-Vis, CD, Fluorescence). (3 Lectures + 1 Tutorial)
6. Principles of Centrifugation. (3 Lectures + 1 Tutorial)
7. Uses of radioactive isotopes and autoradiography. (3 Lectures + 1 Tutorial)
8. Biophysical techniques: X-ray crystallography; NMR; ORD. (3 Lectures + 1 Tutorial)
9. Principals of chromatography: Ion exchange; Gel filtration; Affinity; Reverse flow; HPLC (6 Lectures + 2 Tutorial)
10. Immunological techniques: Generation of hybridoma and production of Ab; FACS; ELISA. (3 Lectures + 1 Tutorial)
11. Microscopy (light, Fluorescence, UV, Atomic absorption; Confocal). (3 Lectures + 1 Tutorial)
12. Cell culture and developmental biology techniques (FISH); Genetic crosses in model organism. (3 Lectures + 1 Tutorial)

Text Books (if any):

a) “Immunology Laboratory Manual” by Myers and Richard L

b) “Molecular Cloning” by Sambrook and Russel

c) “Genetic Engineering” by Reece

d) “The tools of Biochemistry” by Terrance G. Cooper

e) “Biophysical Chemistry” by Alan Cooper

f) Wilson and Walker’s Principles and Techniques of Biochemistry and Molecular Biology

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

<u>4th Year, Semester VII</u>

B498 Biology Project Credits-4

<u>4th Year, Semester VIII</u>

B499: Biology Project, Credits-8

<u>5th Year, Semester - XI</u>

B598: Biology Project, Credits – 24

<u>5th Year, Semester - X</u>

B599: Biology Dissertation, Credits –24

Laboratory Courses Integrated-MSc

Revised May 2015

Biology Laboratory (B141)

Course Title : Biology Laboratory
Course Code : B141
Credits : 2 Credits
Course Category : core
Course Prerequisites :
Contact Hours (28/42/56) : 28
(including tutorials)

Outcome of the Course:

- Introduce to students analytical tools/approaches to study biomolecules and cell structure.
- Build basics of experimentation and data recording in biology labs

Course Contents:

1. Diversity of life forms & evolution of body plans using stored specimens and deduction of evolutionary relationship.

2. Preparation of Buffer and titration curve

3. Spectrophotometry: Introduction to Beer-Lambert Law; Demonstration of Beer's law

4. Amino acids: Separation of amino acid and their detection

5. Proteins: Comparison of Bradford assay, Folin-Lowry assay and UV absorption methods for protein estimation

6. Carbohydrates: Benedict's test for reducing sugars

7. Iodine test for polysaccharides

8. Estimation of carbohydrate by Anthrone method

9. Isolation and quantification of DNA by agarose gel electrophoresis

10. Lipids: Separation of lipids by TLC / Paper Chromatography

11. DNA melting/Protein folding

Suggested References:

Relevant resources with updates in knowledge as decided by the Instructor.

Biology Laboratory - II (B142)

Course Title: Biology Laboratory - II
Course Code : B142
Credits : 2 Credits
Course Category : Core
Course Prerequisites: Not applicable
Contact Hours (28/42/56): 28
(including tutorials)

Outcome of the Course:

- Understand a microscope and various staining and microscopic techniques
- Use of microscope to know various stages of cell division in mitosis and meiosis
- Knowledge of the basis of human blood groups (ABO)
- Experimental approaches to study cell growth and differentiation and Gene regulation

Course Contents:

1. Use of microscope [3 lectures]
2. Study of various organelles using staining and microscopic techniques [3 lectures]
[6 lectures + 1 tutorial]
3. Trypan blue exclusion – cell viability assay [3 lectures]
4. Onion root tip as a model to see various stages of cell division [3 lectures]
[6 lectures + 1 tutorial]
5. Cell division: Meiosis [3 lectures]
6. Determination of human blood groups (ABO) Precipitin/Agglutination reaction [3 lectures]
[6 lectures + 1 tutorial]
7. Plant cell growth and differentiation [3 lectures]
8. Gene regulation experiments by using Drosophila mutants [3 lectures]
[6 lectures + 1 tutorial]

Suggested References:

Laboratory hand outs and study material as suggested during the class.

Microbiology Laboratory (B241)

Course Title : Microbiology
Course Code : B201
Credits : 2 Credits
Course Category : Core
Course Prerequisites : None
Contact Hours (28/42/56) : 28
(including tutorials)

Outcome of the Course:

- Culturing of microbes as pure culture, growth disinfection & sterilization.
- Microscopic examination of microbial communities.
- Identification of unknown bacterial cultures
- Antibiotic susceptibility testing.

Course Contents:

1. Culture media preparation, Control of microbial growth disinfection & sterilization.
2. Enrichment and isolation and characterization of pure culture, use of selective and differential media
3. Microscopic examination of fresh culture with different staining procedures
4. Culture dependent analysis of microbial communities
5. Culture independent analysis of microbial communities
6. Identification of genus of unknown bacterial cultures
7. Antibiotic susceptibility testing: (i) Disk diffusion (ii) MIC by tube dilution

Suggested References:

Laboratory hand outs and study material as suggested during the class.

Biochemistry Laboratory (B242)

Course Title : Biochemistry Laboratory
Course Code : B242
Credits : 2 Credits
Course Category : Core
Course Prerequisites : None
Contact Hours (28/42/56) : 28
(including tutorials)

Outcome of the Course:

- Understanding the principles and methodology to isolate, purify, quantitate and separate various biomolecules such as protein, DNA, RNA
- Concept and practical experience about the enzyme kinetics, enzyme activity and effect of temperature and pH

Course Contents:

1. Isolation, Estimation and purification of protein
2. SDS-PAGE
3. Enzyme kinetics (catalase, peroxidase)
4. Isolation of genomic DNA
5. Estimation and quantification of DNA
6. Agarose gel electrophoresis for DNA
7. Isolation of Plasmid DNA
8. Isolation and estimation of RNA
9. Thin layer Chromatography

Recommended Books:

a) Principle and techniques of Biochemistry and Molecular Biology by K. Wilson & J. Walker

b) Introduction to Practical Biochemistry by S. K. Sawhney and Randhir Singh

c) Introduction to Practical Biochemistry by David T. Plummer

Suggested References:

Class notes, handouts and other reading as suggested during the class.

Cell Biology Laboratory (B243)

Course Title	:	Cell Biology Laboratory
Course Code	:	B243
Credits	:	Credits – 2
Course Category	:	Core
Course Prerequisite	:	Successful completion of All 1st year courses B201 (Microbiology), B202 (Biochemistry), B203 (Biophysics and Biostatistics)
Contact Hours (28/42/56) (including tutorials)	:	28

Outcome of the Course:
* Direct exposure to different types of plant and animal cells
* Direct labelling of different cell organelles and visualization.
* Direct exposure to different cell biology related techniques and high-end instruments
* Learning of research methodology and conducting experiments

Course Contents:

1. Staining of haploid and diploid cell nucleus (sperm and mammalian cell)
2. Antibody Staining: Visulatization of Histone, Vimentin, Lamin in mammalian cells
3. Cell splitting and Counting of cells by using haemocytometer (Mammalian cells as model system)
4. Visualisation of Actin and Tubulin cytoskeleton in mammalian cells after stabilization or destabilization of cytoskeleton
5. Visualisation of mitochondria, lysosome and nuclei by Mitotracker Red, Lysotracker Red and DAPI in mammalian cells (with/without treatment with disruptors)
6. Analysis of cell adhesion using mammalian cells (after stabilization or destabilization of cytoskeleton)
7. Analysis of endocytosis and exocytosis in mammalian cells (Using Alexa-labelled Transferrin incorporation assay)
8. Culturing of plant cells and visualization of chloroplast (moss cells as a model system)
9. Image analysis and extracting information from images
10. Visualization of a Fluorescent tagged protein in mammalian cells
11. Visualization of Intracellular Metal concentration fluctuations in real time in Osteoblasts and Osteoclasts

Suggested References:
Class notes, handouts and other reading materials as suggested during the class.

Genetics Laboratory (B244)

Course Title : Genetics Laboratory
Course Code : B244
Credits : 2 Credits
Course Category : Core
Course Prerequisites : Successful completion of 1st year courses
Contact Hours (28/42/56) : 28

Outcome of the Course:

- Understanding the basic principles of inheritance
- Knowledge of basic techniques used in population genetics and cytogenetics

Course Contents:

1. Introduction to a model genetic system: Drosophila and demonstration of laws of inheritance

2. Demonstration of linkage and crossing over through genetic crosses

3. Squash preparation of polytene chromosomes from Drosophila larvae

4. Induction and characterization of insertional mutations in Drosophila

5. Mutation Detection- Sequencing, RFLP, insertion-deletion, VNTR, AFLP

6. Karyotyping of Human chromosomes

7. Banding Techniques

8. Pedigree Analysis

Suggested References:

Laboratory hand outs and study material as suggested during the class.

Plant Physiology Laboratory

Course Title : Plant Physiology Laboratory
Course Code : B342
Credits : 2 Credits
Course Category : Core
Course Prerequisites : Successful completion of 1st year courses
Contact Hours (28/42/56) : 28

Outcome of the Course:

- Train students with tissue culture techniques and plant physiology experiments.
- Aims to bring physiology, biochemistry and molecular biology together.

Course Contents:

1. To study the phenomenon of plasmolysis

2. Measurement of imbibitions

3. Measurement of transpiration by using photometer

4. To compare the rate of photosynthesis under different environmental condition

5. Quantification of pigment content in leaves.

6. Measurement of Chl a fluorescence

7. Isolation and quantification of anthocyanin components in plants.

8. Isolation of chloroplast and observation of absorption spectra

9. Phototropism

10. Genetic control of light signaling: Photoreceptor mutants and Over-expressors

11. Purification of plant nuclei and observation of Phytochrome nuclear complexes in them.

12. Genetic control of Flowering time: mutants in these pathways

Recommended Books:-

a. “Experimental Plant Physiology” by Joseph Arditti and Arnold Dunn

b. “Human Anatomy and Physiology Laboratory Mannual” by Elaine and Blinda

c. Class notes, handouts and other reading materials as suggested during the class.

Molecular Biology Laboratory (B343)

Course Title : Molecular Biology Laboratory
Course Code : B343
Credits : 2 Credits
Course Category : Core
Course Prerequisites : B304 (Molecular Biology)
Contact Hours (28/42/56) : 28

Outcome of the Course:

- Hands on training of techniques used in Molecular biology research
- Understanding the working principles by experimental verification

Course Contents:

1. Preparation of competent cell by $CaCl_2$ method and testing its transformation efficiency. (3 contact hours)
2. Plasmid DNA isolation by alkaline lysis method (3 contact hours)
3. Analysis of DNA gyrase and topoisomerase properties. (2 contact hours)
4. Restriction digestion and cloning of DNA into a given vector. (4 contact hours)
5. To study the importance of the 3` nucleotide of the primer in DNA polymerization (PCR). (2 contact hours)
6. Confirmation of DNA fragment by Southern Hybridization. (8 contact hours)
7. Protein-Protein interaction study by Yeast-two hybridization techniques. (6 contact hours)

Suggested References:

Class notes, handouts and other reading materials as suggested during the class.

Immunology Laboratory (B344)

Course Title : Immunology Laboratory
Course Code : B344
Credits : 02
Course Category : Core
Course Prerequisite : Cell Biology, Animal Physiology, Biochemistry, Microbiology, Molecular Biology, Immunology
Contact Hours (28/42/56) : 28
(including tutorials)

Outcome of the Course: Understating the basic concepts and training of immunological techniques associated to experimentation in the field of immunology

Course Contents:

1. Isolation and characterization of lymphocytes from human blood samples and mouse spleen cells (3 Lectures + 1 Tutorial)

2. Estimation of antigen content by ELISA (3Lectures + 1 Tutorial)
3. Immuno-diffusion (2Lectures + 1 Tutorials)
4. Immuno- fluorescence staining of lymphocytes and cell lines (1Lectures + 1 Tutorial)
5. Flow Cytometric analysis of lymphocytes, cell lines (6Lectures + 2 Tutorials)
6. *In vitro* Immune assay(s) with T cell line, Macrophage cell line and lymphocytes (6Lectures + 2 Tutorials)

Text Books (if any):

Kuby IMMUNOLGY 6th Edition by Richard A. Goldsby, Barbara Anne Osborne, Janis Kuby. Publisher: W.H. Freeman

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor

DETAILED SYLLABUS – ELECTIVE COURSES

Principles of Drug Design (B351)

Course Title : **Principles of Drug Design**
Course Code : **B351**
Credits : **4 Credits**
Course Category : **Elective**
Course Prerequisites : **Biochemistry, Cell Biology, Molecular Biology**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- As an interdisciplinary course, the students will be introduced to the different concepts of drug discovery and development.

Course Contents:

1.	Introduction to the Drug Discovery	(4 Lectures + 2 Tutorials)
2.	Source of Drugs	(5 Lectures + 1 Tutorials)
3.	Drug Development	(5 Lectures + 2 Tutorials)
4.	Development of prodrugs	(2 lectures)
5.	Lead Identification and optimization	(3 Lectures + 1 Tutorials)
6.	Pharmacology of drug action	(5 Lectures + 2 Tutorials)
7.	Identification of target for drug discovery	(5 Lectures + 2 Tutorials)
8.	Approaches towards drug design	(5 Lectures + 2 Tutorials)
9.	Drug interactions	(2 lectures)
10.	Computer-aided drug design	(3 Lectures + 1 Tutorials)
11.	High throughput technologies in drug discovery	(3 Lectures + 1 Tutorials)

Recommended Books:

a. Principles of Drug Action: The Basis of Pharmacology. William B. Pratt, Palmer Taylor.

b. High-Throughput Screening in Drug Discovery (Methods and Principles in Medicinal Chemistry). Jörg Hüser, Raimund Mannhold, Hugo Kubinyi, Gerd Folkers.

c. Drug Design: Structure- and Ligand-Based Approaches. Kenneth M. Merz, Dagmar Ringe, Charles H. Reynolds.

d. Burger′s Medicinal Chemistry, Drug Discovery, and Development: 8 Volume Set.

e. Biopharmaeutics and pharmacokinetics – A treatise. Brahmankar DM and Jaiswal SB.

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Endocrinology (B352)

Course Title : **Endocrinology**
Course Code : **B352**
Credits : **4 Credits**
Course Category : **Elective**
Course Prerequisites : **Animal Physiology (B301)**
Contact Hours (including tutorials) : **56**

Outcome of the Course:

- Understanding the concepts of hormones and endocrine regulation.
- Knowledge about the structure and function of different endocrine glands and evolutionary significance.
- Applying the knowledge of endocrine regulation to analyze disorders associates with hormonal imbalance.

Course Contents:

1. Introduction to endocrine glands, hormones and their classification. (2 lectures)

2. Hormone biochemistry, mechanism of hormone synthesis and their transport to target organs or tissues. (3 lectures + 1 Tutorial)

3. Hormone receptors and mechanism of hormone action, Methods of measurement of hormones. (3 Lectures +1 Tutorial)

4. Hypothalamus; Neuroendocrinology: Neurohormones and Neurotransmitters. (6 lectures +2 tutorial)

5. Structure, function, hormones and clinical disorders of following mammalian endocrine glands. Pituitary, Pineal, Adrenal, Thyroid, Parathyroid, Pancreas, Gonads, Gastro intestinal tract, Thymus (9 lectures + 3 Tutorial)

6. Endocrine control of sexual differentiation (3 lectures + 1 Tutorial).

7. Endocrine control of appetite and feeding. (3 lectures + 1 Tutorial)

8. Calcium homeostasis: role of PTH, Vitamin D and calcitonin. (3 lectures + 1 Tutorial)

9. Growth hormone and Insulin like growth factor (IGF) (3 lectures + 2 Tutorial)

10. Important facts of vertebrate endocrinology. (2 lectures)

11. Invertebrate endocrinology. (2 lectures + 1 Tutorial)

12. Environmental endocrinology: endocrine disrupting chemicals (3 lectures + 1 Tutorial).

Text Books (if any)

a) AM Etgen and DW Pfaff (2009): Molecular Mechanisms of Hormone Action on Behaviour. Academic Press, USA

b) Bentley, PJ (1998): Comparative Vertebrate Endocrinology. Cambridge University Press. 3rd Edition

c) Hall J. (2011). Guyton and Hall: Textbook of Medical Physiology, Saunders Publishers, 12th Edition

e) Larsen P., Kronenberg HM, Melmed S, Polonsky KS, Wilson JD, Foster D. (2002) Williams Test Book of Endocrinology. Saunders Publishers, 10th Edition.

Suggested References:

a) Lechan RM and Fekete C. (2010) Neuroendocrine and Metabolic Adaptations in the Central Nervous System that Facilitate Weight Regain. In: Freemark MS (Ed). Pediatric Obesity: Etiology, Pathogenesis and Treatment, Humana Press 2010. Pp 405-421
b) Relevant research/review articles as decided by the Instructor to update the knowledge in the field.

Plant Developmental Biology (B353)

Course Title : Plant Developmental Biology
Course Code : B353
Credits : 4 Credits
Course Category : Core
Course Prerequisites : B302
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Learning molecular genetics approaches to understand plant development.
- Understanding the interaction of biotic and abiotic component is major focus.
- Designing experimental strategies understanding plant development.

Course Contents:

1. Plant Development overview	(1 Lecture)
2. Hormones influencing plant organogenesis and signaling	(7-8 Lectures + 5 Tutorials)
3. Light and plant development and photomorphogenesis	(10 Lectures + 2 Tutorials)
4. Leaf and flower development	(10 Lectures + 2 Tutorials)
5. Circadian clock and plant development	(7-8 Lectures + 2 Tutorials)
6. Epigenetics, siRNA world and plant development	(8 Lecture + 2 Tutorials)

Recommended Books:

a) Plant Physiology Taiz and Zeiger: 5th Ed, 2010, Sinauer Associates Inc. Publishers

b) Plant Biology by Alison M. Smith et al., 2010, Garland Science, Taylor and Francis Gp.
"Research articles"

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

<u>Neurobiology (B354)</u>

Course Title	**: Neurobiology**
Course Code	**: B354**
Credits	**: 4 Credits**
Course Category	**: Elective**
Course Prerequisites	**: Basic cell biology (B204)**
Contact Hours (including tutorials)	**: 56**

Outcome of the Course:

- Understanding the organization of nervous system, structure and function of neuron and glial cells.
- Knowledge about the ion basis of action potential, synapse, neurotransmitter release, neural circuits, and behavior.
- Leaning the key techniques in neuroscience research, organization and evolution of the brain.
- Analyzing the neural basis of behavior and neurological disorders.

Course Contents:

1. Organization of the nervous system (3 Lectures + 1 Tutorial).

2. Introduction to Neurons, the neuron doctrine, components of neurons, types, organization of a neuron, and functions (3 Lectures + 1 Tutorial).

3. Glial cells: structure and function, types, glial neuronal relationship, importance of astrocytes in glutamate uptake and blood-brain barrier, role of tanycytes in the hypothalamus (4 Lectures + 2 Tutorials)

4. Membrane channels, ionic basis of resting potential and action potential (6 Lectures + 2 Tutorials)

5. Neurotransmitters, neurotransmitter receptors, chemical transmission, electrical synapses (4 Lectures + 1 Tutorial)

6. Autonomic nervous system (6 Lectures + 2 Tutorials).

7. Neurobiology of sensory systems: taste, olfaction, vision, auditory perception (4 Lectures + 1 Tutorial)

8. Neuroanatomy of the hypothalamus and neuroendocrine regulation. Central regulation of feeding, appetite, stress and Circadian rhythms, neurobiology of behavior (6 Lectures + 2 Tutorials)

9. Learning and memory, Neurological disorders, Techniques in neuroscience

(6 Lectures + 2 Tutorials)

Text Books (if any):

a) J Hall (2011): Guyton and Hall: Text book of Medical Physiology, Saunders Publishers, 12th Edition.

b) MJ Zigmond, FE Bloom, SC Landis, JL Roberts, LR Squire. (2008). Fundamental Neuroscience. Academic Press.

c) E Kandel, J Schwartz, T Jessell. (2000). Principles of Neural Science. McGraw Hill.

Suggested References:

Relevant research/review articles as decided by the Instructor to update the knowledge in the field.

Structural Biology B306

Course Title : Structural Biology
Course Code : B355
Credits : 4
Course Category : Core/Elective
Course Prerequisite : Basic Biochemistry
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

Understanding the protein structures in modular approach, correlating the structure to function, and deducing the mechanistic models for the functioning, methods for 3D-structure determination, validation of structures

Course Contents (with both Lectures + Tutorials marked:

Prerequisite: Basic understanding of Biochemistry,

1. Introduction to Structural Biology: Scope and definition of Structural Biology. (3 Lectures + 1 Tutorial)
2. Methodologies: (12 Lectures + 4 Tutorials)
3. Macromolecular Structure: Structure of proteins (including protein folding), nucleic acids; membranes, action of other biologically important molecules and molecular assemblies like ribosomes, nucleosomes; functional significance of structure. (14 Lectures + 5 Tutorials)

4. Conformational analysis: Van der Waals radii of atoms (equilibrium separation between non covalently bonded atoms) – contact distance criteria; Noncovalent forces determining biopolymer structure; dispersion; forces; electrostatic interactions; van der Waals interactions; hydrogen bonds; hydrophobic interactions; distortional energies; description of various interactions by potential functions; principles of minimization of conformational energy.
(13 Lectures + 4 Tutorials)

Text Books (if any):

a) "Proteins: structures and molecular properties" by T.E. Creighton

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Cell Biology (B451)

Course Title	**:**	Advanced Cell Biology
Course Code	**:**	B451
Credits	**:**	Credits – 4
Course Category	**:**	Elective
Course Prerequisite	**:**	Successful completion of All 1st year courses B204 (Cell biology) B201 (Microbiology), B202 (Biochemistry), B203 (Biophysics and Biostatistics)
Contact Hours (28/42/56) (including tutorials)	**:**	56

Outcome of the Course:

* Understanding the basic principles governing cell structure and functions
* Biochemcial, biophysical, genetical basis of cell and its response
* Key concepts in maintenance of cell structure
* Evolution of cell organelles, importance in health and disease.
* Importance of ion channels in health and disease, pharmacology and applications
* Advanced knowledge of details of microscopy
* Bridging the gap between theory and research methodology

Course Contents (with both Lectures + Tutorials marked:

A: **Understanding the cell** (7 Lectures + 2 Tutorials)
1) Various cell types as model systems
2) Different sub-cellular structures and their function
3) Ultra structure of subcellular organelles
4) Others

B)Microscopy as tools for understanding cellular structure function (7 Lectures + 2 Tutorials)
1) Biological sample preparation. Difficulties and advancements
2) Various fluorescence proteins and their applications
3) Other fluorescence probes
4) Autofluorescence and its application
5) Others

C) Principle, uniqueness and application of different microscopes (7 Lectures + 2 Tutorials)
1) Fluorescence microscope
2) Phase contrast microscope,
3) DIC microscope
4) Confocal microscope, Spectral detection
5) Total internal reflection fluorescence microscope (TIRF),
6) Electron microscope,
7) Atomic force microscope,
8) Others

D) Application of microscopes (7 Lectures + 2 Tutorials)
1) Live cell imaging difficulties and advantages
2) FLIM application
3) FRET

4) FRAP
5) Photo-activation
6) Metal imaging
7) Others

E) <u>Understanding cellular dynamics</u> (10 Lectures + 3 Tutorials)

a) Cell division
b) Cytoskeletal reorganization, microtubule and actin cytoskeleton
c) Vesicle trafficking and recycling, endocytosis and exocytosis
d) Nuclear dynamics
e) Efflux and influx of ions and others
e) Others

F) <u>Super resolution</u> (4 Lectures + 1 Tutorials)

a) STED
b) PALM
c) STROM
d) Others

Text Books (if any):
Molecular Biology of the Cell: Alberts, Bruce; Johnson, Alexander; Lewis, Julian; Raff, Martin; Roberts, Keith; Walter, Peter, New York and London: Garland Science

Suggested References:
Important research articles and reviews as suggested in the class by the instructor. Nature cell biology, Journal of cell Biology, Journal of cell Science

Genetic Engineering (B452)

Course Title : **Genetic Engineering**
Course Code : **B452**
Credits : **4 Credits**
Course Category : **Elective**
Course Prerequisites : **Molecular Biology, Cell Biology, Genetics**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Understanding the basic principles of Recombinant DNA technology
- Knowledge of various tools and techniques used in genetic engineering
- Applications in the generation of transgenic models

Course Contents:

1. Growth and maintenance of bacterial cultures, bacteriophages plasmids (1 Lecture + 1 Tutorial)
2. Growth and maintenance of animal cells and viruses (2 Lectures)
3. Mutation, mutagenesis and mutant screening (3 Lectures + 1 Tutorial)
4. Enzymes used in genetic engineering experiments, DNA, polymerases, ligase, reverse transcriptase, restriction endonucleases and other enzymes (3 Lectures + 1 Tutorial)
5. Oligonucleotides synthesis & purification (1 Lecture)
6. Antisense DNA/RNA in genetic engineering (2 Lectures + 1 Tutorial)
7. Radiolabelling of nucleic acids (2 Lectures)
8. Transformation & transfection (1 Lecture + 1 Tutorial)
9. Construction of genomic & cDNA library (3 Lectures + 1 Tutorial)
10. Genomic DNA & cDNA cloning (3 Lectures + 1 Tutorial)
11. Analysis of DNA of cloned genes (3 Lectures + 1 Tutorial)
12. Analysis of protein sequencing products & cloned genes (3 Lectures + 1 Tutorial)
13. Nucleic acid & protein sequencing technology (3 Lectures + 1 Tutorial)
14. Protein nucleic interaction and the methods to study those (3 Lectures + 1 Tutorial)
15. Polymerase Chain Reactions, types of PCRs and analysis of PCR, products; Application of PCRs. (3 Lectures + 1 Tutorial)
16. Site directed mutagenesis (1 Lecture)
17. Recombination, site specific recombination (2 Lectures + 1 Tutorial)
18. Transgenic plants (1 Lecture)
19. Transgenic animals (1 Lecture + 1 Tutorial)
20. Other transgenic life forms (1 Lecture)
21. Ethics and economics of GM crops and GM organisms (2 Lectures + 1 Tutorial)

Recommended Books:-

a) “Genetic Engineering” by Reece

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Biochemistry (B453)

Course Title : Advanced Biochemistry
Course Code : B453
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : Biochemistry
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding the mechanism of protein folding
- In depth knowledge about Post translational modifications of proteins
- Mechanisms and implications of protein turn over in cells

Course contents:

1. Protein secretion	(8 Lectures + 3 Tutorials)
2. Protein folding: In vivo - In vitro	(8 Lectures + 3 Tutorials)
3. Conditional enzyme kinetics	(10 Lectures + 3 Tutorials)
4. Post translational modification	(8 Lectures + 3 Tutorials)
5. Protein degradation	(8 Lectures + 2 Tutorials)

Recommended Books:

a) Lehninger Principles of Biochemistry, Fourth Edition by David L. Nelson and Michael M. Cox

b) "Fundamentals of Biochemistry" *by Voet and Voet*

c) "Biochemistry" *by JM Berg, JL Tymoozko, L Stryer*

Suggested References:

Journals
Annual review of Biochemistry, Trends in Biochemical Sciences, Other suggested Journal.

Advanced Microbiology

Course Title : Advanced Microbiology
Course Code : B454
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : Genetics, Molecular Biology, Immunology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the course:

- Develop understanding of bacterial responses to various stimuli
- Gain insights into bacterial biofilm formation and quorum sensing mechanisms

Course Contents:

1. Molecular microbial genetics (10 Lectures + 4 Tutorials)
2. Molecular medical microbiology: microbial pathogenesis & infectious diseases, study of selected pathogenic organisms with emphasis on recent insights into their mechanism of pathogenesis (10 Lectures + 4 Tutorials)
3. Environmental microbiology (11 Lectures + 4 Tutorials)
4. Microbial interactions: Quorum sensing, Biofilms (11 Lectures + 4 Tutorials)

Recommended Books:

a) Brock's Biology of Microorganisms by Madigan et al.;
b) Fundamental bacterial genetics by Trun & Trumphy;
c) Molecular medical microbiology by Sussman M;
d) Microbiology: diversity, disease and the environment Salyers, AA;
e) Colonization of mucosal surfaces by Nataro JP;
f) Medical microbiology by Murray PR;
g) Environmental microbiology by Maier RM;
h) Environmental microbiology by Varnam, AH;
i) Annual review of microbiology by Gottesman, Susan,
j) Marine microbiology: ecology and applications by Munn, CB

Suggested References:

Journals
Nature Review's Microbiology,
Trends in Microbiology,
Critical Reviews in Microbiology,
PNAS,
Molecular Microbiology,
ASM Journals and others

Enzymology (B455)

Course Title : **Enzymology**
Course Code : **B455**
Credits : **4 Credits**
Course Category : **elective**
Course Prerequisites : **Successful completion of biochemistry course**
Contact Hours (28/42/56) : **56**
(including tutorials)

Outcome of the Course:

- Build comprehension on nature and functioning of enzymes.
- Make students understand kinetics of enzyme mediated reactions and enzyme inhibition kinetics
- Develop basic understanding on enzyme engineering

Course Contents:

1. General properties of enzymes (3 Lectures + 1 Tutorial)
2. Enzyme nomenclature (3 Lectures + 1 Tutorial)
3. Activation energy and reaction coordinates (3 Lectures + 2 Tutorials)
4. Denaturation of Enzyme (3 Lectures + 1 Tutorial)
5. Enzyme purification (4 Lectures + 1 Tutorial)
6. Enzyme kinetics: Michaelis Menten Equation, Line-Weaver Burk plot (4 Lectures + 1 Tutorial)
7. Enzyme catalytic mechanism: Acid-Base catalysis, covalent catalysis, Metal ion catalysis (3 Lectures + 1 Tutorial)
8. Enzymes in food technology (3 Lectures + 1 Tutorial)
9. Immobilization of enzyme, biosensor, Bioreactor (3 Lectures + 1 Tutorial)
10. Structure and function of specific enzymes: Lysozyme, serine protease (3 Lectures + 1 Tutorial)
11. Enzyme inhibition: Competitive inhibition, non-competitive inhibition, uncompetitive inhibition (4 Lectures + 1 Tutorial)
12. Allosteric regulation of enzyme activity: Carbonic anhydrase, Chymotrypsin, ATCase (3 Lectures + 1 Tutorial)
13. Allosteric enzyme inhibition (3 Lectures + 1 Tutorial)

Recommended Books: -

a) “Fundamentals of Biochemistry” *by Voet and Voet*
b) “Biochemistry” *by JM Berg, JL Tymoozko, L Stryer*

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Neurobiology (B456)

Course Title	**: Advanced Neurobiology**
Course Code	**: B456**
Credits	**: 4 Credits**
Course Category	**: Elective**
Course Prerequisites	**: Neurobiology (B354)**
Contact Hours (including tutorials)	**: 56**

Course Outcome:

- Develop understanding about the central nervous system-controlled process and their mechanism of regulation.
- In-depth understanding of the neural circuits and behavior.
- Understand and analyze the recent updates in the field and significance.

Course Contents:

1. Autonomic nervous system and regulation of body functions (6 Lectures + 2 Tutorials)
2. Somatic sensory system and Neurobiology of pain (6 Lectures + 2 Tutorials)
3. Regulation of sleep and wakefulness (3 Lectures + 1 Tutorial)
4. Reproductive brain, sex difference and age-related changes in the brain and neural circuitry (9 Lectures + 3 Tutorials)
5. Neurodegenerative disorders (6 Lectures + 2 Tutorials)
6. Neural basis of learning and memory (3 Lectures + 1 Tutorial)
7. Basal ganglia and the neural control of movement (3 Lectures + 1 Tutorial)
8. Blood supply to the brain and cerebrovascular attack, ventricular system in the brain (3 Lectures + 1 Tutorial)
9. Neuro-immune interaction and nonthyroidal illness syndrome (3 Lectures + 1 Tutorial)

Text book (if any):

a) Zigmond, M.J., Bloom, F.E., Landis, S.C., Roberts, J.L., Squire L.R. (2008) Fundamental Neuroscience. Academic Press.

b) Kandel, E., Schwartz, J., Jessell, T. (2000) Principles of Neural Science. McGraw Hill.

c) Guyton, A. and Hall, J. (2006) Text book of medical physiology. Elsevier

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Chemical Biology (B457)

Course Title : Chemical Biology
Course Code : B457
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : None
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Introducing the concept of chemical biology
- Application of chemistry to advance the study of biological systems
- Understanding biology to do new chemistry?
- How is chemical biology used to advance science and human health?
- Understanding chemical structures of bio-molecules
- Comparative understanding of biosynthesis and laboratory synthesis
- Understanding energetics of biochemical pathways and processes
- Be competent in reading and interpreting primary literature in the areas of chemical biology

Course Contents:

- Introduction: (3 Lectures + 1 Tutorial)
  - Structure
  - Chemistry and the Synthesis of Life
  - Central Dogma
  - What is Chemical Biology?
- Proteins and protein folding (6 Lectures + 3 Tutorials)
  - Describe different strategies for the production and isolation of proteins
  - Experimentally determine the physicochemical and functional properties of proteins including laws of photochemistry
  - Analyse and interpret protein sequences and structures and use such information to predict protein function
  - Protein folding--an overview
- Peptide sequencing (6 Lectures + 3 Tutorials)
  - Peptide sequencing, principles and biological databases
  - Pairwise, motifs and domains
  - Mass spectrometric analysis
- Peptide synthesis (6 Lectures + 3 Tutorials)
  - peptide design, synthesis and execution
- Protein synthesis (6 Lectures + 2 Tutorials)
  - genetic code, amino acids, polypeptides
  - nucleotide sequence and mutations

- Natural product synthesis (6 Lectures + 2 Tutorials)
    - Intro, NRPS & PKS
- Nucleic acids and DNA synthesis (2 Lectures + 1 Tutorial)
    - Oligonucleotide synthesis
    - Bioconjugate synthesis
- Molecular Evolution & Chemical Genetics (2 Lectures + 1 Tutorial)
    - classical genetic and chemical genetic procedures, genotype-based and phenotype-based genetic methods
    - explain and contrast how gene expression is controlled by both proteins and small molecules, including regulatory RNA molecules
    - biology and chemistry of RNA
- Protein-protein interactions & proteomics (2 Lectures + 1 Tutorial)
    - introduction, databases
    - principles, methodologies and applications of proteomics and synthetic biology

Suggested reading:

- Blackburn, G.M. & Gait, M.J. Nucleic Acids in Chemistry and Biology. Oxford (1996)
- Branden, C. & Tooze, J. Introduction to Protein Structure.
- Garland (1999) Creighton, T.E. Proteins: Structures and Molecular Properties.
- Freeman (1993) Fersht, A. Structure and Mechanism in Protein Science. Freeman (1999)
- Miller and Tanner (2008). Essentials of Chemical Biology, Wiley

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Virology (B460)

Course Title : Virology
Course Code : B460
Credits : 4 Credits
Course Category : elective
Course Prerequisites :
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

At completion of the course, student is expected to

- comprehend structural organization, and different biological processes of viruses
- Develop basic knowledge of biology and pathological manifestation of few important human and animal viral pathogens
- Develop comprehension of tools and approaches to study viral biology.

Course Contents:

1. Scope and outline of the course, history and introduction to virology (1 lecture)
2. Virus structure and classification: viral genome, capsid and envelope; different classification schemes and ICTV database (4 lectures +1 tutorial)
3. Techniques in virology (2 lectures +1 tutorial)
4. Viral biology: entry to egress (4 lectures +1 tutorial)
5. Virus-host interactions: cell receptors for viral entry, host proteins for replication, translation and processing of viral proteins (3 lectures +1 tutorial)
6. Host cell response to virus infection (2 lectures +1 tutorial)
7. Pathogenesis of viral infection and epidemiology (2 lectures)
8. Cell transformation by viruses (2 lectures +1 tutorial)
9. Vaccines and antiviral drugs (2 lectures +1 tutorial)
10. Use of viruses in gene delivery, molecular biology & as oncolytic agents (2 lectures)
11. Plant viruses and important plant pathogens of relevance to India (1 lecture +1 tutorial)
12. Bacteriophages and insect viruses (2 lectures +1 tutorial)
13. Specific virus families of importance: (13 lectures + 5 tutorials)
    i. Orthomyxoviridae (Influenza virus)
    ii. Paramyxoviridae (Measles, Mumps, New Castle disease viruses and Respiratory syncytial virus)
    iii. Togaviridae/Alphavirus genus (Chikungunya virus)
    iv. Flaviviridae (Dengue, Japanese encephalitis, Tickborne encephalitis, West Nile and Hepatitis C viruses)
    v. Coronaviridae (SARS virus)
    vi. Retroviridae (HIV)
    vii. Papillomaviridae (Human Papilloma viruses)
    viii. Reoviridae (Rotavirus)
    ix. Picornoviridae (common cold and Polio viruses)
    x. Herpesviridae (Herpes Simplex, Chickenpox, Kaposi’s sarcoma and Epstein-Barr viruses)
14. Emerging viruses: SARS, Chikungunya, Dengue, Hendra and Nipah viruses and Crimean-Congo hemorrhagic fever virus (2 lectures)

Reference books:

1. Basic Virology, 3rd edition by Edward K. Wagner, Martinez J. Hewlett, David C. Bloom, David Camerini. Year: 2007; Publisher: Wiley-Blackwell. ISBN: 978-1-4051-4715-6

2. Principles of virology, 3rd edition (vol.1) by S. Jane Flint, Lynn W. Enquist, Vincent R. Racaniello and Anna Marie Skalka. Year: 2008; Publisher:ASM press.ISBN: 978-1-55581-443-4

3. Virology: Molecular Biology and Pathogenesis by Leonard Norkin. Year: 2010; Publisher: ASM press. ISBN: 978-1-55581-453-3

4. Fields Virology, 5th edition. Edited by David. M. Knipe and Peter M. Howley. Year: 2007;Publisher: Lippincott Williams & Wilkins. ISBN/ISSN: 9780781760607

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

Advanced Molecular Biology (B551)

Course Title : Advanced Molecular Biology
Course Code : B551
Credits : 4 Credits
Course Category : Core
Course Prerequisites : B304 (Molecular biology) B205 (Genetics)
Contact Hours (28/42/56) : 56
Outcome of the Course:

Understand the recent advancements in molecular biology, structure-function analysis and regulation. Reading research articles, designing experiment and data analysis.

Course Contents:

1. Signaling pathways and regulation (8 Lectures + 2 Tutorials)

- Translation initiation, translation control in metabolic
- Genetic disorders and development.

2. Importance of cis regulatory elements (8 Lectures + 2 Tutorials)

- mRNA, CAP, 5'UTR, 3'UTR Poly A tail
- IRES structure and function
- trans-acting factors in protein expression, examples of Iron homeostasis.

3. General amino acid control mechanism, translation in developmental decision, GAIT mediated translational silencing, translation silencing by microRNA. (6 Lectures + 2 Tutorials)

4. Yeast mating type switch: Mating type locus, experimental evidence for cis regulatory elements, experimental evidence for transacting factors in mating type switch, donor preference, recombinant enhancers. (7 Lectures + 2 Tutorials)

5. Long term evolution experiment: Evolution of Cit+ function, potentitation of Cit+ function, actualization of Cit+ function, refinement of Cit+ function and molecular mechanism. (5 Lectures + 1Tutorials)

6. Molecular mechanism of PRK action and host-virus evolution. Role of dimerization domain, kinase domain activation independent of dimerization domain, substrate recognition motif, evolutionary pressure on PRK and pox virus pseudosubstrate. (5 Lectures + 1 Tutorials)

7. How do new protein arise: Minimal sequence code for switching protein structure-function, domain rearrangement give rise to new function, horizontal gene transfer between the genome, intergenic region as a potential site for new gene, gene duplication and refinement of its function. (5 Lectures + 1 Tutorials)

Recommended Books:

a) "Molecular Cell Biology" 6th Edition By Lodish
b) "Gene X" By Lewin

c) “Translational Control in Biology and Medicine” By Michael B. Mathews, Nahum Sonenberg, John W.B. Hershey. CSH press
d) “Prokaryotic Gene Expression (Frontiers in Molecular Biology)” Oxford University Press, USA; First edition (July 29, 1999)
e) Class notes and research articles.

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

<u>**Advanced Immunology**</u>

Course Title : Advanced Immunology
Course Code : B552
Credits : 04
Course Category : Elective
Course Prerequisite : Cell Biology, Animal Physiology, Biochemistry, Microbiology, Molecular Biology, Immunology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

Understating the current concepts of immunological processes associated to infection immunity, tumor immunity, autoimmunity and other immuno-regulatory states of altered host immune system.

Prerequisite: Basic understanding of cell biology, animal physiology, molecular biology, biochemistry, microbiology, immunology

Course Contents:

1. Basics of Immune system: Cells and organs of Immune system; Innate and Adaptive Immune Response (5 Lectures + 1 Tutorial)

2. Humoral and Cell Mediated immune response (6 Lectures + 2 Tutorials)

3. MHC and Antigen presentation (6 Lectures + 2 Tutorials)

4. Cellular interaction in immune system (6 Lectures + 3 Tutorials)

5. Signal transduction in immune system (4 Lectures + 2 Tutorials)

6. Cooperation of Innate and Adaptive immunity (6 Lectures + 2 Tutorials)

7. Immune-regulation (6 Lectures + 2 Tutorials)

8. Translational Immunology: Immuno-therapy and Vaccine strategy for Infection Immunity, Cancer Immunity and regulation of Autoimmunity. (3 Lectures + 2 Tutorials)

Text Books (if any):

a) Kuby IMMUNOLGY 6th Edition by Richard A. Goldsby, Barbara Anne Osborne, Janis Kuby. Publisher: W.H. Freeman

b) Cellular and Molecular Immunology by Abul K. Abbas, Andrew H. Lichtman, Shiv Pillai. Publisher: Saunders/Elsevier

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor

Infectious Disease Biology (B553)

Course Title : Infectious Disease Biology
Course Code : B553
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : Basic courses in cell biology, immunology and microbiology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Develop understanding infection process, infection epidemiology, host-pathogen interactions and evolution of pathogens

Course Contents:

1. Introductory lectures to IDB – (4 classes + 1 tutorial)
What is infection, what is disease, Microbes Causing Infectious Diseases- bacteria, viruses, fungi, protozoa, helminthes, prions. Present scenario of IDs worldwide. (General lectures based on journals)

2. Host pathogen interactions (6 classes, 2 tutorials)
Host-pathogen relationship, Toxins, Disease establishment, Disease transmission- zoonotic, nosocomial , epidemiology, Molecular Aspects of Host-Pathogen Interactions, Effect of nutrition on infectious diseases, Viruses and cancer

3. Host defense & Immunopathology (5 classes, 2 tutorials)
Microbial Flora of the Healthy Human Host, Natural Resistance and Nonspecific Defense Mechanisms, Basic and Theoretical Aspects of the Immune Response

4. Evolutionary Biology of Infectious Diseases- (6 classes + 2 tutorials)
Emerging, Reemerging and Deliberately introduced infectious diseases, Factors that Contribute to the Emergence of a New Pathogens- role of evolution, ecology, genetics- HGT or LGT, clustered, regularly interspaced, short palindromic repeats (CRISPER), some EIDs and REIDs- malaria, Tb,influenza (SWINE flu), SARS, chikunguniya, HIV, west nile virus, marburg virus, bioterrorism, anthrax, CJD.

5. Bacterial infections- (5 classes, 1 tutorial)
This willfocus on the major bacterial infections. The infections can be considered in groups related to the body systems infected.

6. Viral infections- (5 classes, 2 tutorials)
Molecular biology of the different types of virus, the different strategies that are involved in their replication and the ways in which they cause disease. Consideration is given to the prevention, treatment and control of virus infections.

7. Parasitic infections- (5 classes, 1 tutorial)
Biology of parasites and the ways that they can cause disease. The organisms responsible for the major parasitic diseases will provide the main focus for instruction as they have also been the main focus for research.

8. Molecular Epidemiology and control of infectious diseases (6 classes, 2 tutorials)

Topics include analytic methods, study design, outbreak investigations, surveillance, vaccine development and evaluations, screening, modeling, and infectious causes of cancer or chronic diseases. Background on important infectious diseases will be presented.

Recommended Books:

a) Alcamo's fundamentals of Microbiology by Jeffrey C. Pommerville,
b) General Microbiology by Roger E Stanier et al.,
c) Brock Biology of Microorganisms by Michael T Madigan
d) General Microbiology by Roger Y Stanier et al.
e) Microbiology 5th ed, Michael Z Pelczar Jr.

Suggested References:

Relevant Journals

Cancer Biology (B554)

Course Title : Cancer Biology
Course Code : B554
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : Cell Biology, Biochemistry, Molecular Biology, Immunology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Understanding basic molecular and cellular mechanisms of carcinogenesis.
- Integrating knowledge to understand therapeutic approaches.
- Stimulate research interest.

Course Contents:

1. Cancer origin and terminology (3 lectures + 1 tutorial)
   - Molecular and cellular origin of cancer
   - Clonal vs. mutational origin of cancer
   - Stem cells and cancer

2. Different classes of cancers (3 lectures + 1 tutorial)
   - Carcinoma, Sarcoma
   - Leukemia, Lymphoma and myeloma
   - Central nervous system cancers

3. Malignant transformation of cells (6 lectures + 2 tutorials)

   - General causes of cancer, mechanisms
   - Characteristics and phenotypes of cancer cells
   - Process of metastasis and its significance

4. Cancer induction and oncogenes (6 lectures + 2 tutorials)

   - Stages in the development of tumorigenesis: initiation and promotion
   - Tumor-suppressor genes and oncogenes and their differences
   - The connection between oncogenes and proto-oncogenes
   - Cancer stem cells

5. Cellular response to Tumors (6 lectures + 2 tutorials)

   - Signal transductions in cancer, G protein coupled-receptors and secondary messengers
   - Receptor tyrosine kinases and SH2-containing proteins
   - Ras protein and the MAP kinase cascade in the control of cell function and aberrations in cancer
   - Convergence, divergence and crosstalk among different signaling pathways
   - Concept of apoptosis and its role in cancer

6. Tumor Antigens and tumor immunity (6 lectures + 2 tutorials)

- Tumor-specific transplantation antigens (TSTAs) and tumor-associated transplantation antigens (TATAs)
- Tumor induced altered Immune response and immune-suppression.

7. Tumor Evasion mechanism (6 lectures + 2 tutorials)

- Changes in tumor cells
- Alteration in antigen presenting cells
- Dysfunction of host effector cells

8. Cancer Therapy (6 lectures + 2 tutorials)

- Chemotherapy
- Radiation therapy
- Surgery
- Cancer immuno-therapy
- Other treatment methods including targeted therapy

Text Books (if any):

1. “Molecular Biology of the Cell” by Alberts, Bruce; Johnson, Alexander; Lewis, Julian; Raff, Martin; Roberts, Keith; Walter, Peter
2. “Molecular Cell Biology” by Lodish, Harvey; Berk, Arnold; Zipursky, S. Lawrence; Matsudaira, Paul; Baltimore, David; Darnell, James E
3. “The Biology of Cancer” by Weinberg, Robert A

Suggested References:

Relevant articles from cancer journals.

Advanced Genetics (B555)

Course Title : Advanced Genetics
Course Code : B555
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : Genetics, Cell Biology, Molecular Biology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Integrating knowledge of Basic genetics, molecular biology and genomics to understand advances in the field of Genetics.
- Stimulate research interest.

Course Contents:

1. Overview of Genetics and terminology (3 lectures + 1 tutorial)

2. Human Genome- Structure, mapping and sequencing (6 lectures + 2 tutorials)

3. Advanced Principles of Inheritance: Genetic variation and heterogeneity, Gene interaction, Polygenic inheritance, Penetrance and expressivity, Epigenetic Inheritance, Genetic Imprinting, Cytoplasmic Inheritance and Maternal Effects (9 lectures + 2 tutorials)

4. Gene Discovery approaches using Model Organisms: Mutant screens and selections, Tools for testing gene function, Mutagenesis and Transgenics (9 lectures + 3 tutorials)

5. Molecular diagnosis of human diseases: Cytogenetics and Molecular cytogenetics, Molecular genetics (6 lectures + 2 tutorials)

6. Identification of genetic component of diseases: Molecular basis of human diseases, Identifying genes for Mendelian traits, Linkage disequilibrium and haplotype analysis, Identifying genes for complex traits (6 lectures + 3 tutorials)

7. Gene therapy (3 lectures + 1 Tutorial)

Text Books (if any):
a)*Concepts of Genetics* (8th Edition) By William S. *Klug*, Michael R. *Cummings*Publisher: Prentice Hall
b)*Human Molecular Genetics* (2nd edition) by Peter Sudbery, published by Pearson/Prentice Hall
c)*Human Genetics* (2nd edition) by A. Gardener and T. Davies Publisher: Scion

Suggested References:
Human Genetics, Clinical Genetics, Nature Genetics, Nature Reviews Genetics

Immune regulation and Infection immunity (B556)

Course Title : Immune Regulation and Infection Immunity
Course Code : B556
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : Cell Biology, Microbiology, Biochemistry, Molecular Biology, Immunology
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Comprehensive understanding on Immune regulation, immune deviation in bacterial, viral and parasitic infections
- Insights in to Translational aspects of Immunology such as vaccines, immunomodulatory agents in infectious as well as autoimmune diseases

Course Contents:

1. Introduction to Infectious Diseases and its worldwide scenario. (3 Lectures + 1 Tutorial)
2. Overview of Host cell immune response (3 Lectures + 1 Tutorial)
3. Outline of immuno- regulatory response and its role in infectious diseases (6 Lectures + 2 Tutorials)
4. Immuno-regulatory response to viral infection (6 Lectures + 2 Tutorials)
5. Immuno-regulatory response to bacterial infection (6 Lectures + 2 Tutorial)
6. Immuno-regulatory response to protozoan infection (6 Lectures + 2 Tutorial)
7. Immuno-regulatory response to helminth infection (6 Lectures + 2 Tutorial)
8. Immuno-therapeutic strategies targeting immuno-regulatory cells in Infectious diseases (6 Lectures + 2 Tutorials)

Suggested Books:

a) Kuby Immunology. Thomas J. Kindt, Richard A. Goldsby, Barbara Anne Osborne, Janis Kuby. W.H. Freeman, 2007
b) Infection and Immunity. Huw Davies, D. H. Davies. Taylor & Francis, 1999

Suggested Journals:

Infection Immunity, Journal of Experimental Medicine, Journal of Infectious Diseases, Immunology Immunotherapy, Nature Medicine, Nature Immunology, Journal of Immunology, Immunity, etc.

Quantitative Biology (B558)

Course Title : Quantitative Biology
Course Code : B558
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : None
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

- Introducing the concepts of mathematics in biology
- Understanding the quantitative aspects of biology
- How is statistics and mathematics required and applied in the field of biology
- Understanding how mathematical models of biology are developed
- Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of quantitative biology
- Understanding quantitative biology to do new and more insightful biology

Course Contents:

1. Recent Trends in Biology and Health Research (3 Lectures + 1 Tutorial)
    a. Modern tools of health research
    b. Existing and emerging health and biological problems
2. Modern Biotechnology (6 Lectures + 2 Tutorials)
    a. Recombinant technology and genetic engineering
    b. Application of biotechnology
3. Integrative and Systems Biology (10 Lectures + 2Tutorials)
    a. Comparative understanding of systems and integrative biology
    b. Concepts and high-throughput techniques of systems Biology
    c. Application of and advances in systems biology
4. Quantitative and Non-linear Biology (10 Lectures + 2Tutorials)
    a. Mathematical modelling and applications in Biology
    b. Lotka-Volterra Model
    c. B-Z reaction, population genetics
5. Statistics-Introduction (3 Lectures + 1 Tutorial)
    a. Simple and effect statistics
    b. Correlation and distribution
6. Univariate Analysis (6 Lectures + 2 Tutorials)
    a. Parametric and non-parametric analysis

    b. t-test, ANOVA, MANOVA

7. Multivariate Analysis (4 Lectures + 2 Tutorials)
    a. Classification and grouping
    b. Clustering, PCA, LDA, DCA
8. Sample size and power of calculation (3 Lectures + 1 Tutorial)

Recommended Books:-

a) Class notes, handouts

b) Systems Biology: A Textbook, Edda Klipp (Author), Wolfram Liebermeister (Author), Christoph Wierling (Author), Axel Kowald (Author), Hans Lehrach (Author), Ralf Herwig (Author)

c) Systems Biology: Properties of Reconstructed Networks by Bernhard O. Palsson, University of California, San Diego; ISBN: 9780521859035; DOI: 10.2277/0521859034

d) Statistics at the Bench: A Step-by-Step Handbook for Biologists by Martina Bremer

e) Nonlinear dynamics and chaos:with applications to physics, biology, chemistry, and engineering; Steven Henry Strogatz

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor

Macromolecular Crystallography (B557)

Course Title : Macromolecular Crystallography
Course Code : B557
Credits : 4
Course Category : Core/Elective
Course Prerequisite : Biochemistry
Contact Hours (28/42/56) : 56
(including tutorials)

Outcome of the Course:

Understand theory behind the X-ray diffraction to structure determination. Data collection strategy, processing, interpretation of data statistics, structure solution methods, refinement methods, interpretation of electron density map.

Course Contents (with both Lectures + Tutorials marked:

Introduction to X-ray crystallography, highlights from 54 years of macromolecular crystallography, future directions [1]

Basics of crystals, symmetry and crystal growth: Crystals, Crystal Systems, Crystal Lattice, Symmetry Elements, Point groups, Space groups, Unit cells, asymmetric units, Matrix representation of Symmetry, physical and energetic principles, Strategies and approaches for growing crystals (protein, DNA) [4 lectures + 2 tutorial]

X-ray sources and detectors: Sealed Tube, Rotating Anode, Synchrotron, Point detector, Area detectors, [3 lectures + 1 tutorial]

Theory of X-ray diffraction: Scattering by an Atom, Diffraction from a Crystal: one dimensional, two-dimensional, and three-dimensional array of atoms, Structure Factor, Reciprocal Lattice, Bragg's law, Ewald Sphere, Resolution [6 lectures + tutorial 2]

Theory of Structure factor, Fourier Syntheses and Electron density: The structure factor in exponential, and vector forms, Temperature factor, Fourier series, Fourier transform, Fourier synthesis, electron density equation, Fridel's law, Anomalous scattering [6 lectures + 2 tutorial]

Data collection: Rotation and oscillation theory, Diffractometer theory, Goniometer, Data collection Strategy, Partial and fully recorded reflections, Wide and fine slicing, Blind region, Total range of data collection, interpretation of diffraction images, Cryo data, Single/Multiple wavelength anomalous dispersion data collection [6, lectures + 2 tutorial]

Data Indexing, integration, scaling (Data reduction), and statistics: Indexing,Integration, Theory of Lorentz and Polarization corrections, Scaling, R-factors, I/sigma (I), completeness, X-ray data quality indicators, Space Group determination [6, lectures + 2 tutorial]

Electron density maps, Refinement and Model building: Difference Fourier map, locating heavy atoms, and anomalous scatter, locating water, ligand molecules, Refinement at atomic resolution: Refinement by Fourier syntheses, Series termination, Locating Hydrogen atoms, Optimization methods, Least-square refinement, full matrix solution, Maximum likelihood, Target function for refinement, Bulk solvent, A prior knowledge, Restrains and Constrains, Non-crystallographic symmetry, Cross-validation, R-factors (Rwork & Rfree) Density modification, Good practice for refinement [10 lectures + 4 tutorial]

Text Books (if any):

X-ray structure determination, a practical guide edited by G. H. Stout and L. H. Jensen ISBN-10: 0471607118

Internal tables for crystallography Vol. F Crystallography of biological macromolecules

Internal tables for crystallography Vol. A Space Group Symmetry

Crystallization of Biological Macromolecules by Alexander MacPherson ISBN-13: 978-0879695279

An introduction to X-ray Crystallography M.M. Woolfson

Biomolecular Crystallography by Bernard Rupp ISBN-13: 978-0815340812

Internal tables for crystallography Vol. F Crystallography of biological macromolecules

Original research articles and reviews for each topic will be provided in the classes

Fundamentals of crystallography” by Giacovazzo,

Suggested References:

Relevant research articles with updates in knowledge as decided by the Instructor.

<u>Ion Channels (B559)</u>

Course Title	**:**	Ion channels
Course Code	**:**	B559
Credits	**:**	Credits – 4
Course Category	**:**	Elective
Course Prerequisite	**:**	Successful completion of All 1st year courses B202 (Biochemistry), B203 (Biophysics and Biostatistics) B204 (Cell biology) B354 (Neurobiology)
Contact Hours (28/42/56) (including tutorials)	**:**	56

Outcome of the Course:
* Understanding the principles governing ion channel functions
* Biochemcial, biophysical, genetical basis of ion channel and its response
* Key concepts in maintenance of ion channel structure, function and ionic homeostasis of the cell
* Importance of ion channels in health and disease, pharmacology and applications
* Advanced knowledge of details of microscopy
* Bridging the gap between theory and research methodology

Course Contents (with both Lectures + Tutorials marked:

1. Introduction to different ion channels (3 Lectures +1 Tutorial)
(Difference between ion channels with pumps and carriers, ion channels in prokaryotes, Fungus, animal and plant systems, selective and non-selective ion channels)

2. Expression of different ion channels in different systems. (3 Lectures +1 Tutorial)
(Why channel expression are specific in certain tissues, Examples: neurons, sperm, bones, keratinocytes, immune cells, retina, pancreas, cardiac muscle, other specific tissues, Pharmacological advantages/disadvantages of expression, useful systems to study ion channels)

3. Importance of ion channels in evolution (3 Lectures +1 Tutorial)
(Evolution of different structural parts such as transmembrane regions, cytosolic domains, loop regions, ligand binding regions, voltage-sensor regions, selection pressure on the ion channels, ion channels and toxins: Pray predator relationship, ion channels and environmental cues, ion channels in reproduction)

4. Structural and functional uniqueness of ion channels (6 Lectures +2 Tutorials)
(Q10 values, thermodynamic properties behind channel opening and closing, conformational changes, ionic filter, voltage gating, ligand gating, voltage sensor, examples of high-resolution ion channel structures)

5. Organization in membranous environment, effect of lipid bilayer and specific lipids on ionic functions (3 Lectures +1 Tutorial)
(Need of specific lipid microenvironments for proper channel functions)

6. Different types of ion channels (6 Lectures +2 Tutorials)

(Different anion and cation channels, basics of Na+, K+, Cl-, Ca^{2+}, transport of other heavy metals)

7. Heteromeric and homomeric ion channels (3 Lectures +1 Tutorials)
(Organization of different polypeptides)

8. How natural and synthetic activators and inhibitors modulate ion channels. (3 Lectures + 1 Tutorials)
(Importance of different metabolites, Chemistry and pharmacology of different activators and inhibitors, effect on metabolism)

9. Measuring ionic conductivity by electrophysiology and imaging (3 Lectures + 1 Tutorial)
(Electrophysiological parameters and methods to analyze channel function, different types of channel recording, Cell biological parameters and methods to analyze channel function, metal imaging and different sensors)

10. Trafficking of ion channels (3 Lectures + 1 Tutorial)
(Different modes of trafficking of ion channels to ER to Golgi, Golgi to plasma membrane, to Lysosomes, Other organelles, prerequisites for such trafficking)

11. Channelopathy and human diseases, potential remedy (6 Lectures + 2 Tutorials)
(Genetic variations in ion channel sequences, information from recent genome sequencing data sets, penetrance effect of mutations)

Text Books (if any): Principles of biochemistry, Channels journal, other journals, distributed hand outs, notes, specific reviews and papers.

Suggested References: Important research articles and reviews as suggested in the class by the instructor

Concepts in Mechanobiology (B561)

Course Title : Concepts in Mechanobiology
Course Code : B561
Credits : 4 Credits
Course Category : Elective
Course Prerequisites : None
Contact Hours (28/42/56): 56
(including tutorials)

Outcome of the Course:

- Comprehend the concept that cells are complex micron-sized machines/ nano-machines.
- Understanding of the mechanical behavior of cell and tissues and the biological responses of these biological systems to mechanical stimuli.
- Gain knowledge on how cells generate and sustain mechanical forces within their environment, as part of their normal physiology.
- Ability to visualize that cells are active materials that can detect mechanical stimulation by the activation of mechanosensitive signaling pathways, and respond to physical cues through cytoskeletal re-organization and force generation
- Competence in reading and interpretation of primary literature in the area of mechanobiology and address research questions relating to cell processes using mechanobiological approaches.
- Enable students of disciplines other than biology to understand how principles of mechanics and engineering can be applied to biological systems and problems.

Course Contents:

Curriculum: (3 lectures [L] + 1 tutorial [T] per week)

Introduction
1. Mechanical framework for understanding biological systems
2. Cell mechanics in basic cellular and pathological processes.

[1 lecture]

Cell architecture
2. Cytoskeletal structure and dynamics

[2 lectures]

Cell mechanics
Basics of Mechanics
Viscoelasticity / basic rheology

[3 lectures + 1 tutorial]

3. Mechanics of cell membrane
4. Mechanics of cellular polymers
5. Controlling Cell and nuclear Morphology

[3 lectures + 1 tutorial]

6. Polymers Networks
7. Molecular motors
8. Tensegrity

[3 lectures + 1 tutorial]

9. Foams

10. Soft Glassy Material
11. Biphasic models of cells

[3 lectures + 1 tutorial]

[Total = 12 lectures + 4 tutorials]

Mechanosensing and Mechanotransduction
12. Mechanical Signals
13. Mechanosensing organelles and structures

[3 lectures + 1 tutorial]

14. Mechanics of receptor binding
15. Intracellular signaling
16. Mechano-chemical coupling

[3 lectures + 1 tutorial]

17. Cellular interactions with biomaterials
18. Mechanical regulation of cell fate

[3 lectures + 1 tutorial]
[Total = 9 lectures + 3 tutorials]

Mechanics of cell proliferation
19. Cytokinesis

[2 lectures]

20. Cancer cells and stem cells

[2 lectures]

21. Apoptosis

[2 lectures]
[Total = 6 lectures + 2 tutorials]

Mechanics of cell adhesion & migration
22. Adhesion proteins
23. Cytoskeletal structures & Forces

[3 lectures + 1 tutorial]

24. Molecular motors
25. Extracellular matrix mechanics

Mechanobiology in tissue engineering - Biomimetics and Cell-like Materials

[3 lectures + 1 tutorial]
[Total = 6 lectures + 2 tutorials]

Mechanical testing of cells
26. instrumentation tools used for mechanical characterization of cells – Microneedles, Micropipette Aspiration, Atomic Force Microscopy, Microrheology, Magnetic Twisting Cytometry, Optical Tweezers, Traction Force Microscopy, Nanofabrication – introduce to MEMS tools, Microfluidics & Lab-on-chip concepts.

[Total = 6 lectures + 2 tutorials]

Recommended Books:

1. Jacobs, Huang, & Kwon. Introduction to Cell Mechanics and Mechanobiology. Garland Science, ISBN-10: 0815344252
2. Boal, Mechanics of the Cell. Cambridge University Press, ISBN-10: 0521796814; ISBN-13: 9780521130691
3. Ethier and Simmons, Introduction to Biomechanics: From Cells to Organisms. Cambridge University Press, ISBN: 0521841127
4. Mofrad & Kamm, Cytoskeletal Mechanics – Models and Measurements. Cambridge University Press, ISBN-10: 0521846374

5. Bray, Cell Movements. Garland Science, ISBN-10: 0815332823; ISBN-13: 9780815332824
6. Alberts et al., Molecular Biology of the Cell. Garland Science, ISBN-10: 0815332181
7. Discher and Wang, Methods in Cell Biology 83: Cell Mechanics. Academic Press. ISBN-10: 0123705002
8. Philip Nelson, Biological Physics, Energy, Information, Life. W.H. Freeman, ISBN-10: 0716798972; ISBN-13: 978-0716798972
9. Jonathon Howard, Mechanics of Motor Proteins and the Cytoskeleton. Sinauer Associates Inc. ISBN-10: 0878933344; ISBN-13: 978-0878933341
10. D'Arcy Wentworth Thompson, On Growth and Form. Dover Publications Inc. ISBN-10: 0486671356; ISBN-13: 978-0486671352
11. Gabor Forgacs, Stuart A. Newman, Biological Physics of the Developing Embryo. Cambridge University Press, ISBN-10: 0521783372; ISBN-13: 978-0521783378

Suggested References:

Other relevant research articles and lecture material will be made available by the instructor during the course from time to time.

Molecular errors in disease pathogenesis (B562)

Course Title : **Molecular errors in disease pathogenesis**
Course Code : **B562**
Credits : **4 Credits**
Course Category : **Elective**
Course Prerequisites : **Basic knowledge of Biochemistry, Genetics, Molecular Biology and Cell biology. Having taken some of the biology core courses of SBS will be advantageous**
Contact Hours (28/42/56) : **56 (including tutorials)**

Outcome of the Course:

- Understanding the concepts of molecular pathogenesis.
- Basic understanding of the common pathologies of organ systems.
- Understanding of the recent advances in molecular explanation for such pathologies.

Course Contents:

1. General introduction to concepts of molecular pathogenesis (3 Lectures + 1 Tutorial)

2. Cardiovascular system (6 Lectures + 2 Tutorials)
   - Heart failure
   - Genetic cardiac diseases
   - Cholesterol metabolism and vascular diseases
   - Sudden cardiac death
   - Gender and cardiovascular system diseases

3. Respiratory system (3 Lectures + 1 Tutorial)
   - Novel pathways in pathogenesis of asthma
   - Cell signalling in asthma
   - Chronic Obstructive Pulmonary Disease
   - Lung matrix remodelling disorders

4. Infectious diseases (3 Lectures + 1 Tutorial)
   - Anti-malarial resistance
   - General vaccine strategies
   - Vaccine development against malaria
   - HIV, SARS, Dengue pathogenesis
   - Biofilms and chronic bacterial infections
   - Quorum sensing, its pharmacological inhibition and quorum sensing as an intervention target
   - Bacterial vaccines
   - Puzzles in sepsis pathogenesis

5. Oncology (3 Lectures + 1 Tutorial)
   - Oncogenes
   - Tumour suppressors
   - Specific example cancers

- Receptor Tyrosine kinases in cancer
- Cellular stress and cancer
- Integrins, Cadherins, Catenins,
- Polarity and cancer
- Relationship between cellular senescence and cancer
- Cancer vaccines

6. Neurological diseases (3 Lectures + 1 Tutorial)
   - Pathogenesis of neuro-degenerative disorders
   - Ageing
   - Mitochondrial dysfunction
   - Oxidative stress and neuro-degeneration
   - Genetics of psychiatric disorders eg. Schizophrenia

7. Genetics (3Lectures + 1Tutorial)
   - Complex genetic diseases
   - Gene therapy
   - Human embryonic stem cell applications, associated issues and debates

8. Ageing and Regeneration (6 Lectures + 2 Tutorials)
   - Pathophysiology of tissue ageing
   - Cellular reprogramming
   - Regeneration of □ cells

9. Haematology (3 Lectures + 1 Tutorial)
   - Genomics and proteomics of blood cells in disease
   - Platelets, inflammation and atherosclerosis, thromboses
   - Issues associated with cord blood banking

10. Endocrinology (3 Lectures + 1 Tutorial)
    - Diabetes mellitus pathogenesis
    - Cell biology and signalling
    - Islet transplantation
    - Gestational diabetes
    - Metabolic syndrome.

11. Musculoskeletal system (3 Lectures + 1 Tutorial)
    - Osteoporosis
    - Menopause and bone metabolism
    - Muscle dystrophies
    - Stem cells in muscle degeneration

12. Summary discussions (3 Lectures + 1 Tutorial)
    - Analyses and review of future perspectives in the field of molecular pathogenesis

Text Books (if any):

a) Introduction to Molecular Medicine, by Dennis W. Ross (ISBN 0-387-95372-8)

b) Principles of Molecular Medicine, by M. S. Runge and C. Patterson

c) Robbins and Cotran Pathologic basis of disease

Suggested References:
Instructor notes, additional reading suggestions and relevant URLs will be provided to the students during the course of the classes. Instructor will be available for individual meetings when required.

Translational Control in Biology (B563)

Course Title **: Translational Control in Biology**
Course Code **: B563**
Credits **: 4 Credits**
Course Category **: Core**
Course Prerequisites **: B304 (Molecular biology) B205 (Genetics)**
Contact Hours (28/42/56) **: 56**

Outcome of the Course:

This course is design to understand the recent advancements in the fundamentals of protein translation and its control. Translation is a fundamental step in the central dogma of molecular biology. The regulation of translation is key to all basic cellular processes. Metabolic pathways, signaling, developmental decisions are tightly linked with the regulation of translation. Any defects associated with this process and its repercussion in cancer, metabolic disorders and human diseases will be covered.

Course contents:

1) Recent advances in the general translation (structure-function and genetics). (6 lectures + 2 tutorial)

2) IRES elements and control of viral translation. (3 lectures)

3) IRES elements in cellular translation control. (3 lectures + 1 tutorial)

4) Cis-acting element and trans-activing factors in translation regulation (3 lectures + 1 tutorial)

5) Role of microRNA in translation control. (3 lectures)

6) Signaling in translation. (3 lectures + 1 tutorial)

7) Role of eIF2α kinase in translational control. (3 lectures + 1 tutorial)

8) Translational control in cancer development. (3 lectures + 1 tutorial)

9) Translational control during apoptosis. (3 lectures)

10) Translational control in metabolic disorder. (3 lectures + 1 tutorial)

11) Translational control in synaptic plasticity, memory and learning. (3 lectures)

12) Translational control in development. (3 lectures)

13) mRNA localization and turnover. (3 lectures + 1 tutorial)

14) Mitochondrial translation and human diseases. (3 lectures + 1 tutorial)

Recommended reading:

1) Translational control in Biology and Medicine (Mathews, Sonenberg, Hershey, CSHL press)

2) Translational control in gene expression (Sonenberg, Hershey, Mathews, CSHL press)

3) Class notes and research articles

Suggested References:
Relevant research articles with updates in knowledge as decided by the Instructor

SCHOOL OF HUMANITIES

DETAILED COURSE STRUCTURE

FOR

INTEGRATED M.Sc. COURSE

Revised Jan 2017

National Institute of Science Education and Research (HBNI)

Humanities courses for integrated M.Sc.

Year/Semester	Course no.	Credits	Course Name
CORE COURSES			
1/Semester I	H109	2	Technical Communication I
1/Semester I	H133	2	Introduction to Sociology
1/Semester II	H110	2	Technical Communication
1/Semester II	H101	2	Introduction to Economics
ELECTIVE COURSES			
2/Semester III	H225	2	Introduction to Psychology
	H201	2	Environmental Economics and Environmental Impact Assessment
	H239	2	Introduction to Innovation System
	H238	2	Life and Community in Urban World.
2/Semester IV	H227	2	Organizational Behaviour
	H235	2	Sociology of Science and Technology
	H236	2	Perspectives on Indian Society
	H237	2	Science Communication and Citizen

SEM- I	**H 109**	+	**H 133**
SEM – II	**H 110**	+	**H 101**
SEM – III			**2 Electives**
SEM-I V			**2 Electives**

Economics

H101:Course title: Introduction to Economics

Instructor/Proposed by: Dr Amarendra Das

Prerequisite: None

Course Content:

1. Role of Government in Organised Society [1 class]
2. Expenditure Obligation of Union, State and Local Government [2 classes]
3. Sources of Revenue for Union, State and Local Governments [4 Classes]
4. Concepts of Budget, and Different deficits [1 class]
5. Channels of Resource Transfer from Union to State Governments [2, classes]
6. Balance of Payment [3 classes]
7. Laws of Demand and Supply [3 classes]
8. Equilibrium Price Determination [1 class]
9. Exchange rate Determination [2 classes]
10. Consumer's Equilibrium [2 classes]
11. Producer's Equilibrium [2 classes]
12. Current Economic events [3 classes]

References:

E.Case and R.C.Fair (2006) Principles of Economics, Prentice Hall, USA,

Samuelson, Paul and William D. Nordhaus (1948) Economics, 19th Edition, Mc Graw Hill

Government of India (2017) Union Budget 2017-18

Government of India (2017) Economic Survey-2016-17

H201: Environmental Economics and Environmental Impact Assessment
Instructor/Proposed by: Dr Amarendra Das
Prerequisite: None

Course Content:

12. Definition of Environmental Economics, Ecological Economics and Natural Resource Economics [1 class]
13. Key environmental problems faced by humanity [2 classes]
14. Limits to Growth [2 classes]
15. Sustainable Development: Strong and weak sustainability [2 classes]
16. Indicators of sustainability [1 class]
17. Market Failure: Causes and Remedies [3 classes]
18. Perspective on Environmental Policy/Regulation [2 classes]
19. Informal Regulation [1 class]
20. Population, Poverty and Economic Growth [1 class]
21. Climate Change, Causes and Consequences [2 classes]
22. Principles of using Renewable resources [2 classes]
23. Principles of using Non-renewable resources [2 classes]
24. Environmental Kuznets Curve [2 classes]
25. Mainstreaming of Environment [2 classes}
26. Environmental Impact Assessment [2 classes}
27. Environmental Regulations in India [1 class]
28. Green Accounting, Concepts, Integrated Economic and Environmental
29. Accounting [2 classes]

References:

Report of the World Commission on Environment and Development: Our Common Future

Baumol, W.J. & Oates, W.E. (1975), “The Theory of Environmental Policy: Externalities, Public Outlays and the Quality of Life”, Prentice Hall Inc.

Bromley, Daniel W. (1995), “The Handbook of Environmental Economics”, Blackwell Publications Ltd.

Pearce, D.W. (1976), “Environmental Economics”, Orient Longman Ltd.

World Bank, (1992). “World Development Report, 1992: Development and the Environment”, Oxford University Press

Bhatacharya R N (2002) Environemntal Ecconomics: An Indian Perspective, Oxford University Press, New Delhi

English

H109: Technical Communication I

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **Ideations of Science** (4 classes)
   Categorization and social perspective.

2. **Inscription and the material arts** (4 classes)
   Scientific representation and the figural social.

3. **Mechanics of Writing** (6 classes)
   Structure and compositional logic

4. **The Rhetorical Process** (6 classes)
   Building the argument

5. **Cultural Context and the Sciences** (4 classes)
   Literature and the aesthetic of science.

References

Barrass, Robert (2002). *Scientists Must Write: A Guide to Better Writing for Scientists, Engineers and Students*. London: Routledge.

Booth, Vernon (1993). *Communicating in Science: Writing a Scientific Paper and Speaking at Scientific Meetings*. Cambridge: Cambridge UP.

Cottrell, Stella (2011). *Critical Thinking Skills: Developing Effective Analysis and Argument*. London: Palgrave Macmillan.

Lynn, Steven (2010). *Rhetoric and Composition: An Introduction*. Cambridge: Cambridge UP.

Ranciere, Jacques (1991). *The Ignorant Schoolmaster*.Redwood:Stanford UP.

Ehrlich, Eugene (2011). *Schaum's Outline of English Grammar*, Third Edition. NY: Schaum's.

H110: Technical Communication II

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **The logic of Critique** (4 classes)
   Notions of evidence, proof and fact.

2. **Humanities and empiricism** (4 classes)
   Empirical fallacy and social intervention.

3. **Mechanics of Writing II** (6 classes)
   The forms of knowledge production. Understanding readership.

4. **The Rhetorical Process II** (6 classes)
   Staging the argument. Perspective and Institutional / Disciplinary norms.

5. **Narrativizing the Sciences** (4 classes)
   Scientific correspondence and reflections. Popular science and Science fiction.

References

Baudrillard, Jean (2012). *The Ecstasy of Communication*. Cambridge: MIT Press.

Fogelin, Robert (2014). *Cengage Advantage Books: Understanding Arguments*. London: Wadsworth.

Heidegger, Martin (2008). *“The question concerning technology,” Basic Writings.* New York: Harper Collins.

Poovey, Mary (1998). *A History of the Modern Fact*. Chicago: University of Chicago press.

Strunk Jr, William (1767). *The Elements of Style: TheOriginal Edition* (2014). London: Dover.

Psychology

H 225: Introduction to Psychology

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. Introduction: perspectives, methods, issues.	(3 classes)
2. Perceptual Process.	(4 classes)
3. Learning Process	(3 classes)
4. Memory	(2 classes)
5. Intelligence	(2 classes)
6. Emotion	(2 classes)
7. Personality	(4 classes)
8. Motivation	(4 classes)
9. Attitude	(3 classes)

References:

Morgan, C.T., King, R.A., Weisz, J.R., Scopler, J. **Introduction to Psychology** (7th ed). Tata McGraw-Hill.

Baron, R.A. **Psychology** (5th ed) PHI New Delhi

Feldman, R.S. **Introduction to Psychology** (6th ed) Tata McGraw-Hill.

H 226: Applied Behavioural Science

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. Introduction: Personality	(1 class)
2. Interpersonal Relationship and Personal Effectiveness	(5 classes)
3. Social Perception: errors, biases, impression management	(3 classes)
4. Emotional Intelligence: managing emotions.	(3 classes)
5. Group and Team Dynamics.	(5 classes)
6. Effective Communication.	(4 classes)
7. Values and Value System	(3 lectures)
8. Stress: coping and managing stress	(4 classes)

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Handouts will be given as and when required.

H 227: Organizational Behaviour

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. **Introduction to Organizational Behaviour** (2 classes)
   Nature of Organizations, what is OB, contributing disciplines, Functions, role and skills of a manager, environmental challenges.
2. **Individual Decision-making process** (3classes)
   Rational decision-making, creativity, bounded rationality, errors and biases, constraints, ethics in decision-making.
3. **Work attitudes** (2 classes)
   Job satisfaction, job involvement, organizational commitment, cognitive dissonance theory.
4. **Motivation** (3 classes)
   Hierarchy of needs theory, two factor theory, ERG theory, equity theory, goal setting and expectancy theory, MBO in practice, other applications.
5. **Power and Politics** (3 classes)
   Bases of power, the general dependency postulate.
6. **Leadership** (3 classes)
   Behavioural theories, contingency theories, contemporary theories, issues in leadership studies.
7. **Groups and team dynamics** (3 classes)
   Stages of group development, group structure, group decision-making, Types of teams, creating effective teams.
8. **Conflict and conflict resolution** (2 classes)
   Functional and dysfunctional conflict, the conflict process, negotiation.
9. **Organizational Structure** (2 classes)
   Elements of organizational structure, common organizational designs, why do structures differ?
10. **Organizational Culture** (2 classes)
    Functions of culture, creating and sustaining culture.
11. **Organizational Change** (3 classes)
    Forces for change, resistance to change, approaches to managing planned change.

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Organizational Behaviour by Steven Mcshane and Mary Von Gilnow, Tata McGraw - Hill

Sociology

H 237: Science Communication & the Citizenship

Instructor/Proposed by: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course content:

1. Introduction, citizenship and Science (4 classes)
2. Science in public, the public understanding of science (4 classes)
3. Public engagement with science (5 classes)
4. Science, communication, ethical codes & scientific norms (4 classes)
5. Patents and dissemination of scientific knowledge (4 classes)
6. Science communication in age of innovation (4 classes)

References

Jane Gregory, J., and Miller, S. *Science in Public: Communication, Culture and Credibility*, New York: Plenum, 2000.

Collins, H., and Trevor Pinch, T. *The Golem: What Everyone should Know about Science*, Cambridge: Cambridge University Press, 1993.

Leach, M., Scoones, I., and Wynne, B. *Science and Citizens: Globalization and the Challenge of Engagement*, London: Zed, 2005.

Irwin, A. *Citizen Science*, London: Routledge, 1995.

Nowotny, H., Scott, P. and Gibbsons, M. *Rethinking Science: Knowledge and the Public in an Age of Uncertainty*, Cambridge: Polity, 2001.

H 238: Life &Community in Urban world

Proposed by: Debashis Pattanaik

Prerequisite: None

Course content:

1. Introduction, urban space and urban thought, urbanization (4 classes)
2. Emergence and evolution of cities (4 classes)
3. Urban life, urban communities (online and offline) (4 classes)
4. The city in context, migration, sorting and niches (4 classes)
5. Markets and networks (5 classes)
6. Urban ecology, suburbia, urban design, policy and planning (4 classes)

References

B. Wellman, *Networks in the Global Village*, Westview Press, Boulder, CO: 1999.

C.S. Fischer, and R.K. Merton, *The Urban Experience,* Houghton Mifflin Harcourt P, Boston: 1984.

E. Ben-Joseph and T. Szold (eds.), *Regulating Place: Standards and the Shaping of Urban America,* Routledge: New York: 2005.

J. Logan and H. Molotch. *Urban Fortunes: Toward a Political Economy of Place,* University of California Press, California: 2007.

R.W. Park, E.W. Burgess and M. Janowitz (eds.), *The City*, University of Chicago Press, Chicago: 1984.

S. Sassen, *Cities in a World Economy*, Pine Forge Press, California: 2011.

S. Zukin, *The Culture of Cities*, Blackwell, New York: 1995.

W.G. Flanagan, *Urban Sociology: Images and Structure,* Rawat Publications, New Delhi: 2011.

H239: Introduction to Innovation System

By: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course Content:

1. Nature of innovation (4 classes)
2. The innovative firm (2 classes)
3. Innovation processes (4 classes)
4. Regional innovation system (3 classes)
5. Innovation and IPR (4 classes)
6. Education, universities and national innovation system (2 classes)
7. Multinational enterprises and innovation processes (2 classes)
8. Science and innovation policy (4 classes)

References

B. Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* Pinter, London: 1992.

C. Christensen, *The Innovators Dilemma,* Harvard University Press, Boston: 1997.

E. Dundon, *The Seeds of Innovation: Cultivating the Synergy that Fosters New Ideas,* Amacom Books, New York: 2002.

H. Braczyk, et.al, *Regional Innovation Systems*, UCL Press, London: 1998.

K. Pavitt, *Technology Management and Systems of Innovation,* Cheltenham: 1999.

M. Gibbons et.al, *The New Production of Knowledge – the Dynamics of Science and Research in Contemporary Societies,* Sage, London: 1994.

P. Drucker, *Innovation and Entrepreneurship,* Harper Collins Publishers, New York: 1993.

R. Katz, *The Human Side of Managing Technological Innovation*, Oxford University Press, New York: 2004.

S. Borras, *The Innovation Policy of the EU,* Edward Elgar, Cheltenham: 2003.

H 133: Introduction to Sociology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Origin and Growth of Sociology (2 Lectures)

    Origin and development of sociology as a separate discipline,
    Nature and Scope of Sociology,
    Sociology as a Scientific Discipline.

2. Sociological Perspectives (2 Lectures)

    Conflict, Functionalism and Interactionsim

3. Basic Sociological Concepts (6 Lectures)

Society, Community, Association, Institution, Status and Role, Types of Society: From early hunting gathering to industrial development and globalization, Culture: Components of culture; Norms, values, folkways, mores, Cultural unity and diversity.

Socialization: Agents of Socialization, Early development of infant, stages of socialization

4. Social Groups (4 Lectures)

Meaning of Social Groups and Types: Primary Group, Secondary Group, In-Groups, Out- Group, Quasi- Group, Reference Group

5. Structure and Stratification (4 Lectures)

Structure, System and Function, caste and class and Racial and Ethnic group inequalities Social Stratification: Meaning and Types, Functionalist and Conflict Perspectives of Stratification, Social mobility: Meaning, horizontal and vertical mobility

6. Social Institutions (4 Lectures)

Family, marriage and kinship, religion, economy, polity and education. Functionalist and Conflict Perspectives of institutions.

7. Social processes and Change (4 Lectures)

Social Processes: Co-operation, accommodation, integration, competition and conflict;

Social Change: Meaning and Definition, Factors of change.

8. Social Problems and Social Control (2 Lectures)

Social Problems and Social disorganization

Social control : Meaning and Types

References

Harlambous, M. (1980) Sociology, Oxford University Press, New Delhi.

Inkeles, A. (1982). What is Sociology, Eastern Economic Edition, New Delhi

Johnson, H.M. (1991). Sociology – A Systematic Introduction, Allied Publishers, New Delhi

Bottomore, T.B. (2000). Sociology: A Guide to Problems and Literature, S Chand Publisher, Dehradun

Gisbert, P. (2004, 3rd edition). Fundamentals of Sociology, Orient Longman

Rao, C.N.(2001) Sociology, Rawat Publication, Jaipur

Giddens, A. (2001). Sociology, Polity Press, UK.

H 235: Sociology of Science and Technology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Social significance of science and technology (4 Lectures)
   a. Contextual nature of science
   b. Scientist as Indexical and Analogical reasoner
2. Robert Merton's approach to science (3 Lectures)
   a. Ethos of science;
   b. Thomas Theorem and Matthew Effect
3. Perspectives on scientific knowledge (8 Lectures)
   a. Karl Marx, Emile Durkheim, Karl Manheim's sociology of knowledge,
   b. Thomas Kuhn's structures of scientific revolutions
   c. Karl Popper's theory of falsification
4. Recent trends in Sociology of Science (8 Lectures)
   a. Science and technology in developing and developed countries,
   b. Indian context,
   c. Information Technology and globalization,
   d. Manuel Castell's network society, internet and social inequality
5. Case Study Discussions (4 Lectures)

References

"The Historian and the History of Science" – Harry Elmer Barnes, *The Scientific Monthly*, Vol 11, No. 2(August 1920!!!), pp. 112-126.

"What is the History of Science?"- *History Today*, pp. 32-53. April 1985. (This article is an interview of six scientists/practitioners of science)

The Structure of Scientific Revolutions, Thomas Kuhn, Chicago: Chicago University Press, 1970. (First Edition 1962). Preface, Chapter, 12,3.

The Sociology of Science – Robert Merton, Chapters, 13,14,20, 21.

"The Scientist as a Practical Reasoner: Introduction to a Constructivist and Contextual Theory of knowledge"-. K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981.

(Chapter I) **A must read, highly recommended.**

"The Scientist as an Indexical Reasoner: The Contextuality and the Opportunism of Research" – K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981. (Chapter II) **A must read, highly recommended.**

"Is Science Losing its Objectivity?" – John Ziman, Nature, Vol.382, pp. 751-756, 1996

Kuhn, Thomas, "Structure of Scientific Revolutions", Chicago University Press. 1996

Merton, Robert K., Social Theory and Social Structure, Amerind. 1981

H 236: Perspectives on Indian Society

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content:

1. Indian Social Structure (2 Lectures)
    - a- Traditional Social Organizations
    - b- Culture and Tradition
2. Caste System and Class Structure (7 Lectures)
    - a- Cultural and Structural Views about Caste System
    - b- Inequality, Differentiation and Hierarchy
    - c- Dominant Caste, Sanskritization
    - d- Change and Persistence of Caste system in Modern India
    - e- Caste in Indian Politics
    - f- Backward Caste Movements
    - g- Social Backwardness and Social Justice
3. Class Structure (3 Lectures)
    - a- Class Structure in India
    - b- Agrarian and Industrial Class Structure
    - c- Emergence of Middle Class and Elites
4. Social Institutions: Marriage, Kinship and Family (2 Lectures)
5. Rural and Urban Social Structure: Poverty, Unemployment, etc. (2 Lectures)

6. Changing faces of Rural society/economy/market, Green revolution (2 Lectures)

6. Political processes: Political system and Governance (2 Lectures)

7. Education (2 Lectures)

8. Religion and Society (2 Lectures)

9. Social Change and Development Sustainable and Inclusive (2 Lectures)
   Development, Basic developmental issues: Health, Education and Livelihood

10. Contemporary Social Issues (2 Lectures)

References:

Mandelbam, D. : Society in India (Part I & II), Popular Prakashan, Bombay, 1970
Srinivas, M.N. : Caste in Modern India and Other Essays, Asia Publishing House, Bombay,1964
Kapadia, K,M, : Marriage and Family in India, Oxford University Press, Calcutta,1981
Srinivas, M.N. : Social Change in Modern India, Orient Longman, New Delhi, 1995
Rao, M.S.A. (ed): Urban Sociology in India, Orient Longman, New Delhi, 1974
Ahuja, Ram : Social Problems in India, Rawat Publications, Jaipur, 1992
Kosambi, D.D. : The Culture & Civilization of Ancient India in Historical Perspective, New Delhi, 1982
Uberoi Patrcia (ed), Family, Kinship And Marriages in India, Oxford University Press, New Delhi.
Omen, T.K. and Mukharjee, P.N. (ed),: Indian Sociology : Reflection and Introspection, Popular Prakashan, Bombay, 1986

SCHOOL OF COMPUTER SCIENCES

A proposal for minor in Computer Science

1 Structure of the curriculum

The curriculum is divided in two category of courses, core courses and optional courses.

1.1 Core Courses

The following courses have been recommended by the steering committee as core courses. The Programming and Data Structure course are proposed to be two lab courses (2 credit each).

1. CS141 and CS142: Programming and Data Structures Lab
2. CS201: Theory of Computation
3. CS202: Discrete Structures and Computation[1]
4. CS301: Design and Analysis of Algorithms

1.2 Elective Courses

For the initial years, we shall offer the following optional courses. A student has to do three courses from the following list to obtain minor.

- CS451: Modern Cryptology
- CS452: Algorithmic Coding Theory
- CS453: Complexity Theory
- CS454: Linear Programming and Combinatorial Optimization
- CS455: Distributed Network Algorithms

In future, more elective courses will be offered based on the interests of the faculties.

1.3 Similarity with other courses

School of Mathematical Sciences offer some courses which are similar to the courses listed above. We make the following observations regarding this.

- Programming and Data Structure course can be merged with the existing Computational Laboratory courses (M141 and M142). I141 and I142 are the two lab courses, which may be offered instead of M141 and M142. The major difference in syllabus is the inclusion of different data structures which are core concepts in Computer Science.

[1] This course was originally titled Discrete Mathematics for Computer Science. We have renamed the course to capture the spectrum of the topics covered, and to avoid any confusion.

- School of Mathematical Sciences also offer Algorithms, Theory of Computation, Cryptology, Information and Coding Theory as PG optional courses. However, in Computer Science, Algorithms and Theory of Computation are fundamental courses, and need to be offered to the undergraduate students. The syllabus of Modern Cryptology, as well as Algorithmic Coding Theory has been designed from Computer Science point of view and significantly different from the SMS courses.

  However, to avoid repetition, we propose, students who take M462 (Cryptology) and M464 (Information and Coding Theory) will not be allowed to take CS451 (Modern Cryptology), and CS452 (Algorithmic Coding Theory) respectively.

2 Syllabi

Syllabi of the courses are given in the following pages. For each subject, the syllabus is organized as follows

1. prerequisite
2. topics
3. references

3 Core Courses

3.1 CS141: Programming and Data Structures Lab-I

Credit : 2

Prerequisite: None

Classes per week: 3P+1L.

Topics Module 0: (6P+2L): Introduction to Computers, Notion of Algorithm, Linux Bash Shell, Simple Shell Programs.
Module 1 (12P+4L): Introduction to Programming: Variables, operators and expressions, input and output statements, Conditions and loops. Functions and recursions.
Module 2 (12P+4L): Arrays, Pointers, Structures, Classes and Objects.
Module 3 (9P+3L): File i/o, command line arguments.
Module 4 (6P+2L). Abstract data type. Linked lists.

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

3.2 CS142: Programming and Data Structures Lab-II

Credit : 2

Prerequisite: CS141 **Classes per week**: 3P+1L. **Topics**

Module 0 (9P+3L): Review of programming, Arrays and Linked List. Bubble Sort and Quick Sort. Binary Search.
Module 1 (12P+4L): Circular Linked Lists, Doubly Linked Lists, Stacks, Queues.
Module 2 (12P+4L): Trees. Binary Search Trees, Tree traversal, Balanced Binary trees. Module 3 (6P+2L): Heap, Priority Queues.

Module 4 (3P+1L). Strings and Searching for Phrases.
Module 6:(Optional) (3P+1L) Dictionaries: universal, k-wise independent, simple tabulation hashing; chaining, dynamic perfect hashing, linear probing, cuckoo hashing

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973
- E. Horowitz,S . Sahni, Fundamentals of Data Structures in C++, Universities Press, 2008.

3.3 CS201: Theory of Computation

Credit : 4

Prerequisite: None **Classes per week**: 3L+1T. **Topics**

Module 1 (12L+4T): Introduction to Finite State Automata; DFA,NFA, and their equivalence, Regular Ex- pressions and equivalence with finite state automata.Regular Languages and Properties, Pumping Lemma and applications, Myhill-Nerode Theorem, State Minimization.

Module 2 (12L+4T): Context Free Languages (CFL) and grammars, parse trees, Chomsky Normal Form. Pushdown Automata (PDA), Equivalence of acceptance by final state and empty stack. Equivalence of CFL and PDA, Pumping Lemma for CFL.

Module 3 (12L+4T): Turing Machines and equivalence of different models. Universality. Decidability, Recog- nizability, Enumeration, and Undecidability. Reductions. Rice’s Theorem, recursion theorem.

Module 4 (9L+3T): Notions of P,NP,co-NP, hierarchy theorem, NP completeness, Cook-Levin Theorem, NP completeness proofs of some NP complete problems.

References

- J. Hopcroft, JD Ulman. Introduction to Automata Theory, Languages and Computations. Narosa Publishing 2002. (Indian Edition)
- M. Sipser. Introduction to the Theory of Computation. Cengage, 3rd Edition, 2014.
- H. R. Lewis and C. H. Papadimitriou: Elements of The Theory of Computation, Prentice Hall, Englewood Cliffs, 1981
- M. R. Garey and D. S. Johnson: Computers and Intractability: A Guide to The Theory of NP Completeness, Freeman, New York, 1979.

3.4 CS202: Discrete Structures and Computation

Credit 4
Prerequisite: none **Classes per week**: 3L+1T. **Topics**

Module 1 (6L+2T): Review of Sets, Operations, Principles of Inclusion and Exclusion. Functions, relations, Equivalence relations. Countable and uncountable sets. Review of Pigeonhole principle.

Module 2 (6L+2T): Introduction to Propositional Logic, Equivalence and Implications. Truth tables, De Mor- gan's Law, Quantifiers, Inference and Proofs. Introduction to First Order Logic, Syntax and Semantics, Soundeness and Completeness.

Module 3 (6L+2T): Mathematical Induction, Recursions, First order linear recurrence, Geometric series, Re- cursion trees and growth rates of solutions to recurrences, Master Theorem. Generating Functions.

Module 4 (6L+2T): Introduction to counting, sum and product principles, counting subsets. Binomial coefficients and Pascal's triangles. Polya's theory of counting (optional).

Module 5 (3L+1T): Arithmetic Algorithms: Computing GCD, primality testing, RSA.

Module 6 (12L+4T): Graph Theory: Graphs, representations, connectivity, cycles, trees, Spanning tree of a graph, Algorithms to find minimum spanning trees. Eulerian Cycle and Hamiltonian paths, independence number and clique number, chromatic number, Dominating Sets, and Covering Sets. Planar Graphs. Directed Graphs and tournaments.

Module 7(3L+1T) Probabilistic tools, Tail Bounds and Applications.
Module 8 (3L+1T)(optional): Linear Algebraic tools in Combinatorics.

References

- J. Gallier, Logic for Computer Science: Foundations of Automatic Theorem Proving, Wiley.
- Kenneth Rosen. Discrete Mathematics and Its Applications, 7th Edition , McGraw Hill Publishing Co., 2012.
- Ken Bogart. Discrete Mathematics for Computer Science. available at https://www.kth.se/social/files/557ec6b0f27654
- J. L. Mott, A. Kandel and T. P. Baker: Discrete Mathematics for Computer Scientists, Reston, Virginia, 1983
- J. A. Bondy and U. S. R. Murty: Graph Theory with Applications, Macmillan Press, London, 1976.
- F. S. Roberts: Applied Combinatorics, Prentice Hall, Englewood Cliffs, NJ, 1984

3.5 CS301: Design and Analysis of Algorithms

Credit 4
Prerequisite: CS201, CS202
Classes per week: 3L+1T.
Topics

Module 1 (4L+1T). Introduction and basic concepts - mathematics of algorithm analysis, asymptotic notations, worst case and average case complexity. Review of Searching and Union Find.

Module 2 (8L+3T): Divide and conquer- Motivating algorithms that leads into recurrences, solving recurrences, merge sort and its recurrence, Median computation. Analysis of quicksort.

Module 3 (9L+3T). Greedy algorithms- Greedy choice, optimal structure property, minimum spanning tree, knapsack

Module 4 (8L+2T). Dynamic programming- Integral knapsack, longest increasing subsequence, edit distance, independent sets in trees

Module 5 (8L+3T). Graph algorithms- Recall of representation of graphs, BFS, DFS, shortest path, connected components, topological sort of DAGs, biconnected components and strongly connected components in directed graphs

Module 6. (Optional)(3L+1T) Randomization- Median, randomized quicksort, probabilistic primality testing.

Algebraic Algorithms. Karatsuba's algorithm and the Fast Fourier transform

References

- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- S. Dasgupta, C. Papadimitrou, U. Vazirani, Algorithms, McGraw-Hill Education, 2006.
- A. Levitin, Introduction to Design and Analysis of Algorithms, Pearson 2007 (Lev)
- J. Kleinberg and E. Tardos, Algorithm Design, Pearson, 2005 (KT)
- E. Horowitz, S. Sahni, and S. Rajasekaran, Computer Algorithms, Silicon Press, 2007
- M. Goodrich, R. Tamassia, Algorithm Design, Wiley, 2001.
- D. Knuth: The Art of Computer Programming. Vol. 1 and Vol 3. , 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

4 Optional Courses

4.1 CS451: Modern Cryptology

Credit 4

Prerequisite: CS202, CS301.

Classes per week: 3L+1T.

Topics

Module 1: (3L+1T) Introduction and Classical Cryptography, Perfect Secrecy, One Time Pad.

Module 2: (9L+3T) Symmetric Key Encryption. Computational Security, Concrete vs Asymptotic Approach. Semantic Security. Pseudorandom generators and Stream ciphers, Pseudorandom Functions and Block Ciphers. Practical Constructions.

Module 3: (6L+2T) Hash Functions and Message Authentication Codes. Notions of Security, Generic Attacks, Domain Extension techniques, CBC MAC, HMAC, PMAC, Idea of Authenticated Encryption.

Module 4: (6L+2T) Review of Basic Number Theory. Hardness Assumptions. One-way functions, Trapdoor Permutations, RSA assumptions, Discrete Log and Diffie Hellman Assumptions, SIS and LWE Assumptions. Introduction to Elliptic Curves (Optional)

Module 5. (3L+1T) Key Exchange Protocols and Key Management.

Module 6. (6L+2T) Public Key Encryption, Semantic Security, El Gamal Encryption, Padded RSA PKCS#1 v1.5. Random Oracle Technique, OAEP.

Module 7. (6L+2T) Digital Signatures, Hash and Sign paradigm, Schnorr Signature, Forking Lemma, DSA. SSL/TLS.

Module 8. (6L+2T) (Optional) Idea of some of the following notions, Protocols and Zero Knowledge Proofs, Multiparty Computations and Oblivious Transfers, Secret Sharing. Algorithms for factoring and computing discrete logarithms, Linear and Differential Cryptanalysis, Crypto Currencies.

References

- J. Katz and Y. Lindell, Introduction to Modern Cryptography. CRC, 2014.

Possible Instructor: Rishiraj Bhattacharyya.

4.2 CS452: Agorithmic Coding Theory

Credit 4

Prerequisite: CS202

Classes per week: 3L+1T.

Topics Module 1: (9L+3T) Entropy, Characterization and Properties. Application to Combinatorics. Mutual Information and KL Divergence.

Module 2: (6L+2T) Source coding theorem, lossless compression of data, Lempel-Ziv Algorithm, Optimal lossless coding.

Module 3 (6L+2T) Communication channels (binary symmetric, erasure) and channel capacity, channel coding theorem.

Module 3: (6L+2T) Introduction to Error Correcting Codes. Hamming Codes and Hamming Bounds. BCH Codes, Maximum likelihood decoding and syndrome decoding; coding theory bounds.

Module 4: (9L+3T) Reed-Solomon codes and the Berlekamp-Welch decoding algorithm with Analysis. List Decoding of Reed-Solomon Codes.

Module 5. (6L+2T)Reed-Muller Code and Local decoding. Module 6.

(3L+1T) (Optional) Lovasz Local lemma and proof.

References

- T. M. Cover and J. A. Thomas, "Elements of Information Theory" (Second Edition, Wiley).
- S. Ling C. Xing, "Coding Theory: A First Course", Cambridge University Press.
- J. Radhakrishnan, "Entropy and Counting", http://www.tcs.tifr.res.in/ jaikumar/Papers/EntropyAndCounting.pdf
- V. Guruswami, A. Rudra and M. Sudan, "Essential Coding Theory (Draft of a new book)" available at http://www.cse.buffalo.edu/faculty/atri/courses/coding-theory/book/
- F.J. MacWilliams and N.J.A. Sloane, The Theory of Error-Correcting Codes, North-Holland ML, 1983.

Possible Instructor: Rishiraj Bhattacharyya.

4.3 CS453: Complexity Theory

Credit 4

Prerequisite: CS201, CS202, CS301

Classes per week: 3L+1T.

Topics

Module 1 (9L+3T): Introduction, P and NP - Review of Turing machines, universal Turing machines, and uncomputable functions, P vs. NP, NP vs. co-NP, and NP-completeness, EXP, NEXP

Module 2: (3L) Cook Levin's Theorem

Module 3 (12L+4T): Diagonalization, Space complexity, Polynomial Hierarchy

Module 4 (9L+3T): Interactive Proofs - PCP theorem and its application to approximability Module 5 (4L+1T): Circuit complexity and lower bounds

Module 6 (6L+2T): Hardness vs. Randomness - Randomized Computation, derandomization, Pseudo-random generators

Module 7 (3L+1T): Polynomial identity testing vs Lower bounds for arithmetic circuits

References:

- S. Arora and B. Barak, "Computational Complexity: A Modern Approach", Cambridge University Press.
- O. Goldreich, "Computational Complexity: A conceptual perspective", Cambridge University Press.
- J. Hopcroft, R. Motwani, J. D. Ullman. Introduction to Automata Theory, Languages, and Computation. Pearson Education.
- J. Raddhakrishnan, Graduate course on Computational Complexity, http://www.tcs.tifr.res.in/ jaikumar/Courses/Com

Possible Instructor: Anisur Rahaman Molla.

4.4 CS454: Linear Programming and Combinatorial Optimization

Credit 4

Prerequisite: CS202, CS301
Classes per week: 3L+1T.

Topics

Module 1: (10L+3T) Basic geoemetry and linear algebra related to Linear Programming. Simplex-method and Duality theorem (leading to Von Neumann's minmax principle) and complimentary slackness.

Module 2: (8L+3T) Ellipsoid algorithm. separation oracles.

Module 3: (9L+3T) Semidefinite programming as an extension of linear programming.

Module 4: (9L+3T) LP relaxation. Examples of problems where LP relaxation achieves optimum. Examples where LP/SDP relaxation achieves approximate solution. Integrality gaps.

Module 5: (6L+2T) Rounding, probabilistic roundings, iterative rounding, primal dual methods.

Module 6 (Optional): (3L+1T) Gale-Shapley algorithm, Connection of LP to Cooperative Game Theory core, nucleolus, combinatorial optimization games.

References

- A. Schrijver, "Theory of Linear and Integer Programming", Wiley.
- A. Schrijver, "Combinatorial Algorithm: Polyhedra and Efficiency, Volume A", Springer.
- V. Vazirani, "Approximation Algorithm", Springer.
- S. Chakraborty, M. Mitra, P. Sarkar, "A Course on Cooperative Game Theory", Cambridge University Press.

Possible Instructor: Rishiraj Bhattacharyya, Anisur Rahaman Molla.

4.5 CS455: Distributed Network Algorithms

Credit 4

Prerequisite: CS202, CS301

Classes per week: 3L+1T. **Topics** Module 1: (9L+3T) Foundations of distributed network algorithms - Broad- cast, converge-cast, maximal independent set, coloring, leader election, spanning tree algorithms, shortest paths, and routing.

Module 2:(9L+3T) Fundamental concepts in distributed algorithms - Symmetry breaking, locality, synchronizers Module 3:(9L+3T) Basics of distributed network systems - Communication, synchronization, fault-tolerance,

and resource allocation

Module 4:(9L+3T) Applications to real-world networks - Internet, peer-to-peer networks, wireless networks, sensor networks and dynamic networks

Module 5:(9L+3T) Lower bounds using communication complexity, distributed computation of large-scale data, dynamic network algorithms.

References

- D. Peleg, “Distributed Computing: A Locality-Sensitive Approach”, SIAM 2000.
- Distributed Computing: Fundamentals, Simulations and Advanced Topics, by Hagit Attiya, Jennifer Welch, McGraw-Hill Publishing, 1998.
- N. Lynch, “Distributed Algorithms”, Morgan Kaufmann 1996.
- G. Tel, Introduction to Distributed Algorithms, Cambridge University Press 2000.
- G. Pandurangan, “Distributed Network Algorithms, a monograph”, Department of CS, University of Houston.

Possible Instructor: Anisur Rahaman Molla.

SYLLABUS

Integrated M.Sc. in Mathematics

Applicable from the Academic Year 2017–2018

INTEGRATED M.Sc. MATHEMATICAL SCIENCES (PROGRAM CODE: MATH13)

NATIONAL INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

BHUBANESWAR

Course Structure for Integrated M.Sc. in Mathematics

Semester	Course No.		Credits		Course Name
Semester I	M101	-	3	-	Mathematics-I
	CS141	-	2	-	Computation Laboratory-I
	B101	-	3	-	Biology-I
	B141	-	2	-	Biology Laboratory-I
	C101	-	3	-	Chemistry-I
	C141	-	2	-	Chemistry Laboratory-I
	P101	-	3	-	Physics-I
	P141	-	2	-	Physics Laboratory-I
	H109	-	2	-	Technical Communication-I
	H125	-	2	-	Introduction to Psychology
Semester II	M102	-	3	-	Mathematics-II
	CS142	-	2	-	Computation Laboratory-II
	B102	-	3	-	Biology-II
	B142	-	2	-	Biology Laboratory-II
	C102	-	3	-	Chemistry-II
	C142	-	2	-	Chemistry Laboratory-II
	P102	-	3	-	Physics-II
	P142	-	2	-	Physics Laboratory-II
	H110	-	2	-	Technical Communication -II
	H133	-	2	-	Introduction to Sociology
Semester III	M201	-	4	-	Real Analysis
	M202	-	4	-	Group Theory
	M203	-	4	-	Discrete Mathematics
	M207	-	4	-	Number Theory
	****	-	4	-	Elective-I
	****	-	4	-	Elective-II
Semester IV	M204	-	4	-	Metric Spaces
	M205	-	4	-	Linear Algebra
	M206	-	4	-	Probability Theory
	M208	-	4	-	Graph Theory
	****	-	4	-	Elective-III
	****	-	4	-	Elective-IV
Semester V	M306	-	4	-	Calculus of Several Variables
	M302	-	4	-	Rings and Modules
	M303	-	4	-	Differential Equations
	M304	-	4	-	Topology
	M305	-	4	-	Statistics
	****	-	4	-	Elective-V

Semester	Course No.		Credits		Course Name
Semester VI	M301	-	4	-	Lebesgue Integration
	M307	-	4	-	Field Theory
	M308	-	4	-	Complex Analysis
	M310	-	4	-	Geometry of Curves and Surfaces
	M311	-	4	-	Numerical Analysis
	****	-	4	-	Elective-VI
Semester VII	M401	-	4	-	Functional Analysis
	M403	-	4	-	Commutative Algebra
	M498	-	4	-	Project-I
	****	-	4	-	Elective-VII
	****	-	4	-	Elective-VIII
	****	-	4	-	Elective-IX
Semester VIII	M404	-	4	-	Algebraic Topology
	M402	-	4	-	Representations of Finite Groups
	M499	-	4	-	Project-II
	****	-	4	-	Elective-X
	****	-	4	-	Elective-XI
	****	-	4	-	Elective-XII
Semester IX	M598	-	20	-	Dissertation
	****	-	4	-	Elective-XIII
Semester X	M599	-	20	-	Dissertation
	****	-	4	-	Elective-XIV

Out of 56 credits as Electives, at least 8 credits from the School of Humanities and Social Sciences and at least 16 credits from other science schools must be taken.

Course Structure for a Minor in Mathematics

All the following courses are compulsory to get a Minor in Mathematics.

1. M101 - Mathematics-I
2. M102 - Mathematics-II
3. M201 - Real Analysis
4. M202 - Group Theory
5. M204 - Metric Spaces
6. M205 - Linear Algebra
7. M206 - Probability Theory
8. M303 - Differential Equations

A student may have the following two options to cover the last six courses from the above list of courses during his/her stay at NISER based on the present syllabus.

1.
   - Semester 3: Group Theory
   - Semester 4: Linear Algebra
   - Semester 5: Real Analysis
   - Semester 6/8/10: Metric Spaces/ Probability Theory
   - Semester 7/9: Differential Equations
2.
   - Semester 3: Real Analysis
   - Semester 4/6/8/10: Metric Spaces/ Linear Algebra/ Probability Theory
   - Semester 5/7/9: Group Theory/ Differential Equations

List of Courses from School of Mathematical Sciences

Compulsory Courses

Course No.		Credits		Course Name
M101	-	3	-	Mathematics-I
M102	-	3	-	Mathematics-II
M201	-	4	-	Real Analysis
M202	-	4	-	Group Theory
M203	-	4	-	Discrete Mathematics
M207	-	4	-	Number Theory
M204	-	4	-	Metric Spaces
M205	-	4	-	Linear Algebra
M206	-	4	-	Probabilty Theory
M208	-	4	-	Graph Theory
M306	-	4	-	Calculus of Several Variables
M302	-	4	-	Rings and Modules
M303	-	4	-	Differential Equations
M304	-	4	-	Topology
M305	-	4	-	Statistics
M301	-	4	-	Lebesgue Integration
M307	-	4	-	Field Theory
M308	-	4	-	Complex Analysis
M310	-	4	-	Geometry of Curves and Surfaces
M311	-	4	-	Numerical Analysis
M401	-	4	-	Functional Analysis
M403	-	4	-	Commutative Algebra
M404	-	4	-	Algebraic Topology
M402	-	4	-	Representations of Finite Groups

Elective Courses

Course No.		Credits		Course Name
M451	-	4	-	Advanced Complex Analysis
M452	-	4	-	Advanced Functional Analysis
M453	-	4	-	Advanced Linear Algebra
M454	-	4	-	Partial Differential Equations
M455	-	4	-	Introduction to Stochastic Processes
M456	-	4	-	Algebraic Geometry
M457	-	4	-	Algebraic Graph Theory
M458	-	4	-	Algebraic Number Theory
M460	-	4	-	Algorithm
M462	-	4	-	Cryptology
M463	-	4	-	Finite Fields
M464	-	4	-	Information and Coding Theory
M465	-	4	-	Mathematical Logic
M466	-	4	-	Measure Theory
M467	-	4	-	Nonlinear Analysis
M468	-	4	-	Operator Theory
M469	-	4	-	Theory of Computation
M470	-	4	-	Abstract Harmonic Analysis
M471	-	4	-	Advanced Number Theory
M472	-	4	-	Advanced Probability
M473	-	4	-	Algebraic Combinatorics
M474	-	4	-	Foundations of Cryptography
M475	-	4	-	Incidence Geometry
M476	-	4	-	Lie Algebras
M477	-	4	-	Optimization Theory
M478	-	4	-	Advanced Partial Differential Equations
M479	-	4	-	Random Graphs
M480	-	4	-	Randomized Algorithms and Probabilistic Methods
M481	-	4	-	Statistical Inference I
M482	-	4	-	Multivariate Statistical Analysis
M483	-	4	-	Introduction to Manifolds

Course No.		Credits		Course Name
M551	-	4	-	Algebraic Computation
M552	-	4	-	Analytic Number Theory
M553	-	4	-	Classical Groups
M554	-	4	-	Ergodic Theory
M555	-	4	-	Harmonic Analysis
M556	-	4	-	Lie Groups and Lie Algebras-I
M557	-	4	-	Operator Algebras
M558	-	4	-	Representations of Linear Lie Groups
M559	-	4	-	Harmonic Analysis on Compact Groups
M560	-	4	-	Modular Forms of One Variable
M561	-	4	-	Elliptic Curves
M562	-	4	-	Brownian Motion and Stochastic Calculus
M563	-	4	-	Differentiable Manifolds and Lie Groups
M564	-	4	-	Lie Groups and Lie Algebras-II
M565	-	4	-	Mathematical Foundations for Finance
M566	-	4	-	Designs and Codes
M567	-	4	-	Statistical Inference II

Program outcome: Integrated M.Sc. in Mathematics

The Integrated M.Sc. Program in Mathematics aims to provide comprehensive training to the students so that they will be able to build a carrier in Mathematics for themselves. The program aims to train people who are oriented towards research and teaching in both basic and advanced areas of Mathematical sciences. The core courses of the program provide a basic understanding in all areas of Mathematics which will be a foundation for further study of advanced topics. The electives courses provide knowledge in specialized topics and interconnection between different areas of Mathematics. Projects/Dissertation under the guidance of the faculty members give students exposure to current research in different areas of Mathematics and imbibe effective scientific and/or technical communication in both oral and writing. After successful completion of this program students will be able to apply knowledge of Mathematics in different fields of science and technology.

Syllabus of Compulsory Courses

M101: Mathematics-I

L	P	T	C
2	0	1	3

Outcome: Expects students to learn how to prove theorems, expressing mathematical objects, and understand the construction of natural numbers and symmetry of plane figures.

Contents: Method of Mathematical Proofs: Induction, Construction, Contradiction, Contrapositive. Set: Union and Intersection of sets, Distributive laws, De Morgan's Law, Finite and infinite sets. Relation: Equivalence relation and equivalence classes. Function: Injections, Surjections, Bijections, Composition of functions, Inverse function, Graph of a function. Countable and uncountable sets, Natural numbers via Peano arithmetic, Integers, Rational numbers, Real Numbers and Complex Numbers. Matrices, Determinant, Solving system of linear equations, Gauss elimination method, Linear mappings on $\mathbb{R}^2$ and $\mathbb{R}^3$, Linear transformations and Matrices. Symmetry of Plane Figures: Translations, Rotations, Reflections, Glide-reflections, Rigid motions.

References:

1. G. Polya, "How to Solve It", Princeton University Press, 2004.
2. K. B. Sinha et. al., "Understanding Mathematics", Universities Press (India), 2003.
3. M. Artin, "Algebra", Prentice-Hall of India, 2007 (Chapters 1, 4, 5).
4. J. R. Munkres, "Topology", Prentice-Hall of India, 2013 (Chapter 1).

M102: Mathematics-II

L	P	T	C
2	0	1	3

Outcome: Upon successful completion of the course students will become aware of some basic properties of real line and real valued functions.

Contents: Concept of ordered field, Bounds of a set, ordered completeness axiom and characterization of $\mathbb{R}$ as a complete ordered field. Archimedean property of real numbers. Modulus of real numbers, Intervals, Neighbourhood of a point. Sequences of Real Numbers: Definition and examples, Bounded sequences, Convergence of sequences, Uniqueness of limit, Algebra of limits, Monotone sequences and their convergence, Sandwich rule. Series: Definition and convergence, Telescopic series, Series with non-negative terms. Tests for convergence [without proof]: Cauchy condensation test, Comparison test, Ratio test, Root test, Absolute and conditional convergence, Alternating series and Leibnitz test. Limit of a function at a point, Sequential criterion for the limit of a function at a point. Algebra of limits, Sandwich theorem, Continuity at a point and on intervals, Algebra of continuous functions. Discontinuous functions, Types of discontinuity. Differentiability: Definition and examples, Geometric and physical interpretations, Algebra of differentiation, Chain rule, Darboux Theorem, Rolle's Theorem, Mean Value Theorems of Lagrange and Cauchy. Application of derivatives: Increasing and decreasing functions, Maxima and minima of functions. Higher order derivatives, Leibnitz rule, L'Hopital rule.

Text Book:

1. R. G. Bartle, D. R. Sherbert, “Introduction to Real Analysis”, John Wiley & Sons, 1992.

References:

1. K. A. Ross, “Elementary Analysis”, Undergraduate Texts in Mathematics, Springer, 2013.
2. S. K. Berberian, “A First Course in Real Analysis”, Undergraduate Texts in Mathematics, Springer-Verlag, 1994.

M201: Real Analysis

Prerequisites: M102

L	P	T	C
3	0	1	4

Outcome: Knowledge on Continuity differentiable and Riemann integration theory. Sequence and series and it’s application to numerical analysis.

Contents: Countability of a set, Countability of rational numbers, Uncountability of real numbers. Limit point of a set, Bolzano-Weirstrass theorem, Open sets, Closed sets, Dense sets. Subsequence, Limit superior and limit inferior of a sequence, Cauchy criterion for convergence of a sequence, Monotone subsequence. Tests of convergence of series, Abel’s and Dirichlet’s tests for series, Riemann rearrangement theorem. Continuous functions on closed and bounded intervals, Intermediate value theorem, Monotone functions, Continuous monotone functions and their invertibility, Discontinuity of monotone functions. Uniform continuity, Equivalence of continuity and uniform continuity on closed and bounded intervals, Lipschitz condition, Other sufficient condition for uniform continuity. Riemann Integration: Darboux’s integral, Riemann sums and their properties, Algebra of Riemann integrable functions, Class of Riemann integrable functions, Mean value theorem, Fundamental theorems of calculus, Change of variable formula (statement only), Riemann-Stieltjes integration (definition). Taylor’s theorem and Taylor’s series, Elementary functions. Improper integral, Beta and Gamma functions.

Text Books:

1. R. G. Bartle, D. R. Sherbert, “Introduction to Real Analysis”, John Wiley & Sons, 1992.
2. K. A. Ross, “Elementary Analysis”, Undergraduate Texts in Mathematics, Springer, 2013.

References:

1. T. M. Apostol, “Calculus Vol. I”, Wiley-India edition, 2009.
2. S. K. Berberian, “A First Course in Real Analysis”, Undergraduate Texts in Mathematics, Springer-Verlag, 1994.

M202: Group Theory

Prerequisites: M101

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will be able to understand the notion of symmetries in the language of groups. Furthermore, students will become aware of various properties of groups and subgroups.

Contents: Groups, subgroups, normal subgroups, quotient groups, homomorphisms, isomorphism theorems, automorphisms, permutation groups, group actions, Sylow’s theorem, direct products, finite abelian groups, semidirect products, free groups.

Text Book:

1. D. S. Dummit, R. M. Foote, "Abstract Algebra", Wiley-India edition, 2013.

References:

1. I. N. Herstein, "Topics in Algebra", Wiley-India edition, 2013.
2. M. Artin, "Algebra", Prentice-Hall of India, 2007.

M203: Discrete Mathematics

Prerequisites: M101

L	*P*	*T*	*C*
3	0	1	4

Outcome: Learning different combinatorial techniques to solve many counting problems and understanding some mathematical structures

Contents: Pigeonhole principle, Counting principles, Binomial coefficients, Principles of inclusion and exclusion, recurrence relations, generating functions, Catalan numbers, Stirling numbers, Partition numbers, Schröder numbers, Block designs, Latin squares, Partially ordered sets, Lattices, Boolean algebra.

Text Books:

1. R. A. Brualdi, "Introductory Combinatorics", Pearson Prentice Hall, 2010.
2. J. P. Tremblay, R. Manohar, "Discrete Mathematical Structures with Application to Computer Science", Tata McGraw-Hill Edition, 2008.

References:

1. J. H. van Lint, R. M. Wilson, "A Course in Combinatorics", Cambridge University Press, 2001.
2. I. Anderson, "A First Course in Discrete Mathematics", Springer Undergraduate Mathematics Series, 2001.
3. R. P. Stanley, "Enumerative Combinatorics Vol. 1", Cambridge Studies in Advanced Mathematics, 49, Cambridge University Press, 2012.

M204: Metric Spaces

Prerequisites: M201

L	*P*	*T*	*C*
3	0	1	4

Outcome: Upon successful completion of the course students will become aware about generalisation of euclidean distance on arbitrary sets and various properties of functions defined on them.

Contents: Metric spaces, open balls and open sets, limit and cluster points, closed sets, dense sets, complete metric spaces, completion of a metric space, Continuity, uniform continuity, Banach contraction principle, Compactness, Connectedness, pathconnected sets. Sequences of functions, Pointwise convergence and uniform convergence, Arzela-Ascoli Theorem, Weierstrass Approximation Theorem, power series, radius of convergence, uniform convergence and Riemann integration, uniform convergence and differentiation, Stone-Weierstrass theorem for compact metric spaces.

Text Books:

1. G. F. Simmons, "Introduction to Topology and Modern Analysis", Tata McGraw-Hill, 2013.
2. S. Kumaresan, "Topology of Metric Spaces", Narosa Publishing House, 2005.

References:

1. R. R. Goldberg, "Methods of Real Analysis", John Wiley & Sons, 1976.
2. G. B. Folland, "Real Analysis", Wiley-Interscience Publication, John Wiley & Sons, 1999.

M205: Linear Algebra

Prerequisites: M101

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will learn the relation between linear transformations and matrices. Moreover, student will also learn various fundamental results of matrices, namely, diagonalisation, triangulation and primary decomposition theorem.

Contents: System of Linear Equations, Matrices and elementary row operations, Row-reduced echelon form of matrices, Vector spaces, subspaces, quotient spaces, bases and dimension, direct sums, Linear transformations and their matrix representations, Dual vector spaces, transpose of a linear transformation, Polynomial rings (over a field), Determinants and their properties, Eigenvalues and eigenvectors, Characteristic polynomial and minimal polynomial, Triangulation and Diagonalization, Simultaneous Triangulation and diagonalization, Direct-sum decompositions, Primary decomposition theorem.

Text Book:

1. K. Hoffman, R. Kunze, "Linear Algebra", Prentice-Hall of India, 2012.

References:

1. S. H. Friedberg, A. J. Insel, L. E. Spence, "Linear Algebra", Prentice Hall, 1997.
2. A. Ramachandra Rao, P. Bhimasankaram, "Linear Algebra", Texts and Readings in Mathematics, 19. Hindustan Book Agency, New Delhi, 2000.
3. M. Artin, "Algebra", Prentice-Hall of India, 2007.

M206: Probability Theory

Prerequisites: M102

L	P	T	C
3	0	1	4

Outcome: Students will be introduced to the basic theory of probability starting from axiomatic definition of probability up to limit theorems of probability.

Contents: Combinatorial probability and urn models; Conditional probability and independence; Random variables – discrete and continuous; Expectations, variance and moments of random variables; Transformations of univariate random variables; Jointly distributed random variables; Conditional expectation; Generating functions; Limit theorems; Simple symmetric random walk.

Text Books:

1. S. Ross, "A First Course in Probability", Pearson Education, 2012.
2. D. Stirzaker, "Elementary Probability", Cambridge University Press, Cambridge, 2003.

References:

1. K. L. Chung, F. AitSahlia, "Elementary Probability Theory", Undergraduate Texts in Mathematics. Springer-Verlag, 2003.
2. P. G. Hoel, S. C. Port, C. J. Stone, "Introduction to Probability Theory", The Houghton Mifflin Series in Statistics. Houghton Mifflin Co., 1971.
3. W. Feller, "An Introduction to Probability Theory and its Applications Vol. 1 and Vol. 2", John Wiley & Sons, 1968, 1971.

M207: Number Theory

Prerequisites: M101

L	P	T	C
3	0	1	4

Outcome: Expects students to learn elementary properties of rings of integers including divisibility, congruences, continued fractions and Gauss reciprocity laws.

Contents: Divisibility, Primes, Fundamental theorem of arithmetic, Congruences, Chinese remainder theorem, Linear congruences, Congruences with prime-power modulus, Fermat's little theorem, Wilson's theorem, Euler function and its applications, Group of units, primitive roots, Quadratic residues, Jacobi symbol, Binary quadratic form, Arithmetic functions, Möbius Inversion formula, Dirichlet product, Sum of squares, Continued fractions and rational approximations.

Text Book:

1. I. Niven, H. S. Zuckerman, H. L. Montgomery, "An Introduction to the Theory of Numbers", Wiley-India Edition, 2008.

References:

1. T. M. Apostol, "Introduction to Analytic Number Theory", Springer International Student Edition, 2000.
2. G. A. Jones, J. M. Jones, "Elementary Number Theory", Springer Undergraduate Mathematics Series. Springer-Verlag, 1998.

M208: Graph Theory

Prerequisites: M101

L	P	T	C
3	0	1	4

Outcome: Understanding the fundamentals of graph theory and learning the structure of graphs and techniques used to analyze different problems

Contents: Graphs, subgraphs, graph isomorphisms, degree sequence, paths, cycles, trees, bipartite graphs, Hamilton cycles, Euler tours, directed graphs, matching, Tutte's theorem, connectivity, Menger's theorem, planar graphs, Kuratowski's theorem, vertex and edge colouring of graphs, network flows, max-flow min-cut theorem, Ramsey theory for graphs, matrices associated with graphs.

Text Book:

1. R. Diestel, "Graph Theory", Graduate Texts in Mathematics, 173. Springer, 2010.

References:

1. B. Bollobás, "Modern Graph Theory", Graduate Texts in Mathematics, 184. Springer-Verlag, 1998.
2. F. Harary, "Graph Theory", Addison-Wesley Publishing Co., 1969.
3. J. A. Bondy, U. S. R. Murty, "Graph Theory", Graduate Texts in Mathematics, 244. Springer, 2008.

M301: Lebesgue Integration

Prerequisites: M201

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will learn the concept of measures and measurable functions. Students also learn Lebesgue integration and their various properties

Contents: Outer measure, measurable sets, Lebesgue measure, measurable functions, Lebesgue integral, Basic properties of Lebesgue integral, convergence in measure, differentiation and Lebesgue measure. L_p Spaces, Holder and Minkowski inequalities, Riesz-Fisher theorem, Radon-Nykodin theorem, Riesz representation theorem. Fourier series, L_2-convergence properties of Fourier series, Fourier transform and its properties.

Text Books:

1. H. L. Royden, “Real Analysis”, Prentice-Hall of India, 2012.
2. G. B. Folland, “Real Analysis”, Wiley-Interscience Publication, John Wiley & Sons, 1999.

References:

1. G. de Barra, “Measure Theory and Integration”, New Age International, New Delhi, 2003.
2. W. Rudin, “Principles of Mathematical Analysis”, Tata McGraw-Hill, 2013.

M302: Rings and Modules

Prerequisites: M202, M205

L	P	T	C
3	0	1	4

Outcome: Expects students to learn structure and various properties of rings and modules, structure of finitely generated modules over PID.

Contents: Rings, ideals, quotient rings, ring homomorphisms, isomorphism theorems, prime ideals, maximal ideals, Chinese remainder theorem, Field of fractions, Euclidean Domains, Principal Ideal Domains, Unique Factorization Domains, Polynomial rings, Gauss lemma, irreducibility criteria.
Modules, submodules, quotients modules, module homomorphisms, isomorphism theorems, generators, direct product and direct sum of modules, free modules, finitely generated modules over a PID, Structure theorem for finitely generated abelian groups, Rational form and Jordan form of a matrix, Tensor product of modules.

Text Book:

1. D. S. Dummit, R. M. Foote, “Abstract Algebra”, Wiley-India edition, 2013.

References:

1. I. N. Herstein, “Topics in Algebra”, Wiley-India edition, 2013.
2. M. Artin, “Algebra”, Prentice-Hall of India, 2007.

M303: Differential Equations

Prerequisites: M201, M205

L	P	T	C
3	0	1	4

Outcome: This course starts with the origin and applications of differential equations and discusses many solution techniques such as separation of variable, variation of parameter, annihilator method and Frobenious method, etc. Then it introduces basic theory of existence and uniqueness for the system of first order ODEs which is essential for many branches of mathematics. This course also gives a glimpse how to analyze the behavior of solutions (maximum principle, stability, asymptotic stability, etc.). This course ends with an introduction to partial differential equations and method of characteristics, a technique to solve first order partial differential equations. Upon successful completion of this course the student will be able to model some practical situations into ordinary differential equations or partial differential equations and analyze the solution to get information about the parameters involved in the model.

Contents: Classifications of Differential Equations: origin and applications, family of curves, isoclines. First order equations: separation of variable, exact equation, integrating factor, Bernoulli equation, separable equation, homogeneous equations, orthogonal trajectories, Picard’s existence and uniqueness theorems. Second order equations: variation of parameter, annihilator methods. Series solution: power series solutions about regular and singular points. Method of Frobenius, Bessel's equation and Legendre equations. Wronskian determinant, Phase portrait analysis for 2nd order system, comparison and maximum principles for 2nd order equations. Linear system: general properties, fundamental matrix solution, constant coefficient system, asymptotic behavior, exact and adjoint equation, oscillatory equations, Green's function. Sturm-Liouville theory. Partial Differential Equations: Classifications of PDE, method of separation of variables, characterstic method.

Text Books:

1. S. L. Ross, "Differential Equations", Wiley-India Edition, 2009.
2. E. A. Coddington, "An Introduction to Ordinary Differential Equations", Prentice-Hall of India, 2012.

References:

1. G. F. Simmons, S. G. Krantz, "Differential Equations", Tata Mcgraw-Hill Edition, 2007.
2. B. Rai, D. P. Choudhury, "A Course in Ordinary Differential Equation", Narosa Publishing House, New Delhi, 2002.
3. R. P. Agarwal, D. OŔegan, "Ordinary and Partial Differential Equations", Universitext. Springer, 2009.

M304: Topology

Prerequisites: M204

L	*P*	*T*	*C*
3	0	1	4

Outcome: This course builds the foundations of point set topology and also covers basic algebraic topology (basics of covering spaces and fundamental group). After taking this course the students will be proficient in the abstract notion of a topological space, where continuous functions are defined in terms of open sets (and not the traditional $\varepsilon - \delta$ definition used in analysis). The students will appreciate some of the most important concepts in analysis from a topological perspective. For example, they will realize Intermediate value theorem is a statement about connectedness, Bolzano Weirstrass Theorem is a statement about compactness and so on. They will also get a solid grasp of quotient topology (which is a fundamentally new concept that is not an extension of the things already taught in analysis). The students will then be taught deeper concepts such as Ursysohn Lemma, Tietze extension theorem and Tychonoff Theorem. These topics will be of great use to anyone pursuing further studies in Topology, Functional Analysis, PDE and Probability.
The students will also learn the basics of fundamental group and covering spaces; they will be able to compute the fundamental group of a circle (but not much more beyond that in this course). After this course, they will be fully ready to study a more advanced course in Algebraic Topology that gets into the intricate details of fundamental group and singular homology. This course will also be very useful to anyone pursuing further studies in Differential Geometry (theory of manifolds).

Contents: Topological Spaces, Open and closed sets, Interior, Closure and Boundary of sets, Basis for Topology, Product Topology, Subspace Topology, Metric Topology, Compact Spaces, Locally compact spaces, Continuous functions, Open map, Homeomorphisms, Function Spaces, Separation Axioms: T1, Hausdorff, regular, normal spaces; Uryshon's lemma, Tietze

Extension Theorem, One point compactification, Connected Spaces, Path Connected Spaces, Quotient Topology, Homotopic Maps, Deformation Retract, Contractible Spaces, Fundamental Group, The Brouwer fixed-point theorem.

Text Books:

1. J. R.Munkres, "Topology", Prentice-Hall of India, 2013.
2. M. A. Armstrong, "Basic Topology", Undergraduate Texts in Mathematics, Springer-Verlag, 1983.

References:

1. J. L. Kelley, "General Topology", Graduate Texts in Mathematics, No. 27. Springer-Verlag, New York-Berlin, 1975.
2. K. Jänich, "Topology", Undergraduate Texts in Mathematics. Springer-Verlag, 1984.

M305: Statistics

Prerequisites: M206

L	P	T	C
3	0	1	4

Outcome: Students will be introduced to the discipline of statistics, learn about descriptive statistics of data sets including graphical representation using some statistical software. The focus is to learn about basic theory of point estimation, interval estimation, hypothesis testing and linear regression.

Contents: Descriptive Statistics, Graphical representation of data, Curve fittings, Simple correlation and regression, Multiple and partial correlations and regressions, Sampling, Sampling distributions, Standard error. Normal distribution and its properties, The distribution of $\overline{X}$ and S^2 in sampling from a normal distribution, Exact sampling distributions: χ^2, t, F. Theory and Methods of Estimation: Point estimation, Criteria for a good estimator, Properties of estimators: Unbiasedness, Efficiency, Consistency, Sufficiency, Robustness. A lower bound for a variance of an estimate, Method of estimation: The method of moment, Least square method, Maximum likelihood estimation and its properties, UMVU Estimator, Interval estimation. Test of Hypothesis: Elements of hypothesis testing, Unbiased test, Neyman-Pearson Theory, MP and UMP tests, Likelihood ratio and related tests, Large sample tests, Test based on χ^2, t, F.

Text Books:

1. H. J. Larson, "Introduction to Probability Theory and Statistical Inference", John Wiley & Sons, 1982.
2. V. K. Rohatgi, "Introduction to Probability Theory and Mathematical Statistics", John Wiley & Sons, 1976.

References:

1. I. Miller, M. Miller, "John E. Freund's Mathematical Statistics with Applications", Pearson, 2013.

M306: Calculus of Several Variables

Prerequisites: M201, M204

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will learn the notion of limits, continuity, differentiation and integration in the higher dimensional euclidean spaces.

Contents: Differentiability of functions from an open subset of $\mathbb{R}^n$ to $\mathbb{R}^m$ and properties, chain rule, partial and directional derivatives, Continuously differentiable functions, Inverse function theorem, Implicit function theorem, Interchange of order of differentiation, Taylor's series, Extrema of a function, Extremum problems with constraints, Lagrange multiplier method with applications, Integration of functions of several variables, Change of variable formula (without proof) with examples of applications of the formula, spherical coordinates, Stokes theorem (without proof), Deriving Green's theorem, Gauss theorem and Classical Stokes theorem.

Text Books:

1. W. Fleming, "Functions of Several Variables", Undergraduate Texts in Mathematics. Springer-Verlag, 1977.
2. T. M. Apostol, "Calculus Vol. II", Wiley-India edition, 2009.

References:

1. W. Kaplan, "Advanced Calculus", Addison-Wesley Publishing Company, 1984.
2. T. M. Apostol, "Mathematical Analysis", Narosa Publishing House, 2013.

M307: Field Theory

Prerequisites: M205, M302

L	*P*	*T*	*C*
3	0	1	4

Outcome: Expects students to learn basic properties of fields including the fundamental theorem of Galois theory.

Contents: Field extensions, algebraic extensions, Ruler and compass constructions, splitting fields, algebraic closures, separable and inseparable extensions, cyclotomic polynomials and extensions, automorphism groups and fixed fields, Galois extensions, Fundamental theorem of Galois theory, Fundamental theorem of algebra, Finite fields, Galois group of polynomials, Computations of Galois groups over rationals, Solvable groups, nilpotent groups, Solvability by radicals, Transcendental extensions.

Text Book:

1. D. S. Dummit, R. M. Foote, "Abstract Algebra", Wiley-India edition, 2013.

References:

1. I. N. Herstein, "Topics in Algebra", Wiley-India edition, 2013.
2. M. Artin, "Algebra", Prentice-Hall of India, 2007.
3. J. Rotman, "Galois Theory", Universitext, Springer-Verlag, 1998.

M308: Complex Analysis

Prerequisites: M306

L	*P*	*T*	*C*
3	0	1	4

Outcome: Upon successful completion of the course students will learn the concept of (complex) differentiation and integration of functions defined on the complex plane and their properties.

Contents: Algebraic and geometric representation of complex numbers; elementary functions including the exponential functions and its relatives (log, cos, sin, cosh, sinh, etc.); concept of holomorphic (analytic) functions, complex derivative and the Cauchy-Riemann equations; harmonic functions. Conformal Mapping, Linear Fractional Transformations, Complex line integrals and Cauchy Integral formula, Representation of holomorpic functions in terms of power series, Morera's theorem, Cauchy estimates and

Liouville's theorem, zeros of holomorphic functions, Uniform limits of holomorphic functions. Behaviour of holomorphic function near an isolated singularity, Laurent expansions, Counting zeros and poles, Argument principle, Rouche's theorem, Calculus of residues and evaluation of integrals using contour integration. The Open Mapping theorem, Maximum Modulus Principle, Schwarz Lemma.

Text Books:

1. J. B. Conway, "Functions of One Complex Variable", Narosa Publishing House, 2002.
2. R. E. Greene, S. G. Krantz, "Function Theory of One Complex Variable", American Mathematical Society, 2011.

References:

1. W. Rudin, "Real and Complex Analysis", Tata McGraw-Hill, 2013.
2. L. V. Ahlfors, "Complex Analysis", Tata McGraw-Hill, 2013.
3. T. W. Gamelin, "Complex Analysis", Undergraduate Texts in Mathematics, Springer, 2006.
4. E. M. Stein, R. Shakarchi, "Complex Analysis", Princeton University Press, 2003.

M310: Geometry of Curves and Surfaces

Prerequisites: M306

L	P	T	C
3	0	1	4

Outcome: Knowledge on curve and surfaces, manifold and vector field some application on geometry of surfaces.

Contents: Curves in two and three dimensions, Curvature and torsion for space curves, Existence theorem for space curves, Serret-Frenet formula for space curves, Jacobian theorem, Surfaces in $\mathbb{R}^3$ as 2-dimensional manifolds, Tangent spaces and derivatives of maps between manifolds, Geodesics, First fundamental form, Orientation of a surface, Second fundamental form and the Gauss map, Mean curvature, Gaussian Curvature, Differential forms, Integration on surfaces, Stokes formula, Gauss-Bonnet theorem.

Text Books:

1. M. P. Do Carmo, "Differential Geometry of Curves and Surfaces", Prentice Hall, 1976.
2. Andrew Pressley, "Elementary Differential Geometry", Springer, 2010.

References:

1. M. P. Do Carmo, "Differential Forms and Applications", Springer, 1994.
2. J. A. Thorpe, "Elementary Topics in Differential Geometry", Undergraduate texts in mathematics, Springer, 2011.

M311: Numerical Analysis

Prerequisites: M201, M303

L	P	T	C
2	1	1	4

Outcome: Upon successful completion of the course students will learn practical use of some important results from real analysis and linear algebra.

Contents: Errors in computation: Representation and arithmetic of numbers, source of errors, error propagation, error estimation. Numerical solution of non-linear equations: Bisection method, Secant method, Newton-Raphson method, Fixed point methods, Muller's method. Interpolations: Lagrange interpolation, Newton divided differences, Hermite interpolation, Piecewise polynomial interpolation. Approximation of functions: Weierstrass and Taylor expansion, Least square approximation. Numerical Integration: Trapezoidal rule, Simpson's rule, Newton-Cotes rule, Guassian quadrature. Numerical solution of ODE: Euler's method, multi-step methods, Runge-Kutta methods, Predictor-Corrector methods. Solutions of systems of linear equations: Gauss elimination, pivoting, matrix factorization, Iterative methods – Jacobi and Gauss-Siedel methods. Matrix eigenvalue problems: power method.

Text Book:

1. K. E. Atkinson, "An Introduction to Numerical Analysis" Wiley-India Edition, 2013.

References:

1. S. D. Conte, C. De Boor, "Elementary Numerical Analysis, Tata McGraw-Hill, 2006.
2. W. H. Press et. al., "Numerical Recipes - The Art of Scientific Computing", Cambridge University Press, 2007.

M401: Functional Analysis

Prerequisites: M204, M205

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will learn the concept of normed linear space and various properties of operators defined on them.

Contents: Normed linear spaces and continuous linear transformations, Hahn-Banach theorem (analytic and geometric versions), Baire's theorem and its consequences – three basic principles of functional analysis (open mapping theorem, closed graph theorem and uniform boundedness principle), Computing the dual of wellknown Banach spaces, Hilbert spaces, Riesz representation theorem, Adjoint operator, Compact operators, Spectral theorem for self adjoint compact operators.

Text Books:

1. J. B. Conway, "A Course in Functional Analysis", Graduates Texts in Mathematics 96, Springer, 2006.
2. B. Bollobás, "Linear Analysis", Cambridge University Press, 1999.

References:

1. G. F. Simmons, "Introduction to Topology and Modern Analysis", Tata McGraw-Hill, 2013.

M402: Representations of Finite Groups

Prerequisites: M202, M205, M302

L	P	T	C
3	0	1	4

Outcome: This course gives an introduction to the representation of finite groups via character theory.

Contents: Group representations, Maschke's theorem and completely reducibility, Characters, Inner product of Characters, Orthogonality relations, Burnside's theorem, induced characters, Frobenius reciprocity, induced representations, Mackey's Irreducibility Criterion, Character table of some wellknown groups, Representation theory of the symmetric group: partitions and tableaux, constructing the irreducible representations.

Text Book:

1. G. James, M. Liebeck, "Representations and Characters of Groups", Cambridge University Press, 2010.

References:

1. J. L. Alperin, R. B. Bell, "Groups and Representations", Graduate Texts in Mathematics 162, Springer, 1995.
2. B. Steinberg, "Representation Theory of Finite Groups", Universitext, Springer, 2012.
3. J-P. Serre, "Linear Representations of Finite Groups", Graduate Texts in Mathematics 42, Springer-Verlag, 1977.
4. B. Simon, "Representations of Finite and Compact Groups", Graduate Studies in Mathematics 10, American Mathematical Society, 2009.

M403: Commutative Algebra

Prerequisites: M302

L	P	T	C
3	0	1	4

Outcome: Expects students to understand various properties of commutative rings, various class of commutative rings, and dimension theory.

Contents: Commutative rings, ideals, operations on ideals, prime and maximal ideals, nilradicals, Jacobson radicals, extension and contraction of ideals, Modules, free modules, projective modules, exact sequences, tensor product of modules, Restriction and extension of scalars, localization and local rings, extended and contracted ideals in rings of fractions, Noetherian modules, Artinian modules, Primary decompositions and associate primes, Integral extensions, Valuation rings, Discrete valuation rings, Dedekind domains, Fractional ideals, Completion, Dimension theory.

Text Book:

1. M. F. Atiyah, I. G. Macdonald, "Introduction to Commutative Algebra", Addison-Wesley Publishing Co., 1969.

References:

1. R. Y. Sharp, "Steps in Commutative Algebra", London Mathematical Society Student Texts, 51. Cambridge University Press, 2000.
2. D. S. Dummit, R. M. Foote, "Abstract Algebra", Wiley-India edition, 2013.

M404: Algebraic Topology

Prerequisites: M302, M304

L	P	T	C
3	0	1	4

Outcome: This course lays down the foundations of fundamental group (π_1) and singular homology. The students will get a good in-depth knowledge of covering spaces. To begin with, they will study covering spaces as a tool to compute fundamental group (such as the circle, torus etc). Later on, they will study covering spaces in much greater depth; they will get an understanding of the correspondence between conjugacy classes of π_1 and the different covering spaces they correspond to. They will also learn that this correspondence is bijective if and only if the space is reasonable (path connected, locally path connected and semi-locally simply connected). Students will also learn different techniques to compute the fundamental group such as homotopy invariance and Van-Kampen Theorem.

The students will also learn about the basics of singular homology. They will learn different techniques to compute singular homology of a space, including homotopy invariance, Mayer-Vietoris, excision, long exact sequence etc. The students will also learn about the degree of a map. They will be able to use these concepts to prove non-trivial theorems such as invariance of domain, hairy ball theorem etc.

Contents: Homotopy Theory: Simply Connected Spaces, Covering Spaces, Universal Covering Spaces, Deck Transformations, Path lifting lemma, Homotopy lifting lemma, Group Actions, Properly discontinuous action, free groups, free product with amalgamation, Seifert-Van Kampen Theorem, Borsuk-Ulam Theorem for sphere, Jordan Separation Theorem. Homology Theory: Simplexes, Simplicial Complexes, Triangulation of spaces, Simplicial Chain Complexes, Simplicial Homology, Singular Chain Complexes, Cycles and Boundary, Singular Homology, Relative Homology, Short Exact Sequences, Long Exact Sequences, Mayer-Vietoris sequence, Excision Theorem, Invariance of Domain.

Text Books:

1. J. R. Munkres, "Topology", Prentice-Hall of India, 2013.
2. A. Hatcher, "Algebraic Topology", Cambridge University Press, 2009.

References:

1. G. E. Bredon, "Topology and Geometry", Graduates Texts in Mathematics 139, Springer, 2009.

Syllabus of Elective Courses

M451: Advanced Complex Analysis

Prerequisites: M308

L	P	T	C
3	0	1	4

Outcome: Students will learn some important theorems in complex analysis such as Riemann mapping theorem, Weirstrass factorization theorem, Runges theorem, Hardamard factorization theorem, Little Picards theorem and Great Picards theorem. They will also learn some basic techniques of harmonic functions and characterization of Dirichlet Region. These results are very useful in many branches of mathematics such as Number Thoery, Differential Geometry, Operator theory, Partal Differential Equations etc.

Contents: Review of basic Complex Analysis: Cauchy-Riemann equations, Cauchy's theorem and estimates, power series expansions, maximum modulus principle, Classification of singularities and calculus of residues. Space of continuous functions, Arzela's theorem, Spaces of analytic functions, Spaces of meromorphic functions, Riemann mapping theorem, Weierstrass Factorization theorem, Runge's theorem, Simple connectedness, Mittag-Leffler's theorem, Analytic continuation, Schwarz reflection principle, Mondromy theorem, Jensen's formula, Genus and order of an entire function, Hadamard factorization theorem, Little Picard theorem, Great Picard theorem, Harmonic functions.

References:

1. L. V. Ahlfors, "Complex Analysis", Tata McGraw-Hill, 2013.
2. J. B. Conway, "Functions of One Complex Variable II", Graduate Texts in Mathematics 159, Springer-Verlag, 1996.
3. W. Rudin, "Real and Complex Analysis", Tata McGraw-Hill, 2013.
4. R. Remmert, "Theory of Complex Functions", Graduate Texts in Mathematics 122, Springer, 2008.

M452: Advanced Functional Analysis

Prerequisites: M401

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will become aware of the concept of topological vector space, as a generalisation of normed linear spaces, and various properties of operators defined on them.

Contents: Definition and examples of topological vector spaces (TVS) and locally convex spaces (LCS); Linear operators; Hahn-Banach Theorems for TVS/ LCS (analytic and geometric forms); Uniform boundedness principle; Open mapping theorem; Closed graph thoerem; Weak and weak* vector topologies; Bipolar theorem; dual of LCS spaces; Krein-Milman theorem for TVS; Krien-Smulyan theorem for Banach spaces; Inductive and projective limit of LCS.

References:

1. W. Rudin, "Functional Analysis", Tata McGraw-Hill, 2007.
2. A. P. Robertson, W. Robertson, "Topological Vector Spaces", Cambridge Tracts in Mathematics 53, Cambridge University Press, 1980.
3. J. B. Conway, "A Course in Functional Analysis", Graduates Texts in Mathematics 96, Springer, 2006.

M453: Advanced Linear Algebra

Prerequisites: M205

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will become aware of various decomposition results of matrices and their applications.

Contents: Rational and Jordan canonical forms, Inner product spaces, Unitary and Normal operators, Forms on inner product spaces, Spectral theorems, Bilinear forms, Matrix decomposition theorems, Courant- Fischer minimax and related theorems, Nonnegative matrices, Perron-Frobenius theory, Generalized inverse, Matrix Norm, Perturbation of eigenvalues.

References:

1. R. A. Horn, C. R. Johnson, "Matrix Analysis", Cambridge University Press, 2010.
2. K. Hoffman, R. Kunze, "Linear Algebra", Prentice-Hall of India, 2012.
3. S. Roman, "Advanced Linear Algebra", Graduate Texts in Mathematics 135, Springer, 2008.

M454: Partial Differential Equations

Prerequisites: M301, M303, M306

L	P	T	C
3	0	1	4

Outcome: Students will learn explicit representations of solutions of four important classes of PDEs, namely, Transport equations, Heat equation, Laplace equation and wave equation for initial value problems. They will study the properties of solutions of these equations such as mean value property, maximum principles and regularity. They will also study Cauchy-Kowalevski Theorem and uniqueness theorem of Holmgreen for quasilinear equations.

Contents: Classification of Partial Differential Equations, Cauchy Problem, Cauchy-Kowalevski Theorem, Lagrange-Green identity, The uniquness theorem of Holmgren, Transport equation: Initial value problem, nonhomogeneous problem. Laplace equation: Fundamental solution, Mean Value formula, properties of Harmonic functions, Green's function, Energy methods, Harnack's inequality. Heat Equation: Fundamental solution, Mean value formula, properties of solutions. Wave equation: Solution by spherical means, Nonhomogeneous problem, properties of solutions.

References:

1. L. C. Evans, "Partial Differential Equations", Graduate Studies in Mathematics 19, American Mathematical Society, 2010.
2. F. John, "Partial Differential Equations", Springer International Edition, 2009.
3. G. B. Folland, "Introduction to Partial Differential Equations", Princeton University Press, 1995.
4. S. Kesavan, "Topics in Functional Analysis and Applications", John Wiley & Sons, 1989.

M455: Introduction to Stochastic Processes

Prerequisites: M206

L	P	T	C
3	0	1	4

Outcome: Students will be introduced to the theory of both discrete time and continuous time Markov chains.

Contents: Discrete Markov chains with countable state space; Classification of states: recurrences, transience, periodicity. Stationary distributions, reversible chains, Several illustrations including the Gambler's Ruin problem, queuing chains, birth and death chains etc. Poisson process, continuous time Markov chain with countable state space, continuous time birth and death chains.

References:

1. P. G. Hoel, S. C. Port, C. J. Stone, "Introduction to Stochastic Processes", Houghton Mifflin Co., 1972.
2. R. Durrett, "Essentials of Stochastic Processes", Springer Texts in Statistics, Springer, 2012.
3. G. R. Grimmett, D. R. Stirzaker, "Probability and Random Processes", Oxford University Press, 2001.
4. S. M. Ross, "Stochastic Processes", Wiley Series in Probability and Statistics: Probability and Statistics, John Wiley & Sons, 1996

M456: Algebraic Geometry

Prerequisites: M205, M302

L	*P*	*T*	*C*
3	0	1	4

Outcome: This course will introduce the students to the fundamentals of classical algebraic geometry. They will learn about the theory of Riemann surfaces, divisors, line bundles, Chern Classes and the Riemann Roch Theorem.

Contents: Prime ideals and primary decompositions, Ideals in polynomial rings, Hilbert Basis theorem, Noether normalisation lemma, Hilbert's Nullstellensatz, Affine and Projective varieties, Zariski Topology, Rational functions and morphisms, Elementary dimension theory, Smoothness, Curves, Divisors on curves, Bezout's theorem, Riemann-Roch for curves, Line bundles on Projective spaces.

References:

1. K. Hulek, "Elementary Algebraic Geometry", Student Mathematical Library 20, American Mathematical Society, 2003.
2. I. R. Shafarevich, "Basic Algebraic Geometry 1: Varieties in Projective Space", Springer, 2013.
3. J. Harris, "Algebraic geometry", Graduate Texts in Mathematics 133, Springer-Verlag, 1995.
4. M. Reid, "Undergraduate Algebraic Geometry", London Mathematical Society Student Texts 12, Cambridge University Press, 1988.
5. K. E. Smith et. al., "An Invitation to Algebraic Geometry", Universitext, Springer-Verlag, 2000.
6. R. Hartshorne, "Algebraic Geometry", Graduate Texts in Mathematics 52, Springer-Verlag, 1977.

M457: Algebraic Graph Theory

Prerequisites: M205, M208

L	*P*	*T*	*C*
3	0	1	4

Outcome: Learning the different algebraic techniques used in the study of the graphs

Contents: Adjacency matrix of a graph and its eigenvalues, Spectral radius of graphs, Regular graphs and Line graphs, Strongly regular graphs, Cycles and Cuts, Laplacian matrix of a graph, Algebraic connectivity, Laplacian spectral radius of graphs, Distance matrix of a graph, General properties of graph automorphisms, Transitive and Arc-tranisitve graphs, Symmetric graphs.

References:

1. N. Biggs, "Algebraic Graph Theory", Cambridge University Press, 1993.

2. C. Godsil, G. Royle, “Algebraic Graph Theory”, Graduate Texts in Mathematics 207, Springer-Verlag, 2001.
3. R. B. Bapat, “Graphs and Matrices”, Universitext, Springer, Hindustan Book Agency, New Delhi, 2010.

M458: Algebraic Number Theory

Prerequisites: M207, M307, M403

L	P	T	C
3	0	1	4

Outcome: This course gives an introduction to the basic properties of number fields, computation of class numbers and zeta functions.

Contents: Number Fields and Number rings, prime decomposition in number rings, Dedekind domains, Ideal class group, Galois theory applied to prime decomposition, Gauss reciprocity law, Cyclotomic fields and their ring of integers, finiteness of ideal class group, Dirichlet unit theorem, valuations and completions of number fields, Dedekind zeta function and distribution of ideal in a number ring.

References:

1. D. A. Marcus, “Number Fields”, Universitext, Springer-Verlag, 1977.
2. G. J. Janusz, “Algebraic Number Fields”, Graduate Studies in Mathematics 7, American Mathematical Society, 1996.
3. S. Alaca, K. S. Williams, “Introductory Algebraic Number Theory”, Cambridge University Press, 2004.
4. S. Lang, “Algebraic Number Theory”, Graduate Texts in Mathematics 110, Springer-Verlag, 1994.
5. A. Frohlich, M. J. Taylor, “Algebraic Number Theory”, Cambridge Studies in Advanced Mathematics 27, Cambridge University Press, 1993.
6. J. Neukirch, “Algebraic Number Theory”, Springer-Verlag, 1999.

M460: Algorithm

Prerequisites: M208

L	P	T	C
3	0	1	4

Outcome: Students will learn (i) Data structure, (ii) design and analysis algorithms and (iii) some important algorithms like sortings, graph theoretics, polynomial related and optimization related.

Contents: Algorithm analysis, asymptotic notation, probabilistic analysis; Data Structure: stack, queues, linked list, hash table, binary search tree, red-black tree; Sorting: heap sort, quick sort, sorting in linear time; Algorithm design: divide and conquer, greedy algorithms, dynamic programming; Algebraic algorithms: Winograd’s and Strassen’s matrix multiplication algorithm, evaluation of polynomials, DFT, FFT, efficient FFT implementation; Graph algorithms: breadth-first and depth-first search, minimum spanning trees, single-source shortest paths, all-pair shortest paths, maximum flow; NP-completeness and approximation algorithms.

References:

1. A. V. Aho, J. E. Hopcroft, J. D. Ullman, “The Design and Analysis of Computer Algorithms”, Addison-Wesley Publishing Co., 1975.
2. T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, “Introduction to Algorithms”, MIT Press, Cambridge, 2009.
3. E. Horowitz, S. Sahni, “Fundamental of Computer Algorithms”, Galgotia Publication, 1987.
4. D. E. Knuth, “The Art of Computer Programming Vol. 1, Vol. 2, Vol 3”, Addison-Wesley Publishing Co., 1997, 1998, 1998.

M462: Cryptology

Prerequisites: M202, M207

L	P	T	C
3	0	1	4

Outcome: It introduces the basics of Cryptography and cryptanalysis. Students learn theory and design of cryptographic schemes like stream ciphers, block ciphers and public key ciphers like RSA, El-Gamal, elliptic curve cryptosystem. Further, they learn about data authentication, integrity and secret sharing.

Contents: Overview of Cryptography and cryptanalysis, some simple cryptosystems (e.g., shift, substitution, affine, knapsack) and their cryptanalysis, classification of cryptosystems, classification of attacks; Information Theoretic Ideas: Perfect secrecy, entropy; Secret key cryptosystem: stream cipher, LFSR based stream ciphers, cryptanalysis of stream cipher (e.g., correlation attack, algebraic attacks), block cipher, DES, linear and differential cryptanalysis, AES; Public-key cryptosystem: Implementation and cryptanalysis of RSA, ElGamal public-key cryptosystem, Discrete logarithm problem, elliptic curve cryptography; Data integrity and authentication: Hash functions, message authentication code, digital signature scheme, ElGamal signature scheme; Secret sharing: Shamir's threshold scheme, general access structure and secret sharing.

References:

1. D. R. Stinson, "Cryptography: Theory And Practice", Chapman & Hall/CRC, 2006.
2. A. J. Menezes, P. C. van Oorschot, S. A. Vanstone, "Handbook of Applied Cryptography", CRC Press, 1997.

M463: Finite Fields

Prerequisites: M307

L	P	T	C
3	0	1	4

Outcome: This course gives a structure of finite fields, factorization of polynomials, some applications towards cryptography, coding theory and combinatorics.

Contents: Structure of finite fields: characterization, roots of irreducible polynomials, traces, norms and bases, roots of unity, cyclotomic polynomial, representation of elements of finite fields, Wedderburn's theorem; Polynomials over finite field: order of polynomials, primitive polynomials, construction of irreducible polynomials, binomials and trinomials, factorization of polynomials over small and large finite fields, calculation of roots of polynomials; Linear recurring sequences: LFSR, characteristic polynomial, minimal polynomial, characterization of linear recurring sequences, Berlekamp-Massey algorithm; Applications of finite fields: Applications in cryptography, coding theory, finite geometry, combinatorics.

References:

1. R. Lidl, H. Neiderreiter, "Finite Fields", Cambridge university press, 2000.
2. G. L. Mullen, C. Mummert, "Finite Fields and Applications", American Mathematical Society, 2007.
3. A. J. Menezes et. al., "Applications of Finite Fields", Kluwer Academic Publishers, 1993.
4. Z-X. Wan, "Finite Fields and Galois Rings", World Scientific Publishing Co., 2012.

M464: Information and Coding Theory

Prerequisites: M205, M307

L	P	T	C
3	0	1	4

Outcome: It introduces information theory and coding theory. In information theory, students learn how to measure information and encoding of information. In coding theory, students learn theory and techniques of error correcting codes like Reed-Muller codes, BCH codes, Reed-Solomon codes, Algebraic codes.

Contents: Information Theory: Entropy, Huffman coding, Shannon-Fano coding, entropy of Markov process, channel and mutual information, channel capacity;
Error correcting codes: Maximum likelihood decoding, nearest neighbour decoding, linear codes, generator matrix and parity-check matrix, Hamming bound, Gilbert-Varshamov bound, binary Hamming codes, Plotkin bound, nonlinear codes, Reed-Muller codes, Cyclic codes, BCH codes, Reed-Solomon codes, Algebraic codes.

References:

1. R. W. Hamming, "Coding and Information Theory", Prentice-Hall, 1986.
2. N. J. A. Sloane, F. J. MacWilliams, "Theory of Error Correcting Codes", North-Holland Mathematical Library 16, North-Holland, 2007.
3. S. Ling, C. Xing, "Coding Theory: A First Course", Cambridge University Press, 2004.
4. V. Pless, "Introduction to the Theory of Error-Correcting Codes", Wiley-Interscience Publication, John Wiley & Sons, 1998.
5. S. Lin, "An Introduction to Error-Correcting Codes", Prentice-Hall, 1970.

M465: Mathematical Logic

Prerequisites: M101

L	P	T	C
3	0	1	4

Outcome: Students will learn Mathematical logic. It starts from the propositional logic and then first order theory. Then introduces the completeness and compactness theorems with Godels incompleteness theorem.

Contents: Propositional Logic, Tautologies and Theorems of propositional Logic, Tautology Theorem. First Order Logic: First order languages and their structures, Proofs in a first order theory, Model of a first order theory, validity theorems, Metatheorems of a first order theory, e. g., theorems on constants, equivalence theorem, deduction and variant theorems etc. Completeness theorem, Compactness theorem, Extensions by definition of first order theories, Interpretations theorem, Recursive functions, Arithmatization of first order theories, Godels first Incompleteness theorem, Rudiments of model theory including Lowenheim-Skolem theorem and categoricity.

References:

1. J. R. Shoenfield, "Mathematical logic", Addison-Wesley Publishing Co., 1967.
2. E. Mendelson, "Introduction to Mathematical Logic", Chapman & Hall, 1997.

M466: Measure Theory

Prerequisites: M301

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will learn the concept of measures and measurable functions. Students also learn integration and their various properties.

Contents: $\sigma-$algebras of sets, measurable sets and measures, extension of measures, construction of Lebesgue measure, integration, convergence theorems, Radon-Nikodym theorem, product measures, Fubini's theorem, differentiation of integrals, absolutely continuous functions, L_p-spaces, Riesz representation theorem for the space $C[0, 1]$.

References:

1. G. De Barra, "Measure theory and integration".
2. J. Nevue, "Mathematical foundations of the calculus of probability", Holden-Day, Inc., 1965.
3. I. K. Rana, "An introduction to measure and integration", Narosa Publishing House.
4. P. Billingsley, "Probability and measure", John Wiley & Sons, Inc., 1995.
5. W. Rudin, "Real and complex analysis", McGraw-Hill Book Co., 1987.
6. K. R. Parthasarathy, "Introduction to probability and measure", The Macmillan Co. of India, Ltd., 1977.

M467: Nonlinear Analysis

Prerequisites: M306, M401

L	P	T	C
3	0	1	4

Outcome: Students will learn Calculus in Banach Spaces and degree theory. As an application of degree theory, they will study fixed point theorems of Brouwer and Schauder. Students will also learn homotopy, homotopy extension and invariance theorems and its applications. This course is very useful for the students who want to specialize in Partial Differential Equations.

Contents: Calculus in Banach spaces, inverse and multiplicit function theorems, fixed point theorems of Brouwer, Schauder and Tychonoff, fixed point theorems for nonexpansive and set-valued maps, predegree results, compact vector fields, homotopy, homotopy extension, invariance theorems and applications.

References:

1. S. Kesavan, "Nonlinear Functional Analysis", Texts and Readings in Mathematics 28, Hindustan Book Agency, 2004.

M468: Operator Theory

Prerequisites: M401

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will become familiar with concepts of C*-algebra, von-Neuman algebra and toeplitz operators and the notion of index for Fredholm operators.

Contents: Compact operators on Hilbert Spaces. (a) Fredholm Theory (b) Index, C*-algebras - noncommutative states and representations, Gelfand-Neumark representation theorem, Von-Neumann Algebras; Projections, Double Commutant theorem, L^∞ functionalCalculus, Toeplitz operators.

References:

1. W. Arveson, "An invitation to C*-algebras", Graduate Texts in Mathematics, No. 39. Springer-Verlag, 1976.
2. N. Dunford and J. T. Schwartz, "Linear operators. Part II: Spectral theory. Self adjoint operators in Hilbert space", Interscience Publishers John Wiley i& Sons 1963.
3. R. V. Kadison and J. R. Ringrose, "Fundamentals of the theory of operator algebras. Vol. I. Elementary theory", Pure and Applied Mathematics, 100, Academic Press, Inc., 1983.

4. V. S. Sunder, "An invitation to von Neumann algebras", Universitext, Springer-Verlag, 1987.

M469: Theory of Computation

Prerequisites: M101

L	P	T	C
3	0	1	4

Outcome: It introduces the theory of computer science. Here, the students learn (i) Automata and Language Theory by studying automata and context free language (ii) Computability theory by studying Turing machine and halting problem (iii) Complexity theory by studying P and NP class problems

Contents: Automata and Language Theory: Finite automata, regular expression, pumping lemma, context free grammar, context free languages, Chomsky normal form, push down automata, pumping lemma for CFL; Computability: Turing machines, Churh-Turing thesis, decidability, halting problem, reducibility, recursion theorem; Complexity: Time complexity of Turing machines, Classes P and NP, NP completeness, other time classes, the time hierarchy.

References:

1. J. E. Hopcroft, R. Motwani, J. D. Ullman, "Introduction to Automata Theory, Languages, and Computation", Addison-Wesley, 2006.
2. H. Lewis, C. H. Papadimitriou, "Elements of the Theory of Computation", Prentice-Hall, 1997.
3. M. Sipser, "Introduction to the Theory of Computation", PWS Publishing, 1997.

M470: Abstract Harmonic Analysis

Prerequisites: M301, M308, M401

L	P	T	C
3	0	1	4

Outcome: Knowledge on Haar measure, convolution structure on Lie group with emphasize to harmonic analysis on the groups Circle and real line.

Contents: Topological Groups: Basic properties of topological groups, subgroups, quotient groups. Examples of various matrix groups. Connected groups. Haar measure: Discussion of Haar measure without proof on $\mathbb{R}$, $\mathbb{T}$, $\mathbb{Z}$ and simple matrix groups, Convolution, the Banach algebra $L^1(G)$ and convolution with special emphasis on $L^1(\mathbb{R})$, $L^1(\mathbb{T})$ and $L^1(\mathbb{Z})$. Basic Representation Theory: Unitary representation of groups, Examples and General properties, The representations of Group and Group algebras, C^*-algebra of a group, GNS construction, Positive definite functions, Schur's Lemma. Abelian Groups: Fourier transform and its properties, Approximate identities in $L^1(G)$, Classical Kernels on $\mathbb{R}$, The Fourier inversion Theorem, Plancherel theorem on $\mathbb{R}$, Plancherel measure on $\mathbb{R}$, $\mathbb{T}$, $\mathbb{Z}$. Dual Group of an Abelian Group: The Dual group of a locally compact abelian group, Computation of dual groups for $\mathbb{R}$, $\mathbb{T}$, $\mathbb{Z}$, Pontryagin's Duality theorem.

References:

1. G. B. Folland, "A Course in Abstract Harmonic Analysis", CRC Press, 2000.
2. H. Helson, "Harmonic Analysis", Texts and Readings in Mathematics, Hindustan Book Agency, 2010.
3. Y. Katznelson, "An Introduction to Harmonic Analysis", Cambridge University Press, 2004.
4. L. H. Loomis, "An Introduction to Abstract Harmonic Analysis", Dover Publication, 2011.
5. E. Hewitt, K. A. Ross, "Abstract Harmonic Analysis Vol. I", Springer-Verlag, 1979.

6. W. Rudin, "Real and Complex Analysis", Tata McGraw-Hill, 2013.

M471: Advanced Number Theory

Prerequisites: M207, M307, M308

L	P	T	C
3	0	1	4

Outcome: This advanced course gives a brief introduction to p-adic numbers, quadratic forms, Dirichlet series and modular forms.

Contents: Review of Finite fields, Gauss Sums and Jacobi Sums, Cubic and biquadratic reciprocity, Polynomial equations over finite fields, Theorems of Chevally and Warning, Quadratic forms over prime fields. Ring of p-adic integers, Field of p-adic numbers, completion, p-adic equations, Hensel's lemma, Hilbert symbol, Quadratic forms with p-adic coefficients. Dirichlet series: Abscissa of convergence and absolute convergence, Riemann Zeta function and Dirichlet L-functions. Dirichlet's theorem on primes in arithmetic progression. Functional equation and Euler product for L-functions. Modular Forms and the Modular Group, Eisenstein series, Zeros and poles of modular functions, Dimensions of the spaces of modular forms, The j-invariant L-function associated to modular forms, Ramanujan τ function.

References:

1. J.-P. Serre, "A Course in Arithmetic", Graduate Texts in Mathematics 7, Springer-Verlag, 1973.
2. K. Ireland, M. Rosen, "A Classical Introduction to Modern Number Theory", Graduate Texts in Mathematics 84, Springer-Verlag, 1990.
3. H. Hasse, "Number Theory", Classics in Mathematics, Springer-Verlag, 2002.
4. W. Narkiewicz, "Elementary and Analytic Theory of Algebraic Numbers", Springer Monographs in Mathematics, Springer-Verlag, 2004.
5. F. Q. Gouvêa, "p-adic Numbers", Universitext, Springer-Verlag, 1997.

M472: Advanced Probability

Prerequisites: M206, M301

L	P	T	C
3	0	1	4

Outcome: Students will learn about measure theoretic probability starting from probability spaces to theory of martingales.

Contents: Probability spaces, Random Variables, Independence, Zero-One Laws, Expectation, Product spaces and Fubini's theorem, Convergence concepts, Law of large numbers, Kolmogorov three-series theorem, Levy-Cramer Continuity theorem, CLT for i.i.d. components, Infinite Products of probability measures, Kolmogorov's Consistency theorem, Conditional expectation, Discrete parameter martingales with applications.

References:

1. A. Gut, "Probability: A Graduate Course", Springer Texts in Statistics, Springer, 2013.
2. K. L. Chung, "A Course in Probability Theory", Academic Press, 2001.
3. S. I. Resnick, "A Probability Path", Birkhäuser, 1999.
4. P. Billingsley, "Probability and Measure", Wiley Series in Probability and Statistics, John Wiley & Sons, 2012.
5. J. Jacod, P. Protter, "Probability Essentials", Universitext, Springer-Verlag, 2003.

M473: Algebraic Combinatorics

Prerequisites: M202, M203

L	P	T	C
3	0	1	4

Outcome: Learning the use of different algebraic technique to study the combinatorial problems

Contents: Catalan Matrices and Orthogonal Polynomials, Catalan Numbers and Lattice Paths, Combinatorial Interpretation of Catalan Numbers, Symmetric Polynomials and Functions, Schur Functions, Jacobi-Trudi identity, RSK Algorithm, Standard Tableaux, Young diagrams and q-binomial coefficients, Plane Partitions, Group actions on boolean algebras, Enumeration under group action, Walks in graphs, Cubes and the Radon transform, Sperner property, Matrix-Tree Theorem.

References:

1. R. P. Stanley, "Algebraic Combinatorics", Undergraduate Texts in Mathematics, Springer, 2013.
2. M. Aigner, "A Course in Enumeration", Graduate Texts in Mathematics 238, Springer, 2007.
3. R. P. Stanley, "Enumerative Combinatorics Vol. 2", Cambridge Studies in Advanced Mathematics 62, Cambridge University Press, 1999.

M474: Foundations of Cryptography

Prerequisites: M102, M206

L	P	T	C
3	0	1	4

Outcome: The theoretical study of cryptography which puts foundation for the study and design of real-life cryptography.

Contents: Introduction to cryptography and computational model, computational difficulty, pseudorandom generators, zero-knowledge proofs, encryption schemes, digital signature and message authentication schemes, cryptographic protocol.

References:

1. O. Goldreich, "Foundations of Cryptography - Vol. I and Vol. II", Cambridge University Press, 2001, 2004.
2. S. Goldwasser, Mihir Bellare, "Lecture Notes on Cryptography", 2008, available online from http://cseweb.ucsd.edu/ mihir/papers/gb.html

M475: Incidence Geometry

Prerequisites: M205

L	P	T	C
3	0	1	4

Outcome: Understanding different kinds of incidence structures such as projective spaces, affine spaces, generalized quadrangles, polar spaces and quadratic sets.

Contents: Definitions and Exampleas, projective planes, affine planes, projective spaces, affine spaces, collineations of projective and affine spaces, fundamental theorem of projective and affine spaces, polar spaces, generalized quadrangles, quadrics and quadratic sets.

References:

1. J. Ueberberg, "Foundations of Incidence Geometry", Springer Monographs in Mathematics, Springer, 2011.
2. L. M. Batten, "Combinatorics of Finite Geometries", Cambridge University Press, 1997.
3. E. E. Shult, "Points and Lines", Universitext, Springer, 2011.
4. L. M. Batten, A. Beutelspacher, "The Theory of Finite Linear Spaces: Combinatorics of points and lines", Cambridge University Press, 1993.
5. G. E. Moorhouse, "Incidence Geometry", 2007, available online from http://www.uwyo.edu/moorhouse/handouts/incidence_geometry.pdf

M476: Lie Algebras

Prerequisites: M202, M205, M307

L	P	T	C
3	0	1	4

Outcome: This course serves two purposes. (i) To introduce the basics of Lie algebras to the students who are interested in algebra and pursue further in the studies of infinite dimensional Lie algebras like Kac-Moody Lie algebras on one hand and finite dimensional Lie algebras and their representations over any field on the other hand. (ii) As Lie algebras play infinitesimal part of Lie groups, they play important role in understanding Lie groups. The theory of semisimple Lie algebras is extremely rich thanks to Cartan, Weyl.. without which, one can not understand the geometry of semisimple Lie groups and their representations and also compact Lie groups.
After having done this course, one can pursue the studies on either Lie algebras or Representation theory of Lie groups.

Contents: Definitions and Examples, Derivations, Ideals, Homomorphisms, Nilpotent Lie Algebras and Engel's theorem, Solvable Lie Algebras and Lie's theorem, Jordan decomposition and Cartan's criterion, Semisimple Lie algebras, Casimir operator and Weyl's theorem, Representations of $sl(2, F)$, Root space decomposition, Abstract root systems, Weyl group and Weyl chambers, Classification of irreducible root systems, Abstract theory of weights, Isomorphism and conjugacy theorems, Universal enveloping algebras and PBW theorem, Representation theory of semi-simple Lie algebras, Verma modules and Weyl character formula.

References:

1. J. E. Humphreys, "Introduction to Lie Algebras and Representation Theory", Graduate Texts in Mathematics 9, Springer-Verlag, 1978.
2. K. Erdmann, M. J. Wildon, "Introduction to Lie Algebras", Springer Undergraduate Mathematics Series, Springer-Verlag, 2006.
3. J.-P. Serre, "Complex Semisimple Lie Algebras", Springer Monographs in Mathematics, Springer-Verlag, 2001.
4. N. Jacobson, "Lie Algebras", Dover Publications, 1979.

M477: Optimization Theory

Prerequisites: M102, M205

L	P	T	C
3	0	1	4

Outcome: Understanding the different techniques used to solve the linear and non-linear programming problem

Contents: Linear programming problem and its formulation, convex sets and their properties, Graphical method, Simplex method, Duality in linear programming, Revised simplex method, Integer programming, Transportation problems, Assignment problems, Games and strategies, Two-person (non) zero-sum games, Introduction to non-linear programming and techniques.

References:

1. J. K. Strayer, "Linear Programming and its Applications", Undergraduate Texts in Mathematics, Springer-Verlag, 1989.
2. P. R. Thie, G. E. Keough, "An Introduction to Linear Programming and Game Theory", John Wiley & Sons, 2008.
3. L. Brickman, "Mathematical Introduction to Linear Programming and Game Theory", Undergraduate Texts in Mathematics, Springer-Verlag, 1989.
4. D. G. Luenberger, Y. Ye, "Linear and Nonlinear Programming", International Series in Operations Research & Management Science 116, Springer, 2008.

M478: Advanced Partial Differential Equations

Prerequisites: M401, M454

L	P	T	C
3	0	1	4

Outcome: Students will learn basics of distribution Theory, Sobolev Spaces and their properties. Using Sobolev space Theory, students will learn existence theory of solutions for Dirichlet, Neuman and oblique derivative problems for second order elliptic partial differential equations. They will also learn weak and strong maximum principles, Hopf Maximum Principle and Alexandrof-Bakelmann-Pucci estimate for the solutions. This course is very useful for the students who want to specialize in Partial Differential Equations.

Contents: Distribution Theory, Sobolev Spaces, Embedding theorems, Trace theorem. Dirichlet, Neumann and Oblique derivative problem, Weak formulation, Lax–Milgram, Maximum Principles– Weak and Strong Maximum Principles, Hopf Maximum Principle, Alexandroff-Bakelmann-Pucci Estimate.

References:

1. L. C. Evans, "Partial Differential Equations", Graduate Studies in Mathematics 19, American Mathematical Society, 2010.
2. H. Brezis, "Functional Analysis, Sobolev Spaces and Partial Differential Equations", Universitext, Springer, 2011.
3. R. A. Adams, J. J. F. Fournier, "Sobolev Spces", Pure and Applied Mathematics 140, Elsevier/Academic Press, 2003.
4. S. Kesavan, "Topics in Functional Analysis and Applications", John Wiley & Sons, 1989.
5. M. Renardy, R. C. Rogers, "An Introduction to Partial Differential Equations", Springer, 2008.

M479: Random Graphs

Prerequisites: M206, M208

L	P	T	C
3	0	1	4

Outcome: The aim is to learn random graphs and its applications.

Contents: Models of random graphs and of random graph processes; illustrative examples; random regular graphs, configuration model; appearance of the giant component small subgraphs; long paths and Hamiltonicity; coloring problems; eigenvalues of random graphs and their algorithmic applications; pseudo-random graphs.

References:

1. N. Alon, J. H. Spencer, "The Probabilistic Method", John Wiley & Sons, 2008
2. B. Bollobás, "Random Graphs", Cambridge Studies in Advanced Mathematics 73, Cambridge University Press, 2001.
3. S. Janson, T. Luczak, A. Rucinski, "Random Graphs", Wiley-Interscience, 2000.
4. R. Durrett, "Random Graph Dynamics", Cambridge University Press, 2010.
5. J. H. Spencer, "The Strange Logic of Random Graphs", Springer-Verlag, 2001.

M480: Randomized Algorithms and Probabilistic Methods

Prerequisites: M206

L	P	T	C
3	0	1	4

Outcome: The aim is to learn how to use probabilistic techniques to different areas of mathematics and computer science.

Contents: Inequalities of Markov and Chebyshev (median algorithm), first and second moment method (balanced allocation), inequalities of Chernoff (permutation routing) and Azuma (chromatic number), rapidly mixing

Markov chains (random walk in hypercubes, card shuffling), probabilistic generating functions (random walk in d-dimensional lattice)

References:

1. R. Motwani, P. Raghavan, "Randomized Algorithms", Cambridge University Press, 2004.
2. M. Mitzenmacher, E. Upfal, "Probability and Computing: Randomized algorithms and probabilistic analysis", Cambridge University Press, 2005.

M481: Statistical Inference I

Prerequisites: M206 and M305 or equivalent courses

L	P	T	C
3	0	1	4

Outcome: The outcome of this course is to learn about parametric statistical inference to be applicable to almost all branches of statistics. Students will learn various methods of estimation and hypothesis testing and their large sample and small sample properties.

Contents: Review: joint and conditional distributions, order statistics, group family, exponential family. Introduction to parametric inference, sufficiency principle and data reduction, factorization theorem, minimal sufficient statistics, Fisher information, ancillary statistics, complete statistics, Basu's theorem. Unbiasedness, best unbiased and linear unbiased estimator, Rao-Blackwell theorem, Lehmann- Scheffe theorem and UMVUE, Cramer-Rao lower bound and UMVUE, multi-parameter cases. Location and scale invariance, principle of equivarience. Methods of estimation: method of moments, likelihood principle and maximum likelihood estimation, properties of MLE: invariance, consistency, asymptotic normality. Hypothesis testing: error probabilities and power, most powerful tests, Neyman-Pearson lemma and its applications, p-value, uniformly most powerful (UMP) test via Neyman- Pearson lemma, UMP test via monotone likelihood ratio property, existence and nonexistence of UMP test for two sided alternative, unbiased and UMP unbiased tests. Likelihood (generalized) ratio tests and its properties, invariance and most powerful invariant tests. Introduction to confidence interval estimation, methods of fining confidence intervals: pivotal quantity, inversion of a test, examples such as confidence interval for mean, variance, difference in means, optimal interval estimators, uniformly most accurate confidence bound, large sample confidence intervals.

References:

1. E. L. Lehmann and G. Casella, "Theory of Point Estimation", 2nd edition, Springer, New York, 1998.
2. E. L. Lehmann and J. P. Romano, "Testing Statistical Hypothesis", 3rd edition, Springer, 2005.
3. N. Mukhopadhyay, "Probability and Statistical Inference", Marcel Dekker, New York. 2000.
4. G. Casella and R. L. Berger, "Statistical Inference", 2nd edition, Cengage Learning, 2001.
5. A. M. Mood, F. A. Graybill and D. C. Boes, "Introduction to the theory of Statistics", 3rd edition, McGraw Hill, 1974.

M482: Multivariate Statistical Analysis

Prerequisites: M305, M306, and M205 or equivalent courses

L	P	T	C
3	0	1	4

Outcome: Students will learn about various modern statistical tools to analyze and draw inference from multivariate data sets. Starting from multivariate normal distribution, students will learn inference about multivariate sample mean and variance, techniques of dimension reduction, introductory factor analysis, cluster analysis and statistical pattern recognition.

Contents: Review of matrix algebra (optional), data matrix, summary statistics, graphical representations. Distribution of random vectors, moments and characteristic functions, transformations, some multivariate distributions: multivariate normal, multinomial, Dirichlet distribution, limit theorems. Multivariate normal distribution: properties, geometry, characteristics function, moments, distributions of linear combinations, conditional distribution and multiple correlation. Estimation of mean and variance of multivariate normal, theoretical properties, James-Stein estimator (optional), distribution of sample mean and variance, the Wishart distribution, large sample behavior of sample mean and variance, assessing normality. Inference about mean vector: testing for normal mean, Hotelling T^2 and likelihood ratio test, confidence regions and simultaneous comparisons of component means, paired comparisons and a repeated measures design, comparing mean vectors from two populations, MANOVA. Techniques of dimension reduction, principle component analysis: definition of principle components and their estimation, introductory factor analysis, multidimensional scaling. Classification problem: linear and quadratic discriminant analysis, logistic regression, support vector machine. Cluster analysis: non-hierarchical and hierarchical methods of clustering.

References:

1. K. V. Mardia, J. T. Kent and J. M. Bibby, "Multivariate Analysis", Academic Press, 1980.
2. T. W. Anderson, "An introduction to Multivariate Statistical Analysis", Wiley, 2003.
3. C. Chatfield and A. J. Collins, "Introduction to Multivariate Analysis", Chapman & Hall, 1980.
4. R. A. Johnson and D. W. Wichern, "Applied Multivariate Statistical Analysis", 6th edition, Pearson, 2007.
5. Brian Everitt and Torsten Hothorn, "An Introduction to Applied Multivariate Analysis with R", Springer, 2011.
6. M. L. Eaton, "Multivariate Statistics", John Wiley, 1983.

M483: Introduction to Manifolds

Prerequisites: M304

L	P	T	C
3	0	1	4

Outcome: This course lays the foundations of modern Differential Geometry. After taking this course, the students will get a good knowledge of smooth manifolds, tangent and cotangent spaces, vector bundles, (co)tangent bundles, vector fields, differential forms, exterior differentiation, De-Rham cohomology, integration on manifolds, homotopy invariance of De-Rham cohomology and the statement of Poincare Duality. After studying this course, students will be fully prepared to pursue further studies in (complex) algebraic geometry, theory of Riemann surfaces and Riemannian Geometry. Students will also be fully equipped to pursue further studies in analysis on manifolds, particularly the theory of Elliptic operators on smooth manifolds and Hodge Theory (which culminates in the proof of Poincare Duality). Students who are interested in either Topology, Differential Geometry, Algebraic Geometry and certain topics in analysis and PDE, with a geometric flavor (i.e. Geometric Analysis) will find this course very useful.

Contents: Differentiable manifolds and maps: Definition and examples, Inverse and implicit function theorem, Submanifolds, immersions and submersions. The tangent and cotangent bundle: Vector bundles, (co)tangent bundle as a vector bundle, Vector fields, flows, Lie derivative. Differential forms and Integration: Exterior differential, closed and exact forms, Poincaré lemma, Integration on manifolds, Stokes theorem, De Rham cohomology.

References:

1. Michael Spivak, "A comprehensive introduction to differential geometry", Vol. 1, 3rd edition, 1999.
2. Frank Warner, "Foundations of differentiable manifolds and Lie groups", Springer-Verlag, 2nd edition, 1983.
3. John Lee, "Introduction to smooth manifolds", Springer Verlag, 2nd edition, 2013.
4. Louis Auslander and Robert E. MacKenzie, "Introduction to differentiable manifolds", Dover, 2nd edition, 2009.

M551: Algebraic Computation

Prerequisites: M205, M307

L	P	T	C
3	0	1	4

Outcome: It is a unique style of course where the mathematics students having interest in computation can learn to compute different algebraic problems in computer. Here students will learn the computation of the problems related (i) linear algebra, (ii) non-linear system of equations like Grobner bases, (iii) polynomial, (iv) algebraic number theory and (v) elliptic curve.

Contents: Linear algebra and lattices: Asymptotically fast matrix multiplication algorithms, linear algebra algorithms, normal forms over fields, Lattice reduction; Solving system of non-linear equations: Gröbner basis, Buchberger's algorithms, Complexity of Gröbner basis computation; Algorithms on polynomials: GCD, Barlekamp-Massey algorithm, factorization of polynomials over finite field, factorization of polynomials over $\mathbb{Z}$ and $\mathbb{Q}$; Algorithms for algebraic number theory: Representation and operations on algebraic numbers, trace, norm, characteristic polynomial, discriminant, integral bases, polynomial reduction, computing maximal order, algorithms for quadratic fields; Elliptic curves: Implementation of elliptic curve, algorithms for elliptic curves.

References:

1. A. V. Aho, J. E. Hopcroft, J. D. Ullman, "The Design and Analysis of Computer Algorithms", Addison-Wesley Publishing Co., 1975.
2. H. Cohen, "A Course in Computational Algebraic Number Theory", Graduate Texts in Mathematics 138, Springer-Verlag, 1993.
3. D. Cox, J. Little, D. O'shea, "Ideals, Varieties and Algorithms: An introduction to computational algebraic geometry and commutative algebra", Undergraduate Texts in Mathematics, Springer-verlag, 2007.

M552: Analytic Number Theory

Prerequisites: M201, M207, M308

L	P	T	C
3	0	1	4

Outcome: Expects students to learn elementary properties of Dirichlet series and distribution of primes.

Contents: Arithmetic functions, Averages of arithmetical functions, Distribution of primes, finite abelian groups and characters, Gauss sums, Dirichlet series and Euler products, Reimann Zeta function, Dirichlet L-functions, Analytic proof of the prime number theorem, Dirichlet Theorem on primes in arithmetic progression.

References:

1. T. M. Apostol, "Introduction to Analytic Number Theory", Springer International Student Edition, 2000.
2. K. Chandrasekharan, "Introduction to Analytic Number Theory", Springer-Verlag, 1968.
3. H. Iwaniec, E. Kowalski, "Analytic Number Theory", American Mathematical Society Colloquium Publications 53, American Mathematical Society, 2004.

M553: Classical Groups

Prerequisites: M202, M205, M307

L	*P*	*T*	*C*
3	0	1	4

Outcome: Understanding the basic facts about classical groups defined over fields such as General Linear groups, Special Linear groups, Symplectic groups, Orthogonal groups and Unitary groups.

Contents: General and special linear groups, bilinear forms, Symplectic groups, symmetric forms, quadratic forms, Orthogonal geometry, orthogonal groups, Clifford algebras, Hermitian forms, Unitary spaces, Unitary groups.

References:

1. L. C. Grove, "Classical Groups and Geometric Algebra", Graduate Studies in Mathematics 39, American Mathematical Society, 2002.
2. E. Artin, "Geometric Algebra", John Wiley & sons, 1988.

M554: Ergodic Theory

Prerequisites:

L	*P*	*T*	*C*
3	0	1	4

Outcome: The origin and motivation of studies of Ergodic theory comes from the statistical physics. One of the main branches in Analysis, it aims to give a formal mathematical treatment of movements of particles in a measure space. The important application is to study the behaviours of atoms and molecules in the ambit of aggregate systems. So, naturally the probability theory lies in the undercurrent of Ergodic theory. This theory emerged as a bridge between Probability theory, Physics and Functional analysis. It has a lot of applications in Statistical physics and mathematical biology.

Contents: Measure preserving systems; examples: Hamiltonian dynamics and Liouvilles theorem, Bernoulli shifts, Markov shifts, Rotations of the circle, Rotations of the torus, Automorphisms of the Torus, Gauss transformations, Skew-product, Poincare Recurrence lemma: Induced transformation: Kakutani towers: Rokhlins lemma. Recurrence in Topological Dynamics, Birkhoffs Recurrence theorem, Ergodicity, Weak-mixing and strong-mixing and their characterizations, Ergodic Theorems of Birkhoff and Von Neumann. Consequences of the Ergodic theorem. Invariant measures on compact systems, Unique ergodicity and equidistribution. Weyls theorem, The Isomorphism problem; conjugacy, spectral equivalence, Transformations with discrete spectrum, Halmosvon Neumann theorem, Entropy. The Kolmogorov-Sinai theorem. Calculation of Entropy. The Shannon McMillanBreiman Theorem, Flows. Birkhoffs ergodic Theorem and Wieners ergodic theorem for flows. Flows built under a function.

References:

1. Peter Walters, "An introduction to ergodic theory", Graduate Texts in Mathematics, 79. Springer-Verlag, 1982.
2. Patrick Billingsley, "Ergodic theory and information", Robert E. Krieger Publishing Co., 1978.
3. M. G. Nadkarni, "Basic ergodic theory", Texts and Readings in Mathematics, 6. Hindustan Book Agency, 1995.
4. H. Furstenberg, "Recurrence in ergodic theory and combinatorial number theory", Princeton University Press, 1981.
5. K. Petersen, "Ergodic theory", Cambridge Studies in Advanced Mathematics, 2. Cambridge University Press, 1989.

M555: Harmonic Analysis

Prerequisites: M301

L	P	T	C
3	0	1	4

Outcome: knowldege on Fourier Series , Fourier transforms and celebrated differentiation theorem and important operators like Hilbert transform and Maximal function.

Contents: Fourier series and its convergences, Dirichlet kernel, Frejer kernel, Parseval formula and its applications. Fourier transforms,the Schwartz space, Distribution and tempered distribution, Fourier Inversion and Plancherel theorem. Fourier analysis on L_p-spaces. Maximal functions and boundedness of Hilbert transform. Paley-Wiener Theorem for distribution. Poisson summation formula, Heisenberg uncertainty Principle, Wiener's Tauberian theorem.

References:

1. Y. Katznelson, "An Introduction to Harmonic Analysis", Cambridge University Press, 2004.
2. E. M. Stein, G. Weiss, "Introduction to Fourier Analysis on Euclidean Spaces", Princeton Mathematical Series 32, Princeton University Press, 1971.
3. G. B. Folland, "Fourier Analysis and its Applications", Pure and Applied Undergraduate Texts 4, America Mathematical Society, 2010.

M556: Lie Groups and Lie Algebras - I

Prerequisites: M205, M304, M306

L	P	T	C
3	0	1	4

Outcome: Understanding the technique used for constructing combinatorial designs and its relation with linear codes Outcomes: The aim of this course and M564- Lie groups and Lie algebras II is to give a strong foundation on the study of Lie groups and their infinitesimal version viz., Lie algebras. The prominent role played by Lie groups in the study of Geometry and theoritical physics needs no further emphasis. This course is tremendously beneficial for the mathematics students and physics students as well. It begins with the rudiments of Lie groups and finally ends with irreducible representations of compact Lie groups parametrised by Weyl Character formula.

Contents: General Properties: Definition of Lie groups, subgroups, cosets, group actions on manifolds, homogeneous spaces, classical groups. Exponential and logarithmic maps, Adjoint representation, Lie bracket, Lie algebras, subalgebras, ideals, stabilizers, center Baker-Campbell-Hausdorff formula, Lie's Theorems. Structure Theory of Lie Algebras: Solvable and nilpotent Lie algebras (with Lie/Engel theorems), semisimple and reductive algebras, invariant bilinear forms, Killing form, Cartan criteria, Jordan decomposition. Complex semisimple Lie algebras, Toral subalgebras, Cartan subalgebras, Root decomposition and root systems. Weight decomposition, characters, highest weight representations, Verma modules, Classification of irreducible finite-dimensional representations, BGG resolution, Weyl character formula.

References:

1. D. Bump, "Lie Groups", Graduate Texts in Mathematics 225, Springer, 2013.
2. J. Faraut, "Analysis on Lie Groups", Cambridge Studies in Advanced Mathematics 110, Cambridge University Press, 2008.
3. B. C. Hall, "Lie Groups, Lie algebras and Representations", Graduate Texts in Mathematics 222, Springer-Verlag, 2003.
4. W. Fulton, J. Harris, "Representation Theory: A first course", Springer-Verlag, 1991.
5. J. E. Humphreys, "Introduction to Lie Algebras and Representation Theory", Graduate Texts in Mathematics 9, Springer-Verlag, 1978.
6. A. Kirillov, "Introduction to Lie Groups and Lie Algebras", Cambridge Studies in Advanced Mathematics 113, Cambridge University Press, 2008.
7. V. S. Varadharajan, "Lie Groups, Lie Algebras and their Representations", Springer-Verlag, 1984.

M557: Operator Algebras

Prerequisites: M401

L	P	T	C
3	0	1	4

Outcome: Upon successful completion of the course students will become familiar with concepts and various structure theorems of C*-algebra and von-Neuman algebra.

Contents: Banach algebras/C*–algebras: Definition and examples; Spectrum of a Banach algebra; Gelfand transform; Gelfand-Naimark theorem for commutative Banach algebras/ C*-algebras; Functional calculus for C*-algebras; Positive cone in a C*-algebra; Existance of an approximate identity in a C*-algebra; Ideals and Quotients of a C*-algebra; Positive linear functionals on a C*-algebra; GNS construction. Locally convex topologies on the algebras of bounded operators on a Hilbert space, von-Neumann's bicommutant theorem; Kaplansky's density theorem. Ruan's characterization of Operator Spaces (if time permites).

References:

1. R. V. Kadison, J. R. Ringrose, "Fundamentals of the Theory of Operator Algebras Vol. I", Graduate Studies in Mathematics 15, American Mathematical Society, 1997.
2. G. K. Pedersen, "C*–algebras and their Automorphism Groups", London Mathematical Society Monographs 14, Academic Press, 1979.
3. V. S. Sunder, "An Invitation to von Neumann Algebras", Universitext, Springer-Verlag, 1987.
4. M. Takesaki, "Theory of Operator Algebras Vol. I", Springer-Verlag, 2002.

M558: Representations of Linear Lie Groups

Prerequisites: M205, M304, M306

L	P	T	C
3	0	1	4

Outcome: This course is a more basic than M556 and M564 laying foundation for the students who want to take up one of the branches of mainstream mathematics namely, non-abelian harmonic analysis. The prototype of the complications that might arise in the study of non-abelian harmonic analysis, is amply found in the study of Linear Lie groups. Yet, these linear Lie groups are plausible to understand as they are concrete examples of non-compact non-abelian Lie groups.

The course starts from the first principles of representations and goes upto understanding the important examples of 3 different types of groups, viz., compact, nilpotent and solvable groups. It is quite beneficial for the students who want to get into representation theory.

Contents: Introduction to topological group, Haar measure on locally compact group, Representation theory of compact groups, Peter Weyl theorem, Linear Lie groups, Exponential map, Lie algebra, Invariant Differentail operators, Representation of the group and its Lie algebra. Fourier analysis on $SU(2)$ and $SU(3)$. Representation theory of Heisenberg group . Representation of Euclidean motion group.

References:

1. J. E. Humphreys, "Introduction to Lie algebras and representation theory", Springer-Verlag, 1978.
2. S. C. Bagchi, S. Madan, A. Sitaram, U. B. Tiwari, "A first course on representation theory and linear Lie groups", University Press, 2000.
3. Mitsou Sugiura, "Unitary Representations and Harmonic Analysis", John Wiley & Sons, 1975.
4. Sundaram Thangavelu, "Harmonic Analysis on the Heisenberg Group", Birkhauser, 1998.
5. Sundaram Thangavelu, "An Introduction to the Uncertainty Principle", Birkhauser, 2003.

M559: Harmonic Analysis on Compact Groups

Prerequisites: M205, M304, M401

L	P	T	C
3	0	1	4

Outcome: Knowledge on representaion on compact lie groups with examples $SU(2)$, $SO(n)$.

Contents: Review of General Theory: Locally compact groups, Computation of Haar measure on $\mathbb{R}$, $\mathbb{T}$, $SU(2)$, $SO(3)$ and some simple matrix groups, Convolution, the Banach algebra $L^1(G)$. Representation Theory: General properties of representations of a locally compact group, Complete reducibility, Basic operations on representations, Irreducible representations. Representations of Compact groups: Unitarilzibality of representations, Matrix coefficients, Schur's orthogonality relations, Finite dimensionality of irreducible representations of compact groups. Various forms of Peter-Weyl theorem, Fourier analysis on Compact groups, Character of a representation. Schur's orthogonality relations among characters. Weyl's Chracter formula, Computing the Unitary dual of $SU(2)$, $SO(3)$; Fourier analysis on $SO(n)$.

References:

1. T. Brocker, T. Dieck, "Representations of Compact Lie Groups", Springer-Verlag, 1985.
2. J. L. Clerc, "Les Représentatios des Groupes Compacts, Analyse Harmonique" (J. L. Clerc et. al., ed.), C.I.M.P.A., 1982.
3. G. B. Folland, "A Course in Abstract Harmonic Analysis", CRC Press, 2000.
4. M. Sugiura, "Unitary Representations and Harmonic Analysis", John Wiley & Sons, 1975.
5. E. B. Vinberg, "Linear Representations of Groups", Birkhäuser/Springer, 2010.
6. A. Wawrzyńczyk, "Group Representations and Special Functions", PWN–Polish Scientific Publishers, 1984.

M560: Modular Forms of One Variable

Prerequisites: M202, M205, M207, M308

L	P	T	C
3	0	1	4

Outcome: This course gives an introduction to modular forms over 2 and their congruence subgroups, and their Hecke theory.

Contents: $SL_2(\mathbb{Z})$ and its congruence subgroups, Modular forms for $SL_2(\mathbb{Z})$, Modular forms for congruence subgroups, Modular forms and differential operators, Hecke theory, L-series, Theta functions and transformation formula.

References:

1. J.-P. Serre, "A Course in Arithmetic", Graduate Texts in Mathematics 7, Springer-Verlag, 1973.
2. N. Koblitz, "Introduction to Elliptic Curves and Modular Forms", Graduate Texts in Mathematics 97, Springer-Verlag, 1993.
3. J. H. Bruinier, G. van der Geer, G. Harder, D. Zagier, "The 1-2-3 of Modular Forms", Universitext, Springer-Verlag, 2008.
4. F. Diamond, J. Shurman, "A First Course in Modular Forms", Graduate Texts in Mathematics 228, Springer-Verlag, 2005.
5. S. Lang, "Introduction to Modular Forms", Springer-Verlag, 1995.
6. G. Shimura, "Introduction to the Arithmetic Theory of Automorphic Forms", Princeton University Press, 1994.

M561: Elliptic Curves

Prerequisites: M202, M207, M308

L	P	T	C
3	0	1	4

Outcome: This course gives an introduction to elliptic curves and the structure of their rational points.

Contents: Congruent numbers, Elliptic curves, Elliptic curves in Weierstrass form, Addition law, Mordell–Weil Theorem, Points of finite order, Points over finite fields, Hasse-Weil L-function and its functional equation, Complex multiplication.

References:

1. J. H. Silverman, J. Tate, "Rational Points on Elliptic Curves", Undergraduate Texts in Mathematics, Springer-Verlag, 1992.
2. N. Koblitz, "Introduction to Elliptic Curves and Modular Forms", Graduate Texts in Mathematics 97, Springer-Verlag, 1993.
3. J. H. Silverman, "The Arithmetic of Elliptic Curves", Graduate Texts in Mathematics 106, Springer, 2009.
4. A. W. Knapp, "Elliptic Curves", Mathematical Notes 40, Princeton University Press, 1992.
5. J. H. Silverman, "Advanced Topics in the Arithmetic of Elliptic Curves", Graduate Texts in Mathematics 151, Springer-Verlag, 1994.

M562: Brownian Motion and Stochastic Calculus

Prerequisites: M472

L	P	T	C
3	0	1	4

Outcome: Students will learn about the theory of Brownian motion and it applications to stochastic differential equations.

Contents: Brownian Motion, Martingale, Stochastic integrals, extension of stochastic integrals, stochastic integrals for martingales, Itô's formula, Application of Itô's formula, stochastic differential equations.

References:

1. H. H. Kuo, "Introduction to Stochastic Integration", Springer, 2006.
2. J M Steele, "Stochastic Calculus and Financial Applications", Springer-Verlag, 2001.
3. F. C. Klebaner, "Introduction to Stochastic Calculus with Applications", Imperial College, 2005.

M563: Differentiable Manifolds and Lie Groups

Prerequisites: M304, M306

L	P	T	C
3	0	1	4

Outcome: This course will introduce the students to the fundamentals of Lie groups and Lie Algebras. After studying this course, students will get a working knowledge of smooth manifolds, but unlike M483, this course will get into an in depth study of Lie Groups. The students will study about (bi)invariant vector fields, integration on Lie Groups, Cartan's Theorem etc. After studying this course, students will be fully equipped to study Abstract Harmonic Analysis on Lie Groups (and the construction of Haar Measure).

Contents: Review of Several variable Calculus: Directional Derivatives, Inverse Function Theorem, Implicit function Theorem, Level sets in $\mathbb{R}^n$, Taylor's theorem, Smooth function with compact support. Manifolds: Differentiable manifold, Partition of Unity, Tangent vectors, Derivative, Lie groups, Immersions and submersions, Submanifolds. Vector Fields: Left invariant vector fields of Lie groups, Lie algebra of a Lie group, Computing the Lie algebra of various classical Lie groups. Flows: Flows of a vector field, Taylor's formula, Complete vector fields. Exponential Map: Exponential map of a Lie group, One parameter subgroups, Frobenius theorem (without proof). Lie Groups and Lie Algebras: Properties of Exponential function, product formula, Cartan's Theorem, Adjoint representation, Uniqueness of differential structure on Lie groups. Homogeneous Spaces: Various examples and Properties. Coverings: Covering spaces, Simply connected Lie groups, Universal covering group of a connected Lie group. Finite dimensional representations of Lie groups and Lie algebras.

References:

1. D. Bump, "Lie Groups", Graduate Texts in Mathematics 225, Springer, 2013.
2. S. Helgason, "Differential Geometry, Lie Groups and Symmetric Spaces", Graduate Studies in Mathematics 34, American Mathematical Society, 2001.
3. S. Kumaresan, "A Course in Differential Geometry and Lie Groups", Texts and Readings in Mathematics 22, Hindustan Book agency, 2002.
4. F. W. Warner, "Foundations of Differentiable Manifolds and Lie Groups", Graduate Texts in Mathematics 94, Springer-Verlag, 1983.

M564: Lie Groups and Lie Algebras - II

Prerequisites: M556

L	P	T	C
3	0	1	4

Outcome: This course is the sequel of M556 - Lie groups and Lie algebras I. It mostly deals with the representation theory of Lie groups. Lie groups that are studied in this course, are compact Lie groups and the group SL(2,C) . Another aspect of this course is to classify all simple Lie algebras through root system. As it is well known, the study of subatomic particles depend on the irreducible representations of certain Lie groups that are contained in $\mathrm{GL}(n, \mathbb{R})$. This course gives a vivid account of mathematics that is needed to understand these representations. To sum up, it is a gateway for the students of mathematics to pursue harmonic analysis of Lie groups.

Contents: General theory of representations, operations on representations, irreducible representations, Schur's lemma, Unitary representations and complete reducibility. Compact Lie groups, Haar measure on compact Lie groups, Schur's Theorem, characters, Peter-Weyl theorem, universal enveloping algebra, Poincare-Birkoff-Witt theorem, Representations of Lie($SL(2,\mathbb{C})$). Abstract root systems, Weyl group, rank 2 root systems, Positive roots, simple roots, weight lattice, root lattice, Weyl chambers, simple reflections, Dynkin diagrams, classification of root systems, Classification of semisimple Lie algebras. Representations of Semisimple Lie algebras, weight decomposition, characters, highest weight representations, Verma modules, Classification of irreducible finite-dimensional representations, Weyl Character formula, The representation theory of $SU(3)$, Frobenius Reciprocity theorem, Spherical Harmonics.

References:

1. D. Bump, "Lie Groups", Graduate Texts in Mathematics 225, Springer, 2013.
2. J. Faraut, "Analysis on Lie Groups", Cambridge Studies in Advanced Mathematics 110, Cambridge University Press, 2008.
3. B. C. Hall, "Lie Groups, Lie algebras and Representations", Graduate Texts in Mathematics 222, Springer-Verlag, 2003.
4. W. Fulton, J. Harris, "Representation Theory: A first course", Springer-Verlag, 1991.
5. A. Kirillov, "Introduction to Lie Groups and Lie Algebras", Cambridge Studies in Advanced Mathematics 113, Cambridge University Press, 2008.
6. A. W. Knapp, "Lie Groups: Beyond an introduction", Birkäuser, 2002.
7. B. Simon, "Representations of Finite and Compact Groups", Graduate Studies in Mathematics 10, American Mathematical Society, 2009.

M565: Mathematical Foundations for Finance

Prerequisites: M472

L	P	T	C
3	0	1	4

Outcome: Students will learn about the mathematical modeling of simple stock markets and techniques to analyze them.

Contents: Financial market models in finite discrete time, Absence of arbitrage and martingale measures, Valuation and hedging in complete markets, Basic facts about Brownian motion, Stochastic integration, Stochastic calculus: Itô's formula, Girsanov transformation, Itô's representation theorem, Black-Scholes formula

References:

1. J. Jacod, P. Protter, "Probability Essentials", Universitext, Springer-Verlag, 2003.
2. D. Lamberton, B. Lapeyre, "Introduction to Stochastic Calculus Applied to Finance", Chapman-Hall, 2008.
3. H. Föllmer, A. Schied, "Stochastic Finance: An Introduction in Discrete Time", de Gruyter, 2011.

M566: Designs and Codes

Prerequisites: M205, M307

L	P	T	C
3	0	1	4

Outcome: Understanding the technique used for constructing combinatorial designs and its relation with linear codes.

Contents: Incidence structures, affine planes, translation plane, projective planes, conics and ovals, blocking sets. Introduction to Balanced Incomplete Block Designs (BIBD), Symmetric BIBDs, Difference sets, Hadamard matrices and designs, Resolvable BIBDs, Latin squares. Basic concepts of Linear Codes, Hamming codes, Golay codes, Reed-Muller codes, Bounds on the size of codes, Cyclic codes, BCH codes, Reed-Solomon codes.

References:

1. G. Eric Moorhouse, "Incidence Geometry", 2007 (available online).
2. Douglas R. Stinson, "Combinatorial Designs", Springer-Verlag, New York, 2004.
3. W. Cary Huffman, V. Pless, "Fundamentals of Error-correcting Codes", Cambridge Uinversity Press, Cambridge, 2003.

M567: Statistical Inference II

Prerequisites: Statistical Inference I or equivalent courses

L	P	T	C
3	0	1	4

Outcome: Students will be introduced to decision theory and learn about Bayesian estimation and testing. Moreover, students will learn about large sample theory including asymptotic tests, confidence intervals, asymptotic efficiency and optimality of estimators and tests.

Contents: General decision problem, loss and risk function, minimax estimation, minimaxity and admissibility in exponential family. Introduction to Bayesian estimation, Bayes rule as average risk optimality, prior and posterior, conjugate families, generalized Bayes rules. Bayesian intervals and construction of credible sets, Bayesian hypothesis testing. Empirical and nonparametric empirical Bayes analysis, admissibility of Bayes and generalized Bayes rules, discussion on Bayes versus non-Bayes approaches. Large sample theory: review of modes of convergences, Slutsky's theorem, Berry-Essen bound, delta method, CLT for iid and non iid cases, multivariate extensions. Asymptotic level α tests, asymptotic equivalence, comparison of tests: relative efficiency, asymptotic comparison of estimators, efficient estimators and tests, local asymptotic optimality. Bootstrap sampling: estimation and testing.

References:

1. E. L. Lehmann and G. Casella, "Theory of Point Estimation", 2nd edition, Springer, New York, 1998.
2. E. L. Lehmann, "Elements of Large-Sample Theory", Springer-Verlag, 1999.
3. E. L. Lehmann and J. P. Romano, "Testing Statistical Hypothesis", 3rd edition, Springer, 2005.
4. James O Berger, "Statistical Decision Theory and Bayesian Analysis", 2nd edition, Springer, New York, 1985.

SCHOOL OF HUMANITIES

DETAILED COURSE STRUCTURE

FOR

INTEGRATED M.Sc. COURSE

Revised Jan 2017

National Institute of Science Education and Research (HBNI)

Humanities courses for integrated M.Sc.

Year/Semester	**Course no.**	**Credits**	**Course Name**
CORE COURSES			
1/Semester I	H109	2	Technical Communication I
1/Semester I	H133	2	Introduction to Sociology
1/Semester II	H110	2	Technical Communication
1/Semester II	H101	2	Introduction to Economics
ELECTIVE COURSES			
2/Semester III	H225	2	Introduction to Psychology
	H201	2	Environmental Economics and Environmental Impact Assessment
	H239	2	Introduction to Innovation System
	H238	2	Life and Community in Urban World.
2/Semester IV	H227	2	Organizational Behaviour
	H235	2	Sociology of Science and Technology
	H236	2	Perspectives on Indian Society
	H237	2	Science Communication and Citizen

SEM- I	**H 109**	+	**H 133**
SEM – II	**H 110**	+	**H 101**
SEM – III			**2 Electives**
SEM-I V			**2 Electives**

Economics

H101:Course title: Introduction to Economics

Instructor/Proposed by: Dr Amarendra Das

Prerequisite: None

Course Content:

1.	Role of Government in Organised Society	[1 class]
2.	Expenditure Obligation of Union, State and Local Government	[2 classes]
3.	Sources of Revenue for Union, State and Local Governments	[4 Classes]
4.	Concepts of Budget, and Different deficits	[1 class]
5.	Channels of Resource Transfer from Union to State Governments	[2, classes]
6.	Balance of Payment	[3 classes]
7.	Laws of Demand and Supply	[3 classes]
8.	Equilibrium Price Determination	[1 class]
9.	Exchange rate Determination	[2 classes]
10.	Consumer's Equilibrium	[2 classes]
11.	Producer's Equilibrium	[2 classes]
12.	Current Economic events	[3 classes]

References:

E.Case and R.C.Fair (2006) Principles of Economics, Prentice Hall, USA,

Samuelson, Paul and William D. Nordhaus (1948) Economics, 19th Edition, Mc Graw Hill

Government of India (2017) Union Budget 2017-18

Government of India (2017) Economic Survey-2016-17

H201: Environmental Economics and Environmental Impact Assessment

Instructor/Proposed by: Dr Amarendra Das

Prerequisite: None

Course Content:

12. Definition of Environmental Economics, Ecological Economics and Natural Resource Economics [1 class]
13. Key environmental problems faced by humanity [2 classes]
14. Limits to Growth [2 classes]
15. Sustainable Development: Strong and weak sustainability [2 classes]
16. Indicators of sustainability [1 class]
17. Market Failure: Causes and Remedies [3 classes]
18. Perspective on Environmental Policy/Regulation [2 classes]
19. Informal Regulation [1 class]
20. Population, Poverty and Economic Growth [1 class]
21. Climate Change, Causes and Consequences [2 classes]
22. Principles of using Renewable resources [2 classes]
23. Principles of using Non-renewable resources [2 classes]
24. Environmental Kuznets Curve [2 classes]
25. Mainstreaming of Environment [2 classes}
26. Environmental Impact Assessment [2 classes}
27. Environmental Regulations in India [1 class]
28. Green Accounting, Concepts, Integrated Economic and Environmental
29. Accounting [2 classes]

References:

Report of the World Commission on Environment and Development: Our Common Future

Baumol, W.J. & Oates, W.E. (1975), "The Theory of Environmental Policy: Externalities, Public Outlays and the Quality of Life", Prentice Hall Inc.

Bromley, Daniel W. (1995), "The Handbook of Environmental Economics", Blackwell Publications Ltd.

Pearce, D.W. (1976), "Environmental Economics", Orient Longman Ltd.

World Bank, (1992). "World Development Report, 1992: Development and the Environment", Oxford University Press

Bhatacharya R N (2002) Environemntal Ecconomics: An Indian Perspective, Oxford University Press, New Delhi

English

H109: Technical Communication I

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **Ideations of Science** (4 classes)
   Categorization and social perspective.

2. **Inscription and the material arts** (4 classes)
   Scientific representation and the figural social.

3. **Mechanics of Writing** (6 classes)
   Structure and compositional logic

4. **The Rhetorical Process** (6 classes)
   Building the argument

5. **Cultural Context and the Sciences** (4 classes)
   Literature and the aesthetic of science.

References

Barrass, Robert (2002). *Scientists Must Write: A Guide to Better Writing for Scientists, Engineers and Students*. London: Routledge.

Booth, Vernon (1993). *Communicating in Science: Writing a Scientific Paper and Speaking at Scientific Meetings*. Cambridge: Cambridge UP.

Cottrell, Stella (2011). *Critical Thinking Skills: Developing Effective Analysis and Argument*. London: Palgrave Macmillan.

Lynn, Steven (2010). *Rhetoric and Composition: An Introduction*. Cambridge: Cambridge UP.

Ranciere, Jacques (1991). *The Ignorant Schoolmaster*.Redwood:Stanford UP.

Ehrlich, Eugene (2011). *Schaum's Outline of English Grammar*, Third Edition. NY: Schaum's.

H110: Technical Communication II

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **The logic of Critique** (4 classes)
   Notions of evidence, proof and fact.

2. **Humanities and empiricism** (4 classes)
   Empirical fallacy and social intervention.

3. **Mechanics of Writing II** (6 classes)
   The forms of knowledge production. Understanding readership.

4. **The Rhetorical Process II** (6 classes)
   Staging the argument. Perspective and Institutional / Disciplinary norms.

5. **Narrativizing the Sciences** (4 classes)
   Scientific correspondence and reflections. Popular science and Science fiction.

References

Baudrillard, Jean (2012). *The Ecstasy of Communication*. Cambridge: MIT Press.

Fogelin, Robert (2014). *Cengage Advantage Books: Understanding Arguments*. London: Wadsworth.

Heidegger, Martin (2008). *"The question concerning technology," Basic Writings.* New York: Harper Collins.

Poovey, Mary (1998). *A History of the Modern Fact*. Chicago: University of Chicago press.

Strunk Jr, William (1767). *The Elements of Style: TheOriginal Edition* (2014). London: Dover.

Psychology

H 225: Introduction to Psychology

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. Introduction: perspectives, methods, issues.	(3 classes)
2. Perceptual Process.	(4 classes)
3. Learning Process	(3 classes)
4. Memory	(2 classes)
5. Intelligence	(2 classes)
6. Emotion	(2 classes)
7. Personality	(4 classes)
8. Motivation	(4 classes)
9. Attitude	(3 classes)

References:

Morgan, C.T., King, R.A., Weisz, J.R., Scopler, J. **Introduction to Psychology** (7th ed). Tata McGraw-Hill.

Baron, R.A. **Psychology** (5th ed) PHI New Delhi

Feldman, R.S. **Introduction to Psychology** (6th ed) Tata McGraw-Hill.

H 226: Applied Behavioural Science

Instructor/Proposed by: Rooplekha Khuntia

Prerequisite: None

Course Content:

1. Introduction: Personality	(1 class)
2. Interpersonal Relationship and Personal Effectiveness	(5 classes)
3. Social Perception: errors, biases, impression management	(3 classes)
4. Emotional Intelligence: managing emotions.	(3 classes)
5. Group and Team Dynamics.	(5 classes)
6. Effective Communication.	(4 classes)
7. Values and Value System	(3 lectures)
8. Stress: coping and managing stress	(4 classes)

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Handouts will be given as and when required.

H 227: Organizational Behaviour

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. **Introduction to Organizational Behaviour** (2 classes)
   Nature of Organizations, what is OB, contributing disciplines, Functions, role and skills of a manager, environmental challenges.
2. **Individual Decision-making process** (3classes)
   Rational decision-making, creativity, bounded rationality, errors and biases, constraints, ethics in decision-making.
3. **Work attitudes** (2 classes)
   Job satisfaction, job involvement, organizational commitment, cognitive dissonance theory.
4. **Motivation** (3 classes)
   Hierarchy of needs theory, two factor theory, ERG theory, equity theory, goal setting and expectancy theory, MBO in practice, other applications.
5. **Power and Politics** (3 classes)
   Bases of power, the general dependency postulate.
6. **Leadership** (3 classes)
   Behavioural theories, contingency theories, contemporary theories, issues in leadership studies.
7. **Groups and team dynamics** (3 classes)
   Stages of group development, group structure, group decision-making, Types of teams, creating effective teams.
8. **Conflict and conflict resolution** (2 classes)
   Functional and dysfunctional conflict, the conflict process, negotiation.
9. **Organizational Structure** (2 classes)
   Elements of organizational structure, common organizational designs, why do structures differ?
10. **Organizational Culture** (2 classes)
    Functions of culture, creating and sustaining culture.
11. **Organizational Change** (3 classes)
    Forces for change, resistance to change, approaches to managing planned change.

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Organizational Behaviour by Steven Mcshane and Mary Von Gilnow, Tata McGraw - Hill

Sociology

H 237: Science Communication & the Citizenship

Instructor/Proposed by: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course content:

1. Introduction, citizenship and Science (4 classes)
2. Science in public, the public understanding of science (4 classes)
3. Public engagement with science (5 classes)
4. Science, communication, ethical codes & scientific norms (4 classes)
5. Patents and dissemination of scientific knowledge (4 classes)
6. Science communication in age of innovation (4 classes)

References

Jane Gregory, J., and Miller, S. *Science in Public: Communication, Culture and Credibility*, New York: Plenum, 2000.

Collins, H., and Trevor Pinch, T. *The Golem: What Everyone should Know about Science*, Cambridge: Cambridge University Press, 1993.

Leach, M., Scoones, I., and Wynne, B. *Science and Citizens: Globalization and the Challenge of Engagement*, London: Zed, 2005.

Irwin, A. *Citizen Science*, London: Routledge, 1995.

Nowotny, H., Scott, P. and Gibbsons, M. *Rethinking Science: Knowledge and the Public in an Age of Uncertainty*, Cambridge: Polity, 2001.

H 238: Life &Community in Urban world

Proposed by: Debashis Pattanaik

Prerequisite: None

Course content:

1. Introduction, urban space and urban thought, urbanization (4 classes)
2. Emergence and evolution of cities (4 classes)
3. Urban life, urban communities (online and offline) (4 classes)
4. The city in context, migration, sorting and niches (4 classes)
5. Markets and networks (5 classes)
6. Urban ecology, suburbia, urban design, policy and planning (4 classes)

References

B. Wellman, *Networks in the Global Village*, Westview Press, Boulder, CO: 1999.

C.S. Fischer, and R.K. Merton, *The Urban Experience*, Houghton Mifflin Harcourt P, Boston: 1984.

E. Ben-Joseph and T. Szold (eds.), *Regulating Place: Standards and the Shaping of Urban America*, Routledge: New York: 2005.

J. Logan and H. Molotch. *Urban Fortunes: Toward a Political Economy of Place*, University of California Press, California: 2007.

R.W. Park, E.W. Burgess and M. Janowitz (eds.), *The City*, University of Chicago Press, Chicago: 1984.

S. Sassen, *Cities in a World Economy*, Pine Forge Press, California: 2011.

S. Zukin, *The Culture of Cities*, Blackwell, New York: 1995.

W.G. Flanagan, *Urban Sociology: Images and Structure*, Rawat Publications, New Delhi: 2011.

H239: Introduction to Innovation System

By: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course Content:

1. Nature of innovation (4 classes)
2. The innovative firm (2 classes)
3. Innovation processes (4 classes)
4. Regional innovation system (3 classes)
5. Innovation and IPR (4 classes)
6. Education, universities and national innovation system (2 classes)
7. Multinational enterprises and innovation processes (2 classes)
8. Science and innovation policy (4 classes)

References

B. Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* Pinter, London: 1992.

C. Christensen, *The Innovators Dilemma,* Harvard University Press, Boston: 1997.

E. Dundon, *The Seeds of Innovation: Cultivating the Synergy that Fosters New Ideas,* Amacom Books, New York: 2002.

H. Braczyk, et.al, *Regional Innovation Systems*, UCL Press, London: 1998.

K. Pavitt, *Technology Management and Systems of Innovation,* Cheltenham: 1999.

M. Gibbons et.al, *The New Production of Knowledge – the Dynamics of Science and Research in Contemporary Societies,* Sage, London: 1994.

P. Drucker, *Innovation and Entrepreneurship,* Harper Collins Publishers, New York: 1993.

R. Katz, *The Human Side of Managing Technological Innovation*, Oxford University Press, New York: 2004.

S. Borras, *The Innovation Policy of the EU,* Edward Elgar, Cheltenham: 2003.

H 133: Introduction to Sociology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Origin and Growth of Sociology (2 Lectures)
   Origin and development of sociology as a separate discipline,
   Nature and Scope of Sociology,
   Sociology as a Scientific Discipline.

2. Sociological Perspectives (2 Lectures)
   Conflict, Functionalism and Interactionsim

3. Basic Sociological Concepts (6 Lectures)

Society, Community, Association, Institution, Status and Role,
Types of Society: From early hunting gathering to
industrial development and globalization,
Culture: Components of culture; Norms, values,
folkways, mores, Cultural unity and diversity.
Socialization: Agents of Socialization, Early development
of infant, stages of socialization

4. Social Groups (4 Lectures)

Meaning of Social Groups and Types: Primary Group,
Secondary Group, In-Groups, Out- Group, Quasi- Group,
Reference Group

5. Structure and Stratification (4 Lectures)

Structure, System and Function, caste and class and
Racial and Ethnic group inequalities Social Stratification:
Meaning and Types, Functionalist and Conflict Perspectives
of Stratification, Social mobility: Meaning, horizontal and
vertical mobility

6. Social Institutions (4 Lectures)

Family, marriage and kinship, religion, economy, polity and
education. Functionalist and Conflict Perspectives of institutions.

7. Social processes and Change (4 Lectures)

Social Processes: Co-operation, accommodation, integration,
competition and conflict;
Social Change: Meaning and Definition, Factors of change.

8. Social Problems and Social Control (2 Lectures)

Social Problems and Social disorganization
Social control : Meaning and Types

References

Harlambous, M. (1980) Sociology, Oxford University Press, New Delhi.

Inkeles, A. (1982). What is Sociology, Eastern Economic Edition, New Delhi

Johnson, H.M. (1991). Sociology – A Systematic Introduction, Allied Publishers, New Delhi

Bottomore, T.B. (2000). Sociology: A Guide to Problems and Literature, S Chand Publisher, Dehradun

Gisbert, P. (2004, 3rd edition). Fundamentals of Sociology, Orient Longman

Rao, C.N.(2001) Sociology, Rawat Publication, Jaipur

Giddens, A. (2001). Sociology, Polity Press, UK.

H 235: Sociology of Science and Technology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Social significance of science and technology (4 Lectures)
   a. Contextual nature of science
   b. Scientist as Indexical and Analogical reasoner
2. Robert Merton's approach to science (3 Lectures)
   a. Ethos of science;
   b. Thomas Theorem and Matthew Effect
3. Perspectives on scientific knowledge (8 Lectures)
   a. Karl Marx, Emile Durkheim, Karl Manheim's sociology of knowledge,
   b. Thomas Kuhn's structures of scientific revolutions
   c. Karl Popper's theory of falsification
4. Recent trends in Sociology of Science (8 Lectures)
   a. Science and technology in developing and developed countries,
   b. Indian context,
   c. Information Technology and globalization,
   d. Manuel Castell's network society, internet and social inequality
5. Case Study Discussions (4 Lectures)

References

"The Historian and the History of Science" – Harry Elmer Barnes, *The Scientific Monthly*, Vol 11, No. 2(August 1920!!!), pp. 112-126.

"What is the History of Science?"- *History Today*, pp. 32-53. April 1985. (This article is an interview of six scientists/practitioners of science)

The Structure of Scientific Revolutions, Thomas Kuhn, Chicago: Chicago University Press, 1970. (First Edition 1962). Preface, Chapter, 12,3.

The Sociology of Science – Robert Merton, Chapters, 13,14,20, 21.

"The Scientist as a Practical Reasoner: Introduction to a Constructivist and Contextual Theory of knowledge"-. K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981.

(Chapter I) **A must read, highly recommended.**

"The Scientist as an Indexical Reasoner: The Contextuality and the Opportunism of Research" – K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981. (Chapter II) **A must read, highly recommended.**

"Is Science Losing its Objectivity?" – John Ziman, Nature, Vol.382, pp. 751-756, 1996

Kuhn, Thomas, "Structure of Scientific Revolutions", Chicago University Press. 1996

Merton, Robert K., Social Theory and Social Structure, Amerind. 1981

H 236: Perspectives on Indian Society

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content:

1. Indian Social Structure (2 Lectures)
    - a- Traditional Social Organizations
    - b- Culture and Tradition
2. Caste System and Class Structure (7 Lectures)
    - a- Cultural and Structural Views about Caste System
    - b- Inequality, Differentiation and Hierarchy
    - c- Dominant Caste, Sanskritization
    - d- Change and Persistence of Caste system in Modern India
    - e- Caste in Indian Politics
    - f- Backward Caste Movements
    - g- Social Backwardness and Social Justice
3. Class Structure (3 Lectures)
    - a- Class Structure in India
    - b- Agrarian and Industrial Class Structure
    - c- Emergence of Middle Class and Elites

4. Social Institutions: Marriage, Kinship and Family (2 Lectures)

5. Rural and Urban Social Structure: Poverty, Unemployment, etc. (2 Lectures)

6. Changing faces of Rural society/economy/market, Green revolution (2 Lectures)

6. Political processes: Political system and Governance (2 Lectures)

7. Education (2 Lectures)

8. Religion and Society (2 Lectures)

9. Social Change and Development Sustainable and Inclusive (2 Lectures)
Development, Basic developmental issues: Health, Education and Livelihood

10. Contemporary Social Issues (2 Lectures)

References:

Mandelbam, D. : Society in India (Part I & II), Popular Prakashan, Bombay, 1970
Srinivas, M.N. : Caste in Modern India and Other Essays, Asia Publishing House, Bombay,1964
Kapadia, K,M, : Marriage and Family in India, Oxford University Press, Calcutta,1981
Srinivas, M.N. : Social Change in Modern India, Orient Longman, New Delhi, 1995
Rao, M.S.A. (ed): Urban Sociology in India, Orient Longman, New Delhi, 1974
Ahuja, Ram : Social Problems in India, Rawat Publications, Jaipur, 1992
Kosambi, D.D. : The Culture & Civilization of Ancient India in Historical Perspective, New Delhi, 1982
Uberoi Patrcia (ed), Family, Kinship And Marriages in India, Oxford University Press, New Delhi.
Omen, T.K. and Mukharjee, P.N. (ed),: Indian Sociology : Reflection and Introspection, Popular Prakashan, Bombay, 1986

SCHOOL OF COMPUTER SCIENCES

A proposal for minor in Computer Science

1 Structure of the curriculum

The curriculum is divided in two category of courses, core courses and optional courses.

1.1 Core Courses

The following courses have been recommended by the steering committee as core courses. The Programming and Data Structure course are proposed to be two lab courses (2 credit each).

1. CS141 and CS142: Programming and Data Structures Lab
2. CS201: Theory of Computation
3. CS202: Discrete Structures and Computation[1]
4. CS301: Design and Analysis of Algorithms

1.2 Elective Courses

For the initial years, we shall offer the following optional courses. A student has to do three courses from the following list to obtain minor.

- CS451: Modern Cryptology
- CS452: Algorithmic Coding Theory
- CS453: Complexity Theory
- CS454: Linear Programming and Combinatorial Optimization
- CS455: Distributed Network Algorithms

In future, more elective courses will be offered based on the interests of the faculties.

1.3 Similarity with other courses

School of Mathematical Sciences offer some courses which are similar to the courses listed above. We make the following observations regarding this.

- Programming and Data Structure course can be merged with the existing Computational Laboratory courses (M141 and M142). I141 and I142 are the two lab courses, which may be offered instead of M141 and M142. The major difference in syllabus is the inclusion of different data structures which are core concepts in Computer Science.

[1] This course was originally titled Discrete Mathematics for Computer Science. We have renamed the course to capture the spectrum of the topics covered, and to avoid any confusion.

- School of Mathematical Sciences also offer Algorithms, Theory of Computation, Cryptology, Information and Coding Theory as PG optional courses. However, in Computer Science, Algorithms and Theory of Computation are fundamental courses, and need to be offered to the undergraduate students. The syllabus of Modern Cryptology, as well as Algorithmic Coding Theory has been designed from Computer Science point of view and significantly different from the SMS courses.

  However, to avoid repetition, we propose, students who take M462 (Cryptology) and M464 (Information and Coding Theory) will not be allowed to take CS451 (Modern Cryptology), and CS452 (Algorithmic Coding Theory) respectively.

2 Syllabi

Syllabi of the courses are given in the following pages. For each subject, the syllabus is organized as follows

1. prerequisite
2. topics
3. references

3 Core Courses

3.1 CS141: Programming and Data Structures Lab-I

Credit : 2

Prerequisite: None

Classes per week: 3P+1L.

Topics Module 0: (6P+2L): Introduction to Computers, Notion of Algorithm, Linux Bash Shell, Simple Shell Programs.
Module 1 (12P+4L): Introduction to Programming: Variables, operators and expressions, input and output statements, Conditions and loops. Functions and recursions.
Module 2 (12P+4L): Arrays, Pointers, Structures, Classes and Objects.
Module 3 (9P+3L): File i/o, command line arguments.
Module 4 (6P+2L). Abstract data type. Linked lists.

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

3.2 CS142: Programming and Data Structures Lab-II

Credit : 2

Prerequisite: CS141 **Classes per week**: 3P+1L. **Topics**

Module 0 (9P+3L): Review of programming, Arrays and Linked List. Bubble Sort and Quick Sort. Binary Search.
Module 1 (12P+4L): Circular Linked Lists, Doubly Linked Lists, Stacks, Queues.
Module 2 (12P+4L): Trees. Binary Search Trees, Tree traversal, Balanced Binary trees. Module 3 (6P+2L): Heap, Priority Queues.

Module 4 (3P+1L). Strings and Searching for Phrases.
Module 6:(Optional) (3P+1L) Dictionaries: universal, k-wise independent, simple tabulation hashing; chaining, dynamic perfect hashing, linear probing, cuckoo hashing

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973
- E. Horowitz,S . Sahni, Fundamentals of Data Structures in C++, Universities Press, 2008.

3.3 CS201: Theory of Computation

Credit : 4

Prerequisite: None **Classes per week**: 3L+1T. **Topics**

Module 1 (12L+4T): Introduction to Finite State Automata; DFA,NFA, and their equivalence, Regular Ex- pressions and equivalence with finite state automata.Regular Languages and Properties, Pumping Lemma and applications, Myhill-Nerode Theorem, State Minimization.

Module 2 (12L+4T): Context Free Languages (CFL) and grammars, parse trees, Chomsky Normal Form. Pushdown Automata (PDA), Equivalence of acceptance by final state and empty stack. Equivalence of CFL and PDA, Pumping Lemma for CFL.

Module 3 (12L+4T): Turing Machines and equivalence of different models. Universality. Decidability, Recog- nizability, Enumeration, and Undecidability. Reductions. Rice’s Theorem, recursion theorem.

Module 4 (9L+3T): Notions of P,NP,co-NP, hierarchy theorem, NP completeness, Cook-Levin Theorem, NP completeness proofs of some NP complete problems.

References

- J. Hopcroft, JD Ulman. Introduction to Automata Theory, Languages and Computations. Narosa Publishing 2002. (Indian Edition)
- M. Sipser. Introduction to the Theory of Computation. Cengage, 3rd Edition, 2014.
- H. R. Lewis and C. H. Papadimitriou: Elements of The Theory of Computation, Prentice Hall, Englewood Cliffs, 1981
- M. R. Garey and D. S. Johnson: Computers and Intractability: A Guide to The Theory of NP Completeness, Freeman, New York, 1979.

3.4 CS202: Discrete Structures and Computation

Credit 4
Prerequisite: none **Classes per week**: 3L+1T. **Topics**

Module 1 (6L+2T): Review of Sets, Operations, Principles of Inclusion and Exclusion. Functions, relations, Equivalence relations. Countable and uncountable sets. Review of Pigeonhole principle.

Module 2 (6L+2T): Introduction to Propositional Logic, Equivalence and Implications. Truth tables, De Mor- gan's Law, Quantifiers, Inference and Proofs. Introduction to First Order Logic, Syntax and Semantics, Soundeness and Completeness.

Module 3 (6L+2T): Mathematical Induction, Recursions, First order linear recurrence, Geometric series, Re- cursion trees and growth rates of solutions to recurrences, Master Theorem. Generating Functions.

Module 4 (6L+2T): Introduction to counting, sum and product principles, counting subsets. Binomial coefficients and Pascal's triangles. Polya's theory of counting (optional).

Module 5 (3L+1T): Arithmetic Algorithms: Computing GCD, primality testing, RSA.

Module 6 (12L+4T): Graph Theory: Graphs, representations, connectivity, cycles, trees, Spanning tree of a graph, Algorithms to find minimum spanning trees. Eulerian Cycle and Hamiltonian paths, independence number and clique number, chromatic number, Dominating Sets, and Covering Sets. Planar Graphs. Directed Graphs and tournaments.

Module 7(3L+1T) Probabilistic tools, Tail Bounds and Applications.
Module 8 (3L+1T)(optional): Linear Algebraic tools in Combinatorics.

References

- J. Gallier, Logic for Computer Science: Foundations of Automatic Theorem Proving, Wiley.
- Kenneth Rosen. Discrete Mathematics and Its Applications, 7th Edition , McGraw Hill Publishing Co., 2012.
- Ken Bogart. Discrete Mathematics for Computer Science. available at https://www.kth.se/social/files/557ec6b0f27654
- J. L. Mott, A. Kandel and T. P. Baker: Discrete Mathematics for Computer Scientists, Reston, Virginia, 1983
- J. A. Bondy and U. S. R. Murty: Graph Theory with Applications, Macmillan Press, London, 1976.
- F. S. Roberts: Applied Combinatorics, Prentice Hall, Englewood Cliffs, NJ, 1984

3.5 CS301: Design and Analysis of Algorithms

Credit 4
Prerequisite: CS201, CS202
Classes per week: 3L+1T.
Topics

Module 1 (4L+1T). Introduction and basic concepts - mathematics of algorithm analysis, asymptotic notations, worst case and average case complexity. Review of Searching and Union Find.

Module 2 (8L+3T): Divide and conquer- Motivating algorithms that leads into recurrences, solving recurrences, merge sort and its recurrence, Median computation. Analysis of quicksort.

Module 3 (9L+3T). Greedy algorithms- Greedy choice, optimal structure property, minimum spanning tree, knapsack

Module 4 (8L+2T). Dynamic programming- Integral knapsack, longest increasing subsequence, edit distance, independent sets in trees

Module 5 (8L+3T). Graph algorithms- Recall of representation of graphs, BFS, DFS, shortest path, connected components, topological sort of DAGs, biconnected components and strongly connected components in directed graphs

Module 6. (Optional)(3L+1T) Randomization- Median, randomized quicksort, probabilistic primality testing.

Algebraic Algorithms. Karatsuba's algorithm and the Fast Fourier transform

References

- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- S. Dasgupta, C. Papadimitrou, U. Vazirani, Algorithms, McGraw-Hill Education, 2006.
- A. Levitin, Introduction to Design and Analysis of Algorithms, Pearson 2007 (Lev)
- J. Kleinberg and E. Tardos, Algorithm Design, Pearson, 2005 (KT)
- E. Horowitz, S. Sahni, and S. Rajasekaran, Computer Algorithms, Silicon Press, 2007
- M. Goodrich, R. Tamassia, Algorithm Design, Wiley, 2001.
- D. Knuth: The Art of Computer Programming. Vol. 1 and Vol 3. , 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

4 Optional Courses

4.1 CS451: Modern Cryptology

Credit 4

Prerequisite: CS202, CS301.

Classes per week: 3L+1T.

Topics

Module 1: (3L+1T) Introduction and Classical Cryptography, Perfect Secrecy, One Time Pad.

Module 2: (9L+3T) Symmetric Key Encryption. Computational Security, Concrete vs Asymptotic Approach. Semantic Security. Pseudorandom generators and Stream ciphers, Pseudorandom Functions and Block Ciphers. Practical Constructions.

Module 3: (6L+2T) Hash Functions and Message Authentication Codes. Notions of Security, Generic Attacks, Domain Extension techniques, CBC MAC, HMAC, PMAC, Idea of Authenticated Encryption.

Module 4: (6L+2T) Review of Basic Number Theory. Hardness Assumptions. One-way functions, Trapdoor Permutations, RSA assumptions, Discrete Log and Diffie Hellman Assumptions, SIS and LWE Assumptions. Introduction to Elliptic Curves (Optional)

Module 5. (3L+1T) Key Exchange Protocols and Key Management.

Module 6. (6L+2T) Public Key Encryption, Semantic Security, El Gamal Encryption, Padded RSA PKCS#1 v1.5. Random Oracle Technique, OAEP.

Module 7. (6L+2T) Digital Signatures, Hash and Sign paradigm, Schnorr Signature, Forking Lemma, DSA. SSL/TLS.

Module 8. (6L+2T) (Optional) Idea of some of the following notions, Protocols and Zero Knowledge Proofs, Multiparty Computations and Oblivious Transfers, Secret Sharing. Algorithms for factoring and computing discrete logarithms, Linear and Differential Cryptanalysis, Crypto Currencies.

References

- J. Katz and Y. Lindell, Introduction to Modern Cryptography. CRC, 2014.

Possible Instructor: Rishiraj Bhattacharyya.

4.2 CS452: Agorithmic Coding Theory

Credit 4

Prerequisite: CS202

Classes per week: 3L+1T.

Topics Module 1: (9L+3T) Entropy, Characterization and Properties. Application to Combinatorics. Mutual Information and KL Divergence.

Module 2: (6L+2T) Source coding theorem, lossless compression of data, Lempel-Ziv Algorithm, Optimal lossless coding.

Module 3 (6L+2T) Communication channels (binary symmetric, erasure) and channel capacity, channel coding theorem.

Module 3: (6L+2T) Introduction to Error Correcting Codes. Hamming Codes and Hamming Bounds. BCH Codes, Maximum likelihood decoding and syndrome decoding; coding theory bounds.

Module 4: (9L+3T) Reed-Solomon codes and the Berlekamp-Welch decoding algorithm with Analysis. List Decoding of Reed-Solomon Codes.

Module 5. (6L+2T)Reed-Muller Code and Local decoding. Module 6.

(3L+1T) (Optional) Lovasz Local lemma and proof.

References

- T. M. Cover and J. A. Thomas, “Elements of Information Theory” (Second Edition, Wiley).
- S. Ling C. Xing, “Coding Theory: A First Course”, Cambridge University Press.
- J. Radhakrishnan, “Entropy and Counting”, http://www.tcs.tifr.res.in/ jaikumar/Papers/EntropyAndCounting.pdf
- V. Guruswami, A. Rudra and M. Sudan, “Essential Coding Theory (Draft of a new book)” available at http://www.cse.buffalo.edu/faculty/atri/courses/coding-theory/book/
- F.J. MacWilliams and N.J.A. Sloane, The Theory of Error-Correcting Codes, North-Holland ML, 1983.

Possible Instructor: Rishiraj Bhattacharyya.

4.3 CS453: Complexity Theory

Credit 4

Prerequisite: CS201, CS202, CS301

Classes per week: 3L+1T.

Topics

Module 1 (9L+3T): Introduction, P and NP - Review of Turing machines, universal Turing machines, and uncomputable functions, P vs. NP, NP vs. co-NP, and NP-completeness, EXP, NEXP

Module 2: (3L) Cook Levin’s Theorem

Module 3 (12L+4T): Diagonalization, Space complexity, Polynomial Hierarchy

Module 4 (9L+3T): Interactive Proofs - PCP theorem and its application to approximability Module 5 (4L+1T): Circuit complexity and lower bounds

Module 6 (6L+2T): Hardness vs. Randomness - Randomized Computation, derandomization, Pseudo-random generators

Module 7 (3L+1T): Polynomial identity testing vs Lower bounds for arithmetic circuits

References:

- S. Arora and B. Barak, “Computational Complexity: A Modern Approach”, Cambridge University Press.
- O. Goldreich, “Computational Complexity: A conceptual perspective”, Cambridge University Press.
- J. Hopcroft, R. Motwani, J. D. Ullman. Introduction to Automata Theory, Languages, and Computation. Pearson Education.
- J. Raddhakrishnan, Graduate course on Computational Complexity, http://www.tcs.tifr.res.in/ jaikumar/Courses/Com

Possible Instructor: Anisur Rahaman Molla.

4.4 CS454: Linear Programming and Combinatorial Optimization

Credit 4
Prerequisite: CS202, CS301
Classes per week: 3L+1T.

Topics

Module 1: (10L+3T) Basic geoemetry and linear algebra related to Linear Programming. Simplex-method and Duality theorem (leading to Von Neumann's minmax principle) and complimentary slackness.

Module 2: (8L+3T) Ellipsoid algorithm. separation oracles.

Module 3: (9L+3T) Semidefinite programming as an extension of linear programming.

Module 4: (9L+3T) LP relaxation. Examples of problems where LP relaxation achieves optimum. Examples where LP/SDP relaxation achieves approximate solution. Integrality gaps.

Module 5: (6L+2T) Rounding, probabilistic roundings, iterative rounding, primal dual methods.

Module 6 (Optional): (3L+1T) Gale-Shapley algorithm, Connection of LP to Cooperative Game Theory core, nucleolus, combinatorial optimization games.

References

- A. Schrijver, "Theory of Linear and Integer Programming", Wiley.
- A. Schrijver, "Combinatorial Algorithm: Polyhedra and Efficiency, Volume A", Springer.
- V. Vazirani, "Approximation Algorithm", Springer.
- S. Chakraborty, M. Mitra, P. Sarkar, "A Course on Cooperative Game Theory", Cambridge University Press.

Possible Instructor: Rishiraj Bhattacharyya, Anisur Rahaman Molla.

4.5 CS455: Distributed Network Algorithms

Credit 4

Prerequisite: CS202, CS301

Classes per week: 3L+1T. **Topics** Module 1: (9L+3T) Foundations of distributed network algorithms - Broad- cast, converge-cast, maximal independent set, coloring, leader election, spanning tree algorithms, shortest paths, and routing.

Module 2:(9L+3T) Fundamental concepts in distributed algorithms - Symmetry breaking, locality, synchronizers Module 3:(9L+3T) Basics of distributed network systems - Communication, synchronization, fault-tolerance,

and resource allocation

Module 4:(9L+3T) Applications to real-world networks - Internet, peer-to-peer networks, wireless networks, sensor networks and dynamic networks

Module 5:(9L+3T) Lower bounds using communication complexity, distributed computation of large-scale data, dynamic network algorithms.

References

- D. Peleg, “Distributed Computing: A Locality-Sensitive Approach”, SIAM 2000.
- Distributed Computing: Fundamentals, Simulations and Advanced Topics, by Hagit Attiya, Jennifer Welch, McGraw-Hill Publishing, 1998.
- N. Lynch, “Distributed Algorithms”, Morgan Kaufmann 1996.
- G. Tel, Introduction to Distributed Algorithms, Cambridge University Press 2000.
- G. Pandurangan, “Distributed Network Algorithms, a monograph”, Department of CS, University of Houston.

Possible Instructor: Anisur Rahaman Molla.

BACK TO MAIN

NISER

INTEGRATED M.Sc PHYSICAL SCIENCES
(PROGRAM CODE: PHYS13)

Theory courses:

Discipline : **Physical Sciences**
Course Level : **Int. M.Sc**

Course Title : **Physics I (Mechanics and Thermodynamics)**
Course Code : **P101**
Credits : **3**
Course Category : **Core/Elective**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **42**

Proposed by : **UGCS, SPS**

Outcome of the Course:

1. Builds understanding of basic classical mechanics and thermodynamics.

Course Contents:

1. Coordinate systems, elements of vector algebra in plane polar, cylindrical, spherical polar coordinate systems;
2. Dimensional analysis;
3. Solutions for one dimensional equation of motion in various forms, line integrals, conservative forces, potential, work- energy theorems, energy diagrams;
4. Conservation of linear momentum and collisions, variable mass problems;
5. Simple harmonic motion, forced oscillations, damping, resonance;
6. Conservation of angular momentum and elementary rigid body dynamics;
7. principles of thermodynamics, concept of thermodynamic state, extensive and intensive variables;
8. Heat and work, internal energy function and the first law of thermodynamics;
9. Equations of state;
10. Concepts of entropy, entropy maximum and energy minimum principles;
11. Second law of thermodynamics;
12. Thermodynamics potentials, enthalpy, Helmholtz potential, gibbs potential;
13. Conditions of equilibrium, first order phase transitions and Clausius-Clapeyron equation, applications;
14. Chemical reactions;
15. Heat engines and black body radiation;
16. Elementary kinetic theory of gases, equilibrium properties-pressure and equation of state;
17. Transport processes, illustration with simple examples.

Text Books (if any) & Suggested References:

1. Introduction to mechanics: Daniel Kleppner & Robert Kolenkow. new York: Mcgraw-Hill Book Co., inc., 1973.
2. Heat and thermodynamics: an intermediate textbook: Mark W. Zemansky & Richard H. Dittman. 7th ed., new York: Mcgraw-Hill Book co., inc., 1997.
3. Fundamentals of physics: David Halliday, Robert Resnick, & Walker. 8th ed., new Jersey: John Wiley, 2008.
4. University physics: Francis W. Sears, Mark Zemansky, & Hugh D. Young. 7th ed. Massachusetts: addison Wesley, 1987.
5. Mechanics: Keith R. Simon. 3rd ed. Massachusetts: addison Wesley pub. Co., 1971.
6. Thermodynamics, kinetic theory, & statistical thermodynamics: Francis W. Sears, & ger- hard L. Salinger, 3rd ed., norosa 1998.
7. Mechanics: Charles Kittel, Walter D. knight & Malvin a. Ruderman. 2nd ed., new York:
8. Mcgraw-Hill Book Co., inc., 1973.

Course Title : **Physics II (Electricity, Magnetism and Optics)**
Course Code : **P102**
Credits : **3**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **42**

Proposed by : **UGCS, SPS**

Outcome of the Course:

Builds basic understanding of electro and magneto static phenomena and processes. Introduces important concepts of polarization, electromagnetic waves, interference and diffraction.

Course Contents:

1. Summary of electrostatics and magneto statics;
2. gauss law in differential form, electrostatic potential and curl of E;
3. Electric displacement and boundary conditions, linear dielectrics;
4. Motion of charge in electric and magnetic field;
5. Current density, curl and divergence of B, Amperes law, magnetic field H, magnetic susceptibility, boundary conditions
   of B and H;
6. Faradays law in differential form, displacement current;
7. Maxwell’s equations in media, e.m. wave equation, plane waves, polarization and types of polarization, energy and momentum of plane e.m. waves, grating and diffraction experiments, X-rays and Braggs law.

Text Books (if any) & Suggested References:

1. Introduction to Electrodynamics: David J. Griffiths. 3rd ed. New Jersey: Prentice Hall, 1999.
2. Optics: Eugene Hecht. 4th ed. Massachusetts: Addison Wesley, 200
3. Fundamentals of physic: David Halliday, Robert Resnick & Jearl Walker. 8th ed. new York: John Wiley & Sons Inc., 2004.
4. Foundations of Electromagnetic theory: John R. Reitz, Fredrick Milford & Robert Christ. 4th ed. Massachusetts: Addison Wesley, 1993.
5. Fundamentals of optics: Francis a. Jenkins & Harvey e. White 4th ed. new York Mc graw Hill Book Company Inc., 2001
6. Electricity and magnetism (Berkeley physics Course; vol.2): Edward M. Purcell. 2nd ed. new York Mc Graw Hill Book Company Inc., 1985.
7. Optical physics: Stephen g. Lipson, Henry Lipson & D.S. Tannhauser. 3rd ed. new York:
8. Cambridge University press, 1995.

Course Title : **Classical Mechanics I**
Course Code : **P201**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

Training in basic classical mechanics, prepares the student for advanced mechanics courses.

Course Contents:

1. Two-body central force problem (reduced mass); planet orbits; virial theorem.
2. Collisions and scattering, CM and Lab frames, scattering cross section.
3. Motion in non-inertial frames; Coriolis force.
4. principle of virtual work; constraints; D alemberts principle.
5. generalized coordinates, velocities and momenta; Lagranges formulation.
6. principle of least action; formulation by Maupertuis, Euler, Hamilton; Liou- villess theorem.
7. Hamiltons equations; poisson brackets.
8. Canonical transformations; Hamilton-Jacobi equation; generating functions; Symmetries and conservation laws.
9. Small oscillations; normal modes.

Text Books (if any) & Suggested References:

1. Classical Mechanics - Simon
2. Classical Mechanics - Kibble
3. Classical Mechanics - Rana and Jog
4. Classical Mechanics - Goldstein

Course Title : **Mathematical Methods I**
Course Code : **P202**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

Provides training in basic mathematical methods needed in all areas of physics

Course Contents:

1. Vector Calculus.
2. Review of Linear vector spaces, linear operators in linear vector spaces, Hermitian, projection and Unitary operators, normal matrices and diagonalization.
3. Cartesian tensors, 4-vectors and 4-tensors
4. Review of 2nd order linear homogeneous differential equations with variable coefficients, Laplace's equation and method of separation of variables, Solutions to the Bessel, Hermite, Legendre, hyper-geometric and confluent hyper-geometric equations.
5. Review of Bessel functions and spherical Bessel functions.
6. Legendre polynomials and Spherical Harmonics, expansion of a plane wave in terms of spherical waves.

Text Books (if any) & Suggested References:

1. Mathematical Methods in the physical sciences: M. L. Boas
2. Mathematical Methods For physicists: g. B. arfken and H. J. Weber
3. Mathematical Methods for physics: H.W. Wyld
4. Mathematical Methods of physics: Mathews and Walker
5. Mathematical physics i and ii: S.D. Joglekar

Course Title : **Electronics**
Course Code : **P203**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

Provides training in basic methods and theory of electronics needed in all areas of applied physics as well as most experimental fields.

Course Contents:

Foundations, passive elements, sources : dependent sources , survey of network theorems and network analysis, more on dependent sources, transient response of R-L circuit , R-C circuits, sinusoidal steady state response, diodes and diode circuits, power supply: rectifiers, full wave rectifier without center tapped transformer, bipolar junction transistors, constant current source, constant voltage source, field effect transistors, basic differential amplifier circuits, feedback and operational amplifiers, digital electronics, gates, universality of certain gates: using NAND gates, Boolean expressions, other ways of realizing logic functions, multiplexers, flip-flops and latches, counters, sequential circuits: master slave flip-flop (S-R), edge triggered flip-flops, transducers, signal averaging, lock-in amplifier, D/A & A/D converter, multi channel analyzer etc., introduction to microcomputers and microprocessors.

Text Books (if any) & Suggested References:

1. Paul Horowitz, Winfield Hill, The art of electronics, Cambridge University Press
2. Allan R. Hambley, Electronics, prentice Hall
3. Thomas L. Floyd, Electronics Fundamentals, prentice Hall
4. Earl gates, introduction to Electronics, Cengage Learning
5. R.A.gayakwad, Opamps and linear integrated circuits, prentice Hall of india
6. Millman, Grabel, Microelectronics, Mc Graw-Hill
7. DeCarlo, and Lin, Linear circuit analysis, Oxford University press
8. Hayt, Kammerly and Durbin, Engineering Circuit analysis, Tata Mc graw-Hill

Course Title : **Electromagnetism I**
Course Code : **P204**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces to the idea of energy momentum tensor and Gauge invariance.

Course Contents:

1. Coulomb law and electrostatics, greens functions.
2. Laplace and Poisson equations, uniqueness theorem, method of images.
3. Dielectrics, polarization, electric displacement.
4. Steady currents; and magneto statics, magnetic materials.
5. Time-varying fields, Faradays law, displacement current.
6. Maxwell's equations, electromagnetic waves,
7. Lorentz force, Poynting's theorem, electromagnetic energy momentum tensor.
8. Gauge transformations and gauge invariance, electromagnetic potentials.

Text Books (if any) & Suggested References:

1. Classical Electrodynamics: J.D. Jackson 3rd Edition
2. Classical electromagnetic radiation: Mark Heald, J. B. Marion
3. Introduction to electrodynamics: D.J. Griffiths 3rd Edition
4. Foundations of Electromagnetic theory: Reitz and Milford
5. Lectures in physics: Vol. 2: R. P. Feynman, Mathews and Sands

Course Title : **Mathematical Methods II**
Course Code : **P205**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **Mathematical Methods I**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by **: UGCS, SPS**

Outcome of the Course:

Prepares the student in important advanced mathematical concepts and tools. This is needed for advanced physics courses such as applications of quantum mechanics in solid state physics quantum field theory and particle phenomenology

Course Contents:

1. Functions of a complex variable, analytic functions, residue theorem and applications, Taylor and Laurent series, analytic continuation, special analytic functions, method of steepest descent.
2. Hilbert space, Differential operators and Sturm-Liouville theory,
3. partial differential equations,
4. greens functions.
5. generalized functions.
6. Elements of group theory.

Text Books (if any) & Suggested References:

1. Mathematical Methods For physicists: g. B. Arfken and H. J. Weber
2. Mathematical Methods for physics: H.W. Wald
3. Mathematical Methods of physics: Mathews and Walker
4. Mathematics for physicists: P. Dennery and A. Krzywicki

Course Title	**: Quantum Mechanics I**
Course Code	**: P206**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**:**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: UGCS, SPS**

Outcome of the Course:

First in-depth introduction of basic ideas and methods in quantum mechanics. This is necessary across almost all advanced modern physics courses.

Course Contents:

1. Historical development of quantum theory,
2. Schrodinger equation, one-dimensional problems, Scattering and tunneling from 1-dimensional potentials.
3. Central potentials; hydrogen atom,
4. Symmetries in quantum mechanics, general treatment of angular momentum; spin.
5. identical particles; Pauli exclusion principle.

6. Time-independent perturbation theory; degenerate perturbation theory and variational method.

Text Books (if any) & Suggested References:

1. Introduction to Quantum physics by A. P. French , Edwin F. Taylor
2. Quantum Mechanics: Schiff
3. Introduction to Quantum Mechanics: Griffiths
4. principles of Quantum Mechanics: R. Shankar
5. Modern Quantum Mechanics: J. J. Sakurai

Course Title	**: Electromagnetism II**
Course Code	**: P301**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**: Electromagnetism I**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

Provides training in advanced concepts and methods for understanding advanced electromagnetic phenomena. Important concepts of radiation retardation, multipole expansions, covariant formulation of classical mechanics and relativistic kinematics are taught.

Course Contents:

1. Boundary-value problems in electrostatics and magneto statics.
2. Wave propagation in conductors and dielectrics, Reflection, Refraction, Total internal reflection, Attenuation of waves in metals, Brewster's angle; Lorentz theory of dispersion; wave-guides, fibers and plasmas.
3. Special relativity, Minkowski space and four vectors, four-potential, relativistic formulation of electrodynamics, Maxwell equations in covariant form. Relativistic kinematics.
4. Lenard-Weichert potentials, radiation from an accelerated charge, Larmor formula, bremsstrahlung and synchrotron radiation.
5. Multipole radiation, scattering by free charges.
6. Diffraction.

Text Books (if any) & Suggested References:

1. Classical Electrodynamics: J.D. Jackson 3rd Edition
2. Classical electromagnetic radiation: Mark Heald, J. B. Marion
3. Foundations of Electromagnetic theory: Reitz and Milford
4. Classical theory of fields: L. Landau and E. Lifshitz

Course Title	**: Statistical Mechanics**
Course Code	**: P302**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: UGCS, SPS**

Outcome of the Course:

The course trains the student in basics of statistical mechanics, introduces important concepts like the density matrix, different kinds of quantum statistics and the idea of fluctuation dissipation theorem.

Course Contents:

1. Thermodynamic potentials, entropy and concepts related to equilibrium state and thermodynamic stability.
2. Kinetic theory of gases, Boltzmann distribution and its implications.
3. Concepts in statistics; randomness, probability distribution, central limit theorem.
4. Density matrix, Liouville's equation, ensemble theory.
5. Gibbs distribution: Classical and Quantum free particles, systems with continuous and discrete spectrum, application to electrons in metals, black-body radiation, white dwarf and Bose-Einstein condensation.
6. Real gases and gas-liquid transition: virial expansion, radial distribution function, Born green Hierarchy, van der Waals equation.
7. Introduction to response, fluctuation and noise, Einstein formula.

Text Books (if any) & Suggested References:

1. Statistical physics - Reif
2. intro to Stat. physics, Kerson Huang (Taylor and Francis)
3. Statistical physics of particles, M. Kardar (Cambridge)
4. Statistical physics Chandler
5. Statistical physics: R. P. Feynman
6. Statistical physics Vol. I: L. Landau and E. Lifshitz

Course Title : **Quantum Mechanics II**
Course Code : **P303**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **Quantum Mechanics I**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

Prepares the student in intermediate level of quantum mechanics needed across many advanced disciplines. Introduces important concepts for time evolution in quantum mechanics, propagators and path integrals and relativistic quantum mechanics.

Course Contents:

1. Hilbert space formalism for quantum mechanics
2. Review of time independent perturbation theory. WKB approximation, bound state perturbation theory.
3. Time-dependent perturbation theory; scattering theory.
4. greens function methods; path integral in non-relativistic theory.
5. Relativistic wave equations: Dirac Equation, Dirac particle in presence of an electromagnetic field leading to g = 2;
   holes.
6. Foundational issues in quantum theory.

Text Books (if any) & Suggested References:

1. Introduction and advanced Quantum Mechanics books by J. J. Sakurai
2. Principles of Quantum Mechanics: R. Shankar
3. Quantum Mechanics: by Merzbacher
4. Quantum Mechanics (volumes 1 and 2): A. Messiah
5. Quantum Mechanics: Cohen-Tannoudji

Course Title : **Special Theory of Relativity**
Course Code : **P304**
Credits : **4**
Course Category : **Core**
Course Prerequisite :
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

Trains the student in basic and advanced concepts in special relativity and introduces the basic ideas up on which General relativity is based on. Also provides in depth training in applications of group theory in relativity. Prepares the student for studying general relativity in future.

Course Contents:

1. Physics before relativity: Galilean relativity, Newtonian mechanics, electrodynamics and inconsistency with Galilean relativity, ether and experiments for its detection, failure to detect ether. Measurement of velocity of light in moving frames. Lorentz, Poincare and developments towards relativity.
2. Einstein's special theory: Constancy of velocity of light as a postulate. Derivation of Lorentz transformation. Length contraction and time dilation. Mass- energy relation, Doppler shift. Minkowski space-time diagram, boosts as complex rotations in Minkowski space.
3. Four dimensional space-time continuum, Lorentz transformations as coordinate transformations, vectors, scalar product, scalars, tensors, contravariant and covariant objects, laws of physics as tensor equations. Mechanics, hydro-dynamics and electrodynamics as tensor equations.
4. Beyond special relativity: Inertial and gravitational mass. Equivalence principle. Introducing gravitational field as general coordinate transformation. Principle of general covariance. Metric tensor and affine connection. Gravitational potential as metric tensor. Laws of physics in presence of gravitation. gravitational time dilation and red shift. Experimental observation of gravitational red shift.
5. Lorentz and Poincare groups: abelian and non-abelian groups. Rotations in two and three dimensions. generators of rotations. Representations (finite dimensional). Casimir operators. Lorentz transformations as a group. Generators for translations, rotations and boosts. Finite and infinite dimensional representations. Casimir operators.

Text Books (if any) & Suggested References:

1. Introduction to Special Theory of Relativity, Resnick
2. Relativity, a. Einstein

3. Classical Electrodynamics, J. D. Jackson
4. Electrodynamics, Panofsky and Phillips
5. Classical Mechanics, Goldstein
6. GTR and Cosmology, Weinberg
7. Lecture notes in NISER wiki (also at http://www.iopb.ser.in/ phatak)

Course Title	**: Atoms, Molecules and Radiation**
Course Code	**: P305**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**: Quantum Mechanics I and II**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

Important topics in atomic physics, selection rules, atomic and molecular spectroscopy is taught. The training is imperative to work in the area of applied solid state physics and optics.

Course Contents:

1. Hydrogen atom including L.S coupling and hyperfine interaction.
2. Helium atom introduction to exchange and correlation; variational calculation of ground and excited-states.
3. introduction to the idea of effective potentials for electrons in many-electron atoms (Hartree theory and idea of self- consistency); use of Clementi-Roetti wave-functions.
4. One-electron atomic systems in an electromagnetic field; dipole approximation and associated selection rules; Stark and
   Zeeman effect (note: instructor will have to introduce the students to time-dependent perturbation theory here).
5. Einstein's A and B coefficients, population inversion, laser action, derivation of A and B coefficients from semi-classical
   treatment of light-atom interaction.
6. Molecular formation: Discussion of atom-atom interaction, van der Waals force, ionic interaction and covalent bond.
7. Molecular structure: Hydrogen molecule MO and VB pictures; importance of correlations.
8. Molecular spectra (restricted to two atom molecules) electronic, rotational and vibrational.
9. Some lectures left for interesting current topics.

Text Books (if any) & Suggested References:

1. Elementary atomic Structure - G. K. Woodgate
2. atomic physics: C. J. Foot
3. atoms, molecules and photons: W. Demtroder

4. The Theory of atomic Spectra: Condon and Shortley
5. Topics in atomic physics: C.E. Butkhardt and J. L. Leventhal
6. physics of atoms and Molecules - B. H. Bransden and C. J. Joachain

Course Title	**: Introduction to Condensed Matter Physics**
Course Code	**: P306**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**: Quantum Mechanics I and II, Statistical Mechanics**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by	**: UGCS, SPS**

Outcome of the Course:

This is the first course in condensed matter physics and draws on quantum and statistical mechanics to provide a foundation in basic concepts and techniques required to tackle advanced courses in the area of solid state physics.

Course Contents:

1. General introduction, Drude and Sommerfeld model;
2. Crystal structure; x-ray diffraction;
3. Cohesive energy;
4. Bloch's theorem; Band theory nearly free electrons; tight binding approximation; semi-classical dynamics of electrons in a band; motion of electrons in super-lattices; motion of atoms in an optical potential;
5. Semiconductors;
6. Thermal properties of insulators; phonons;
7. Landau levels - de Hass van Alphen effect and integer quantum hall effect;
8. Magnetism;
9. Superconductivity;

Text Books (if any) & Suggested References:

1. Introduction to Solid-state physics, C. Kittel
2. Solid-state physics, N. Ashcroft and N.D. Mermin,
3. Solid-state physics, Rosenberg
4. Solid state physics, Burn
5. Oxford Series in Condensed Matter [Oxford university press]

Course Title : **Nuclei and Particles**
Course Code : **P307**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **Quantum Mechanics I**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

Provides training in basic concepts and methods in nuclear physics, stability of nucleons and classification of interactions. The course prepares the student to begin working in experimental and theoretical high energy physics.

Course Contents:

1. Nuclear systematics and stability (masses, sizes, spins, magnetic moments, quadrupole moments, energetics and stability against particle emission, beta decay).
2. Nucleon-nucleon interaction, space-time symmetries, conservation laws, isospin symmetry, low energy (effective range, shape independence, meson exchange picture (qualitative).
3. Liquid drop model, compound nucleus and fission, nuclear vibrations and rotations.
4. Shell model, introduction to Hartree-Fock, spins and magnetic moments.
5. Direct nuclear reactions.
6. Mesons and baryons, resonances, SU(3) classification, isospin and strangeness, quark model, colour.
7. Weak interactions (nuclear and particle decays, neutrinos).

Text Books (if any) & Suggested References:

1. introduction to nuclear physics - Roy and Nigam
2. nuclear physics - Preston and Bhaduri
3. Introduction to particle physics - Griffith
4. introduction to particle physics - Perkins

Course Title : **Classical Mechanics II: Mechanics of Continuous Media**
Course Code : **P401**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **Classical mechanics I**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

This is an advanced course introducing the students to concepts and techniques in mechanics of continuous media. It prepares them to tackle a variety of problems in many areas such as fiber optics, fluid dynamics and structural stability of materials.

Course Contents:

1. Rigid body dynamics; Euler angle, Euler equations (should solve up to nutation of a top).
2. Elastic Continua: Small deformations, stress tensor, elastic energy, equation of motion. Mechanics of continuous media.
3. Strings: Euler Lagrange equation for continuous medium, Bernoulli's and D'alembert's solutions, Sturm-Liouville theory.
4. Membranes: Scalar Helmholtz equation and its solution in various geometries.
5. Fluids: Newtons second law for an ideal fluid, continuity equation, Euler equation, Bernoulli's theorem, sound waves in fluids.
6. Surface waves on Fluids: Tidal waves (long waves on shallow water), surface waves on deep water, solitary waves.
7. Viscous Fluids: Viscous stress tensor, Navie'r Stokes equation, examples of incompressible flow, sound waves in viscous fluids.

Text Books (if any) & Suggested References:

1. Classical Mechanics - Rana and Joag
2. Classical Mechanics - Goldstein
3. Classical Mechanics - Fetters and Walecka
4. Fluid Mechanics: L. Landau and E. Lifshitz
5. Theory of Elasticity: L. Landau and E. Lifshitz

Laboratory Experiments

Course Title	**: Physics Laboratory I**
Course Code	**: P141**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**

Proposed by **: UGCS, SPS**

Outcome of the Course:

Introduces the students to basic methods in experimental techniques, statistics and error analysis. The focus is on basic mechanics and little amount of solid state physics experiments.

Course Contents:

1. Compound pendulum
2. Moment of Inertia
3. Young's modulus
4. Soft massive spring and standing waves
5. Specific heat of graphite
6. Electrical Equivalent of Heat
7. Measurement of Thermal Conductivity
8. Viscosity
9. Surface tension by capillary rise

Text Books (if any) & Suggested References:
None

Course Title	**: Physics Laboratory II**
Course Code	**: P141**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**

Proposed by **: UGCS, SPS**

Outcome of the Course:

Expands on the training provided in P141 with further basic experiments focused on electromagnetism and optics.

Course Contents:

1. Conversion of Voltmeter to Ammeter and vice-versa.
2. Study of Electromagnetic Damping
3. Tangent Galvanometer
4. Magnetic field variation along the axis of a circular coil and a Helmholtz coil
5. Determination of the resolving power of a telescope
6. Dispersive Power of Prism
7. Study of Newton's rings.
8. Laser Diffraction and Interference
9. Malus's law

Text Books (if any) & Suggested References:

None

Course Title : **General Physics Laboratory**
Course Code : **P241**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

Expands the training of the students, building on P141 and P142 to train them in experimental methods in basic solid state experiments.

Course Contents:

1. Verification of Coulomb's law
2. Coefficient of linear expansion
3. Magnetic susceptibility of a paramagnetic material.
4. Young's modulus of glass by Cornu's method
5. Specific charge (e/m) of electron
6. Magnetic hysteresis
7. Dielectric constant

Text Books (if any) & Suggested References:
None

Course Title	**: Basic Electronics Laboratory**
Course Code	**: P242**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**

Proposed by **: UGCS, SPS**

Outcome of the Course:

This final basic training in experimental physics equips the student with concepts and methods for doing advanced experiments in electronics.

Course Contents:

1. Study of Normal and Zener Diode Characteristics
2. Half-wave Rectifier Circuit Without and with filter
3. Full-wave Rectifier Circuit Without and with filter
4. Setting up a Power Supply using a Zener Diode as Voltage Regulator
5. Study of LCR Resonant Circuit
6. RC CIRCUIT AS A FILTERING AND PHASE SHIFTING NETWORK
7. Bipolar Junction Transistor Static Characteristics
8. Study of Common Emitter Transistor Amplifier circuit

Text Books (if any) & Suggested References:

None

Course Title	**: Modern Physics I & Optics Laboratory**
Course Code	**: P243**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

The course, though experiments introduces to fundamental findings that lead to the discoveries of special relativity and quantum mechanics. In the process the course also teaches them how to use interferometers and diffraction gratings required in future courses.

Course Contents:

1. Franck-Hertz Experiment
2. Emission spectra of metals and hydrogen
3. Planck's constant by Photoelectric Effect
4. Sodium D-line splitting
5. Diffraction by ultrasonic waves in liquids
6. Michelson Interferometer
7. Fabry-Perot Interferometer

Text Books (if any) & Suggested References:

None

Course Title	**: Advanced Electronics Laboratory**
Course Code	**: P244**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

In this course the students learn advanced electronic experimentations. This includes transistors, operational amplifiers digital circuits and counters and are crucial to carrying our future experimental research.

Course Contents:

1. Study of basic configuration of OPAMP (IC-741), simple mathematical operations and its use as comparator and Schmitt trigger
2. Differentiator, Integrator and active filter circuits using OPAMP (IC-741)
3. Phase shift oscillator using OPAMP (IC-741)
4. Study of various logic families (DRL, DTL and TTL)
5. Study of Boolean logic operations using ICs
6. Design and study of full adder and subtractor circuits
7. Design and study of various flip flop circuits (RS, D, JK, T)
8. Design and study of various counter circuits (up, down, ring, mod-n)
9. Design and study of astable multivibrators using IC 555

Text Books (if any) & Suggested References:
None

Course Title	**: Nuclear Physics and Instrumentation Laboratory**
Course Code	**: P341**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**

Proposed by **: UGCS, SPS**

Outcome of the Course:

This course teaches the students about basic experimentation in nuclear physics. It in conjunction with theory course on Nuclear physics P307 builds a background to carry our basic research in the field of experimental particle physics.

Course Contents:

1. Experiments using GM counter and counting statistics
2. Rutherford Alpha scattering
3. Gamma Ray spectroscopy
4. Compton Scattering

Text Books (if any) & Suggested References:

None

Course Title	**: Computational Physics Laboratory**
Course Code	**:**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**

Proposed by **: UGCS, SPS**

Outcome of the Course:

The course provides a basic training in numerical and statistical methods used in all branches of physics though programming and hands on tutorial sessions.

Course Contents:

Language: C++ (adequate background is expected from previous programming Labs in earlier semesters). Statistical description of data: Mean, Variance etc.; Finding zeroes of a function; Differentiation, integration; Matrix algebra; Inverse of Matrix, Differential equations; algebraic computation; Least square fitting for linear and non linear functions, Minimization of a function, General non-linear fit.

Text Books (if any) & Suggested References:

None

Course Title	**: Modern Physics II Laboratory**
Course Code	**: P343**
Credits	**: 2**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 42**

Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course provides further experience to the students in experiments in modern quantum mechanics including highly specialized experiments on electron spin resonance and introduces them to cutting edge research area of solar cells.

Course Contents:

1. Zeeman effect
2. Electron spin resonance of DPPH
3. Experiments using Expeyes interface board
4. Solar cell characteristics

Text Books (if any) & Suggested References:

None

Course Title : **Solid State Physics Lab I Laboratory**
Course Code : **P344**
Credits : **2**
Course Category : **Core**
Course Prerequisite :
Contact Hours (28/42/56) (including tutorials) : **42**

Proposed by : **UGCS, SPS**

Outcome of the Course:

In this course the student is introduced to a variety of basic experiments in solid state physics. This prepares them for taking up more challenging experiments in this are in future courses.

Course Contents:

1. Hall effect with temperature
2. Energy band gap of semiconductor
3. Lattice dynamics of monoatomic and diatomic lattice
4. Study of Magnetoresistance

Text Books (if any) & Suggested References:
None

Course Title	**: Solid State Physics II Laboratory**
Course Codes	**: P441**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**:**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course exposes the student to advanced solid state experiments. It, in part, prepares them in both areas to take on further advanced experiments in future courses.

Course Contents:

1. Superconductivity using LC Circuit
2. Dielectric constant at microwave frequency
3. Study of Magnetostriction using Michelson's interferometry
4. Study of Earth Field Nuclear Magnetic Resonance
5. Study of optical Tamm surfaces

Text Books (if any) & Suggested References:
None

Course Title	**: Laser and spectroscopy Laboratory**
Course Codes	**: P442**
Credits	**: 4**
Course Category	**: Core**
Course Prerequisite	**:**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course exposes the student to basic laser optics and spectroscopy experiments. It, in part, prepares them in both areas to take on further advanced experiments in future courses.

Course Contents:

1. Study of Faraday effect
2. Study of Raman spectroscopy
3. Alignment of He-Ne Laser and study of spectral and spatial properties of the beam
4. Study of Nd-Yag laser
5. Study of Z-scan technique

Text Books (if any) & Suggested References:

None

Course Title : **Integrated Physics Laboratory I**
Course Code : **P443**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course extends the knowledge and expertise of students in advanced experimental techniques readying them to begin experimental research across a multitude of areas in solid state and high energy physics.

Course Contents:

1. Study of Negative group delay in electronics circuit
2. Study of Lock-in-amplifier
3. Study of Coupled Oscillators
4. Study of Holography
5. Study of LED as single photon detector

Text Books (if any) & Suggested References:
None

Course Title : **Integrated Physics Laboratory II**
Course Code : **P444**
Credits : **4**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course extends the knowledge and expertise of students in advanced experimental techniques readying them to begin experimental research across a multitude of areas in solid state and high energy physics.

Course Contents:

1. Study of Laser Gyroscope
2. Study of Noise fundamentals
3. Study of various optical experiments using Microwaves
4. Study of Laser Doppler Anemometry
5. Study of Muon life time using FPGA

Text Books (if any) & Suggested References:

None

Projects

Course Title : Physics Project I
Course Code : **P398**
Credits : **4**
Course Category : **Mandatory**
Course Prerequisite : **None**
Contact Hours (28/42/56) :
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course, is meant to provide mini research or advanced reading project with a supervisor on very specialized topic. At the end the student is expected to have mastered the fundamentals of the relevant area and present a poster on the semester long project work.

Course Contents:
6^{th} semester project

Text Books (if any) & Suggested References:
None

Course Title **:** Physics Dissertation project I
Course Code **: P598**
Credits **: 12**
Course Category **: Mandatory**
Course Prerequisite **:**
Contact Hours (28/42/56) **:**
(including tutorials)

Proposed by **: UGCS, SPS**

Outcome of the Course:

This is the first half of a year-long project that the final year Int. MSc student has to do. This involves preparing adequate reading material that will allow the student to take up challenging reach problem with a supervisor in a specific area of work.

Course Contents:
Project work

Text Books (if any) & Suggested References:
None

Course Title **:** Physics Dissertation project II
Course Code **: P599**
Credits **: 20**
Course Category **: Mandatory**
Course Prerequisite **:**
Contact Hours (28/42/56) **:**
(including tutorials)

Proposed by **: UGCS, SPS**

Outcome of the Course:

In the final semester project, the student is expected to be able to build on the background in the ninth semester to work on a research problem. Many times this typically leads to a publication of a paper is a reputed international journal.

Course Contents:

Project work

Text Books (if any) & Suggested References:
None

Elective courses

Course Title : **Advanced Solid State Physics**
Course Code : **P451**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : P302 (Quantum Mechanics II), P305 (Introduction to condensed matter Physics)
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This is a course which aims to prepare students with advanced concepts, techniques and knowledge of solid state physics that allows them to start working on basic research problems in the broad area of condensed matter theory, materials theory or solid state experiments.

Course Contents:

1. Introduction to physics of metals and insulators. Electrical, thermal and optical properties of metals and insulators, and need to study excitation spectrum in detail.
2. Electrons, phonons and Magnons, Screening and plasma Oscillations
3. Charge impurity in a metal: Friedel Oscillation, Magnetic impurity in a metal,
4. Moment formation and suppression in metals.
5. Electron gas in Low dimension: impurity and interaction effects.
6. Quantum Hall Effect
7. Metal-insulator transition
8. Electron - phonon interaction, Frohlich Hamiltonian and Superconductivity

Text Books (if any) & Suggested References:

1. Advanced Solid State physics: Philip Phillips
2. Elementary Excitations in Solids: D. Pines
3. Solid State physics: Marder
4. Concepts in Solids: P.W. Anderson
5. Basic notions in Condensed Matter: P.W. Anderson

Course Title : **Computational Physics**
Course Code : **P452**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : P206 (Quantum Mechanics I), P301 (Statistical Mechanics)
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course provides training in computation tools required in research across a wide variety of fields including condensed matter, high energy phenomenology and lattice field theories.

Course Contents:

1. Monte Carlo: Markov chain, Metropolis algorithm, Ising Model, Quantum Monte Carlo
2. Molecular Dynamics: integration methods, extended ensembles, molecular systems
3. Variational methods for Schrodinger Equation: Hartree and Hartree-Fock methods, post HF methods
4. Density Functional Theory: Fundamental theorem, XC-potentials
5. Quantum Molecular dynamics: Carr-Parinello approach, hybrid QM/MM method
6. Computational methods for lattice field theories

Text Books (if any) & Suggested References:

1. Computational physics, Joseph Marie Thijssen, Cambridge University press
2. an introduction to Computational physics, Tao pang, Cambridge University press
3. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids, Clarendon press
4. D. p. Landau and K. Binder, a guide to Monte Carlo Simulations in Statistical physics, Cambridge University press
5. M. Suzuki, editor, Quantum Monte Carlo Methods, Springer-Verlag
6. I. Prigogine and Stuart a. Rice, new Methods in Computational Quantum Mechanics, Wiley.
7. D. Frankel and B. Smit, Understanding Molecular Simulation, second edition, academic press.
8. Computational Methods in Field Theory, H. Gausterer and C.B. Lang, Lecture notes in physics 409
9. R. G. Parr and W. Yang, Density Functional theory of atoms and molecules

10. F. Jensen, introduction to Computational Chemistry

11. C. J. Crammer, Essentials of computational chemistry

Course Title : **Quantum Field Theory I**
Course Code : **P453**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : P304 (Electromagnetism II), P302 (Quantum Mechanics II
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This first course on quantum field theory prepares the student for tackling future advanced courses in the area of high energy physics.

Course Contents:

1. Relativistic quantum mechanics - Klein-Gordon equation, Dirac equation, free- particle solutions
2. Lagrangian formulation of Klein-Gordon, Dirac and Maxwell eqns., Symmetries (Norther's theorem), Gauge field, actions.
3. Canonical quantization of scalar and Dirac fields.
4. Interacting fields - Heisenberg picture, perturbation theory, Wicks theorem, Feynman diagram.
5. Cross-section and S-matrix.
6. Quantization of gauge field, gauge fixing.
7. QED and QED processes.
8. Radiative corrections - self-energy, vacuum polarization, vertex correction.
9. LSZ and optical theorem.
10. Introduction to renormalization.

Text Books (if any) & Suggested References:

1. An Introduction to Quantum Field Theory by M. Peskin and D. V. Schroeder
2. Quantum Field theory: From Operators to Path Integrals, 2nd edition by Kerson Huang
3. Quantum Field Theory by Mark Srednicki
4. Quantum Field Theory by Claude Itzykson and Jean Bernard Zuber
5. Notes from Sidney Coleman's Physics 253a, arXiv: 1110.5013

Course Title	**: Particle Physics**
Course Code	**: P454**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**:** P306 (Nuclei & Particles) P303 (Special Theory of Relativity)
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course teaches the basics of particle physics and allows the student to start beginning research work in high energy phenomenology.

Course Contents:

1. Elementary particles, discrete symmetries and conservation laws.
2. Symmetries and Quarks.
3. Klein-Gordon equation, concept of antiparticle.
4. Lorentz symmetry and scalar / vector / spinor fields.
5. Dirac equation
6. Scattering processes of spin-1/2 particles (Feynman rules as thumb rule QFT course), propagators.
7. Current-current interactions, weak interaction, Fermi theory.
8. gauge symmetries, spontaneous symmetry breaking, Higgs mechanism
9. Electroweak interaction, Glashow-Salam-Weinberg model.
10. Introduction to QCD, structure of hadrons (form factors, structure functions), parton model, Deep inelastic scattering.

Text Books (if any) & Suggested References:

1. Gauge Theories in Particle Physics, Vol I & II by Aitchison and Hey
2. Foundations of Quantum Chromodynamics by T. Muta
3. Modern Particle Physics by Mark Thomson
4. Introduction to Elementary Particle by David Griffiths
5. Quarks and Leptons by F. Halzen and A.D. Martin
6. Introduction to High Energy Physics: D.H. Perkins
7. Introduction to Elementary Particle Physics: A. Bettini
8. Particle Physics by B. R. Martin and G. Shaw

Course Title	**: Introduction to Phase Transitions and Critical phenomena**
Course Code	**: P455**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P301 (Statistical Mechanics)**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course teaches the students advanced concepts and methods in statistical mechanics crucial for the student to take up basic research work.

Course Contents:

Experimental evidences of classical and quantum critical phenomena, thermodynamic potentials. heat capacity, magnetic susceptibility, phases, phenomenology of 1st order phase transitions, continuous transitions, order parameters and models: Ising, XY, Heisenberg, universality and scaling, Ginzburg-Landau-Wilson theory, spontaneous symmetry breaking. Bose- Einstein condensation, expansion around upper critical dimension, domain walls and surface tension, 1D Ising model and instantons, critical behavior, critical exponents, relations between critical exponents, Kadanoff scaling, universality conjecture, calculation of critical exponents: real space RG methods, phi- 4 theory, 4-epsilon expansion.? RG of Wilson and Fisher, continuous symmetry: Mermin-Wagner theorem. goldstone modes, non- linear sigma-model, vortices, Kosterlitz-Thouless phase transition, topology and duality, surface roughening and Sine-Gordon models, quantum critical phenomena, dissipative quantum tunneling, quantum phase transitions, Bose-Hubbard model.

Text Books (if any) & Suggested References:

1. Introduction to phase Transitions and Critical phenomena by H. Eugene Stanley
2. Modern approach to Critical phenomena by Igor Herbut
3. Statistical physics: Statics, Dynamics and Renormalization by Leo p. Kadanoff
4. The Theory of Critical phenomena by J. J. Binney, a. J. Fisher, M. E. J. Newman
5. Modern Theory of Critical phenomena by Shang-keng Ma
6. Statistical Mechanics of phase Transitions by J. Yeomans
7. Field Theory, the Renormalization group and Critical phenomena by Daniel J. Amit

Course Title : **Nonlinear Optics and Lasers**
Course Code : **P456**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P204 (Electromagnetism I)**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students advanced concepts and methods in modern topics in laser optics and non-linear optics necessary for the student to take up basic research work in optics.

Course Contents:

1. Introduction to general lasers and their types, emission, absorption processes and rate equations, population inversion, gain, optical cavities, three and four level lasers, CW and pulsed lasers, Q-switching and mode-locking, physics of gas discharge, atomic, ionic, molecular, liquid, and excimer lasers, optical pumping, Holography
2. Overview of non- linear Optics, nonlinear polarization, nonlinear optical susceptibility, Symmetry considerations
3. Wave propagation in nonlinear media
4. Electro optical and magneto optical effects
5. Higher harmonic generations, phase matching and quasi phase matching, Sum and difference frequency generation, Optical parametric amplification and oscillation
6. Kerr effect, Cross-Phase Modulation, Self phase modulation, Multi-photon processes , Self focusing, Four-Wave Mixing
7. Laser Spectroscopy, wave front conjugation Stimulated Raman Scattering, Stimulated Brillouin Scattering, Optical solitons and Optical pulse compression

Text Books (if any) & Suggested References:

1. Lasers by P. W. Milonni and J. H. Eberly
2. Lasers by A. E. Siegman
3. Principles of Lasers by Orazio Svelto
4. The Principles of Nonlinear Optics by Y. R. Shen
5. Nonlinear Optics by Robert W. Boyd
6. Nonlinear Optics: Basic Concepts by D.L. Mills
7. Optical waves in crystals by Amnon Yariv and Pochi Yeh

Course Title	**: General Theory of Relativity and Cosmology**
Course Code	**: P457**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P303 (Special Theory of Relativity)**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: UGCS, SPS**

Outcome of the Course:

This course teaches the students, advanced concepts and methods in general relativity crucial for the student for building their background for research work in general relativity and cosmology.

Course Contents:

1. Review of Newtonian Mechanics. Special theory of relativity. prelude to general relativity, historical developments
2. 4-Vectors and 4-tensors, examples from physics
3. Principle of Equivalence, Equations of motion, gravitational force
4. Tensor analysis in Riemannian space, Effects of gravitation, Riemann-Christoffel curvature tensor, Ricci Tensor, Curvature Scalar
5. Einstein Field Equations, Experimental tests of GTR
6. Schwartzchild Solution, gravitational lensing
7. Gravitational waves: generation and detection
8. Energy, momentum and angular momentum in gravitation
9. Cosmological principle, Robertson-Walker metric, Redshifts
10. Big-Bang Hypothesis, CMB
11. Issues in Quantum gravity

Text Books (if any) & Suggested References:

1. A first course in General Relativity by Bernard Schutz
2. Gravity by James B. Hartle
3. The Classical Theory of Fields by L. D. Landau and E. M. Lifshitz
4. Gravitation and Cosmology by Steven Weinberg
5. Introducing Einstein's Relativity by Ray D'Inverno
6. General Relativity by P. Dirac

Course Title : **Soft Condensed Matter**
Course Code : **P458**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P301 (Statistical Mechanics)**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students advanced concepts and methods in soft matter physics, with the aim to build their background for future research work in this area.

Course Contents:

1. What is Soft Condensed Matter: forces, energies and time scales.
2. phase transition in soft matter, Radial distribution function and description of liquids.
3. Colloids polymers gels Liquid Crystals
4. Soft matter in nature

Text Books (if any) & Suggested References:

1. Principles of Condensed Matter Physics by P. M. Chaikin and T. C. Lubensky
2. Soft Condensed Matter by R. A. L. Jones
3. Structured Fluids: Polymers, Colloids, Surfactants by T. Witten
4. Introduction to Soft Matter: Polymers, Colloids, Amphiphiles and Liquid Crystals by I. W. Hamley
5. Soft Matter Physics by M. Klemanand and O. D. Lavrentovich
6. Colloidal Dispersions by W. B. Russel, D. A. Saville and W. R. Showalter
7. Dynamics of Colloids by J. K. G. Dont
8. Intermolecular and Surface Forces: With Applications to Colloidal and Biological Systems by J. Israelachvili
9. Introduction to Liquid Crystals by P. J. Collings and M. Hird
10. Polymer solutions -- an introduction to physical properties by I. Teraoka

Course Title	**: Applied Nuclear Physics**
Course Code	**: P459**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P303 (Quantum Mechanics II)**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: UGCS, SPS**

Outcome of the Course:

This course teaches the students advanced concepts and methods in applied nuclear physics, with the aim to build their background for future research work in this area.

Course Contents:

1. Basis of nuclear structure and reactions
2. Radioactivity and radioactive decays: Detecting nuclear radiations, Alpha decay, beta decay, gamma decay
3. Passage of charged particle through matter.
4. Detectors and accelerators.
5. Applications: Effects of radiation on biological systems and Nuclear medicine, Industrial Applications
6. Power from Fission and Fusion: Characteristics of Fission, Nuclear Reactors, Thermonuclear fusion.

Text Books (if any) & Suggested References:

1. Nuclear Physics: Principles and Applications, John Lilley, Wiley Publications
2. The Atomic Nucleus, Robley D. Evans, Tata McGraw-Hill Publishing.
3. Fundamentals of Nuclear Reactor Physics, Elmer Lewis, Elsevier Publishing.
4. An Introduction to the Passage of Energetic Particles through Matter, N. J. Carron, CRC Press
5. Accelerator Physics, S. Y. Lee, World Scientific

Course Title	**: Many Particle Physics**
Course Code	**: P460**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P301 (Statistical Mechanics), P302 (Quantum Mechanics II)**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course teaches the students advanced concepts and methods in many particle physics, with the aim to build their background for future research work in this area.

Course Contents:

1. Second Quantization, One and two body operators
2. Observables and their relationship to one and two body greens functions
3. Thermodynamic potential, Spectral functions, analytic properties of greens function
4. Linear Response, correlation function, sum rules
5. Canonical Transformation: Bogoliubov Valetin, Schrieffer Wolf, etc.
6. Equation of motion,
7. Diagrammatic perturbation theory for green function and the thermodynamic potential, Luttinger Ward identities.
8. Mean field theory
9. Functional integration Methods

Text Books (if any) & Suggested References:

1. Statistical Physics part 2 by E.M.Lifshitz & L.P. Pitaevskii
2. Quantum Theory of Many body particle systems by Fetter Walecka
3. Introduction to Many-Body Physics by Piers Coleman
4. Many particle physics by Ben Simon
5. Green’s Function for Solid State Physics by S. Doniach & E.H. Sondheimer
6. Quantum Mechanics R. Shankar

7. Quantum many particle systems J. W. Negele and H. Orland

8. Techniques and Application of Path-integration by S.Schulman

Course Title	**: Physics of Mesoscopic Systems**
Course Code	**: P461**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P305 (Introduction to Condensed Matter Physics)**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: UGCS, SPS**

Outcome of the Course:

This course teaches the students advanced concepts and methods in mesoscopic physics, with the aim to build their background for future research work in this area.

Course Contents:

1. Effects of magnetic fields: The Aharonov Bohm effect; 2D electron gas; Landau levels; Transverse modes in 2D quantum
   wire; Shubnikovde Haas oscillations; Magnetic edge states; integer Quantum Hall effect, Fractional Quantum Hall effect

2. Electron transport: Boltzmann semiclassical transport; Onsager reciprocity relations; Conventional Hall effect; Drude conductivity; Einstein relation; Electronic states in quantum confined systems; Conductance from transmission; Ballistic transport; Quantum of conductance; Landauer formula; Quantum point contact; T .matrices; Smatrix and green functions; Current operator; Landauer Buttiker formalism; Linear response and Kubo formula; nonequilib- rium green's function approach to transport; Scattering: Breit Wigner resonance and Fano resonance; Delay time for resonances; Friedel sum rule; Levin- son.s theorem; Singleelectron tunneling: Coulomb blockade and Kondo effect
3. Quantum information: Josephson Junctions and Cubits; Metastable states and escape dynamics
4. Disordered conductors: Weak localization; Mesoscopic fluctuations; Random Matrices; Anderson localization; Quantum
   Chaos; Dephasing; Decoherence

Text Books (if any) & Suggested References:

1. Electronic Transport in Mesoscopic Systems by S. Datta, Cambridge University press.
2. Introduction to Mesoscopic Physics by Y. Imry
3. Mesoscopic Electronics in Solid State Nanostructures by T. Heinzel
4. Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations by P. Mello and N. Kumar

Course Title : **Introduction to Quantum Optics**
Course Code : **P462**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P204 (Electromagnetism I), P206 (Quantum Mechanics I)**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in quantum optics, with the aim to build their background for future research work in this area.

Course Contents:

1. Electromagnetic field quantization: Quantum fluctuation and Quadrature operators of a single mode field, Thermal fields, Vacuum fluctuation and zero point energy, Quantum phase
2. Coherent and squeezed states of radiation field: Properties and phase space picture of coherent state, Generation of a coherent state, Squeezed state physics, generation and Detection of squeezed light, Schrodinger cat states, Multi- mode squeezing, Broadband squeezed light, Squeezing via non-linear process
3. Atom-field interaction: Rabi model (Semi-classical model for atom-field interaction), Jaynes-Cummings model (fully quantum mechanical model for atom-field interaction), Dressed states, Density operator approach, Hanle effect, Coherent trapping, electromagnetically induced transparency, Four wave mixing
4. Quantum coherence function: photon detection and quantum coherence functions, First order coherence and Youngs type double source experiment, Second order coherence, physics of Hanbury-Brown-Twiss effect, Experiments with single photon, Quantum mechanics of beam splitter, interferometry with single photon
5. Optical test of quantum mechanics: photon sources: spontaneous parametric down-conversion, Hong-Ou-Mandel interferometer, Superluminal tunneling of photons, EPR paradox and optical test of Bell's theorem
6. atom Optics: Mechanical effects of light, Laser cooling, atom interferometry, atoms in cavity, Experimental realization of Jaynes-Cummings model
7. Heisenberg-limited interferometry and quantum information: Entanglement and interferometric measurements, Quantum teleportation, Quantum cryptography, an optical realization of some quantum gates.

Text Books (if any) & Suggested References:

1. Introductory Quantum Optics by C. C. Gerry and P. L. Knight, Cambridge

University press
2. Quantum Optics by M. O. Scully and M. S. Zubairy, Cambridge University press
3. Quantum Optics by M. Fox, Oxford Master series in atomic, Optical and Laser physics
4. Quantum Theory of Light by R. Loudon, Oxford science publication

Course Title : **Astronomy and Astrophysics**
Course Code : **P463**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P201 (Classical Mechanics I), P204 (Electromagnetism I) & P303 (Special Theory of Relativity)**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course introduces the students to the field of Astonomy & Astrophysics, with the aim to build their background for future research work in this area.

Course Contents:

Part I: Introduction and Tools
1. Tools - astronomical objects, scales, distance ladder, astrometry, magnitude scale
2. Gravity - Kepler's law, Virial theorem
3. Radiation physics - radiative flux, transfer function, absorption, scattering and emission, Einstein coefficient, local thermodynamic equilibrium, source function and line formation, concept of opacities

Part II: Stars
1. Stars and stellar structures - stellar spectra, HR diagram • Equilibrium in stars
2. Star formation and Protostar
3. Stellar evolution
4. Supernovae
5. Black holes and gravitational waves

Part III : Interstellar medium

Part IV: Galaxies
1. The Milky way Galaxy - distribution of matter, differential rotation, formation of the spiral arms
2. Elliptical and Spiral Galaxies
3. Evidence for dark matter
4. Active Galaxies - Active Galactic Nuclei, Seyfert Galaxies, Quasars, Blazers

Part V: Magnetic fields
1. Astrophysical phenomena where magnetic fields are critical
2. Galactic magnetic fields - dust and synchrotron polarization, Faraday rotation, Zeeman measurements

Part VI: Gravitational Lensing

Part VII: Clusters and Superclusters (optional)

Part VIII: Cosmology (optional)

- Cosmological Observations and the Cosmological Principle - Newtonian Cosmology and Cosmological Models

- Cosmic Microwave Background

Text Books (if any) & Suggested References:

1. Fundamental Astronomy by H. Karttunen, P. Kröger, H. Oja, M. Poutanen, K. J. Donner
2. Introduction to Modern Astrophysics by B. W. Carroll and D. A. Ostlie
3. An invitation to Astrophysics by T. Padmanabhan
4. Astrophysical Concepts by Martin Harwit
5. Introductory Astronomy and Astrophysics by Zelike and Gregory
6. Universe by Roger Freedman
7. Physical Universe by F. Shu
8. Astrophysics Processes by Hale Bradt
9. Radiative processes in Astrophysics by Rybicki and Lightman
10. An introduction to Astronomy and Astrophysics by Pankaj Jain
11. Quasars and Active Galactic Nuclei by Kembhavi and Narlikar

Course Title	**: Plasma Physics and Magnetohydrodynamics**
Course Code	**: P464**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**:**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.

Course Contents:

1. Introduction to plasmas, applications: in fusion, space and astrophysics, semi-conductor etching, micro- wave generation, characterization of the plasma state, Debye shielding.
2. Plasma and cyclotron frequencies, collision rates and mean-free paths, atomic processes, adiabatic invariance, orbit theory, magnetic confinement of single charged particles.
3. Two-fluid description, magneto-hydrodynamic waves and instabilities, heat flow, diffusion, kinetic description, and Landau damping.
4. Ideal magneto-hydrodynamic (MHD) equilibrium, MHD energy principle, ideal and resistive MHD stability, drift-kinetic equation, collisions, classical and neoclassical transport, drift waves and low-frequency instabilities, high frequency micro instabilities, and quasi-linear theory.

Text Books (if any) & Suggested References:

1. Plasma physics by Peter Andrew Sturrock
2. Principles of Magnetohydrodynamics by J. P. Hans Goedbloed, Stefaan Poedts
3. Hydrodynamic and Hydromagnetic Stability by S. Chandrasekhar
4. The Physics of Plasmas by T. J. M. Boyd, J. J. Sanderson
5. Fundamentals of Plasma Physics by Paul M. Bellan,
6. Introduction to Plasma Physics by R. J. Goldston, P. H. Rutherford
7. An Introduction to Magnetohydrodynamics by P. A. Davidson

8. An Introduction to Plasma Astrophysics and Magnetohydrodynamics by M. Goossens

Course Title : **Quantum and Nanoelectronics**
Course Code : **P466**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P302 (Quantum Mechanics II), P301 (Statistical Mechanics)**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in nanoelectronics, with the aim to build their background for future research work in this area.

Course Contents:

1. Introduction and review of electronic technology
2. From electronics to nano-electronics: particles, waves and Schrodinger equation, quantum description of atoms and molecules, quantum description of metals, semiconductors, junction devices, some newer building blocks for nano-electronic devices
3. Fabrication and characterization methods for nano-electronics
4. The field effect transistor FET: size limits and alternative forms
5. Devices based on electron tunneling, resonant tunnel diodes, single electron transistors, molecular electronics, hybrid electronics
6. Devices based on electron spin and ferromagnetism
7. Qubits vs. binary bits in a quantum computer, applications of nano-electronic technology to energy issues
8. Summary and brief comment on the future of nano-electronic techniques

Text Books (if any) & Suggested References:

1. Quantum nano-electronics: An Introduction to Electronic Nanotechnology and Quantum Computing by Edward L. Wolf
2. Quantum Electronics by Amnon Yariv
3. Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience by Edward L. Wolf
4. Fundamentals of Nanoelectronics by George Hanson

5. Introduction to Nanoelectronics: Science, Nanotechnology, Engineering and Applications by Vladimir Mitin, Viatcheslav, A. Kochelap, Michael, A. Stroscio

Course Title	**: Nonlinear Physics, Chaos and Turbulence**
Course Code	**: P467**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P201 (Classical Mechanics I)**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in classical nonlinear dynamics, with the aim to build their background for future research work in this area.

Course Contents:

1. General introduction and motivation: examples of linearity and nonlinearity in physics and the other sciences; modelling systems using iterated maps or differential equations, nonautonomous systems
2. General features of dynamical systems : Systems of differential equations with examples; control parameters; fixed points and their stability; phase space; linear stability analysis; numerical methods for nonlinear systems; properties of limit cycles; nonlinear oscillators and their applications; the impossibility of chaos in the phase plane; bifurcations: their classification and physical examples; spatial systems, pattern formation and the Turing mechanism; strange attractors and chaotic behaviour
3. The logistic map: Linear and quadratic maps; graphical analysis of the logistic map; linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; chaotic behaviour and the determination of the Lyapunov exponent; universality and the Feigenbaum numbers; other examples of iterated maps
4. Hamiltonian Sytems: Phase space; Constants of motion and integrable Hamiltonians; Nonintegrable systems, the KAM theorem and period-doubling; applications
5. Fractal geometry: dimension of an object, Mandelbrot set, Julia set, iterated function systems
6. Spatio-temporal dynamics: Spatio-temporal chaos
7. Quantum Chaos: Quantum analogies to Chaotic behaviour, Correlations in wave functions, chaos and Semi-classical approaches to Quantum mechanics

Text Books (if any) & Suggested References:

1. S. H. Strogatz, Nonlinear Dynamics and Chaos: With Applications in Physics, Biology, Chemistry and Engineering.

2. Robert C. Hilborn, Chaos and Nonlinear Dynamics.

3. Brian Davies, Exploring Chaos: Theory and Experiment.

4. K. T. Alligood, T. D. Sauer and J. A. Yorke, Chaos: An Introduction to Dynamical Systems.

5. Edward Ott, Chaos in Dynamical Systems.

6. M.Tabor, Chaos and Integrability in Nonlinear Dynamics: An Introduction.

Course Title : Magnetism and Superconductivity
Course Code : P468
Credits : 4
Course Category : Elective
Course Prerequisite : P305 (Introduction to Condensed Matter Physics)

Contact Hours (28/42/56) : 56
(including tutorials)

Proposed by : UGCS, SPS

Outcome of the Course:

This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.

Course Contents:

1. The phenomenon of Superconductivity: historical perspective, characteristics, occurrence,
2. London Equations, Thermodynamics
3. Ginzburg Landau Theory, Abrikosov Vortices,
4. Josephson Effect
5. Cooper instability, BCS wave function, gap equation, thermodynamics and magnetic response
6. Conventional and non-conventional superconductors
7. Diamagnetism paramagnetism Ferromagnetism characteristics, Occurrence
8. Orbital magnetism, de Haas van alfen effect,, Meissner Effect in superconductor
9. Heisenberg Model: ground state, Spin waves
10. Hubbard Model and itinerant exchange
11. Magnetic domains and hysteresis

Text Books (if any) & Suggested References:

1. Theory of Superconductivity by J. R. Schrieffer
2. Superconductivity of Metals and Alloys by P. G. De Gennes
3. Introduction to Superconductivity by M. Tinkham
4. Quantum Theory of Magnetism by R.M.White
5. The theory of Magnetism by D. C. Mattis

Course Title	**: Density Functional Theory of Atoms, Molecules &Solids**
Course Code	**: P469**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P302 (Quantum Mechanics II)**
Contact Hours (28/42/56) (including tutorials)	**: 56**
Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in density functional theory, with the aim to build their background for future research work in this area.

Course Contents:

1. Many-body problem: QM of electrons and nuclei, approximation methods for many electron systems, Born-Oppenheimer approximation, Hartree and HF theory, tight binding method, greens functions, electron correlation, Ci & many-body and Moller-plesset theory, complete active space methods, coupled cluster theory, density matrices, time-dependent approach to all the above formalism
2. Foundations of Density Functional Theory(DFT): Hohenberg-Kohn (HK) theo-rem, degenerate ground states, variational DFT, N − and v− representability problem, Levy-Lieb constrained search, fractional particle number & derivative discontinuity, spin polarized systems, Exited states part i: Effective Single particle picture: Kohn-Sham (KS) construction, non-interacting v− representability, degenerate KS DFT, KS equations for spin polarized systems, interpretation of KS eigenvalues
3. Exchange-Correlation (XC) Energy Functional: exact exchange formalism within DFT, exact representations of the energy functional, LDa, gga, meta-gga, weighted density approximation, self interaction correction (SiC), virial theorems, exact exchange formalism (OpM, KLi, HS), where DFT goes wrong, strengths of DFT, strong correlation: DFT+U, Rpa, gW, DFpT, DMFT, orbital free DFT, DFT- hybrid
4. Crossover to Excited-States: time-dependent DFT: Runge-gross theorem, time- dependent KS equations, adiabatic LDa & TD XC potentials, linear response TDDFT, Excited states part ii, spin polarized TDDFT, frequency dependent XC kernel, TDCDFT, TDOEp, relativistic DFT, molecular orbital theories

Text Books (if any) & Suggested References:

1. Density Functional Theory of atoms and Molecules by Robert G. Parr and Weitao Yang
2. Density functional Theory by R.M. Dreizler and E.K.U. Gross
3. Density Functional Theory by Eberhard Engel
4. Primer in Density Functional Theory by C. Fiolhais, F. nogueira, Miguel and A. L. Marques
5. Fundamentals of TDDFT by Miguel A. L. Marques et al.
6. Time-dependent Density Functional Theory by Miguel A. L. Marques et al.
7. Time-dependent Density Functional Theory by Carsten Ullrich
8. Quantal Density Functional Theory I & II by Viraht Shani
9. Recent advances in Density Functional Methods (Part I, II & III) by Delano P Chong
10. Atomic and Electronic Structure of Solids by Ethimios Kaxiras

11. Electronic Structure: Basic Theory and Practical Methods by Richard M. Martin
12. Many-Body Quantum Theory in Condensed Matter Physics by H. Bruus and K. Flensberg
13. Quantum Theory of the Electron Liquid by Gabriele Giuliani and Giovanni Vignale
14. Molecular Electronic Structure Theory by T. U. Helgaker, P. Jorgensen and J. Olsen
15. Electronic Structure Calculations for Solids and Molecules by J. Kohanoff
16. Methods of Electronic Structure Calculations by M. Springborg
17. Self Consistent Fields in Atoms by Norman March
18. Computational Materials Science by J. G. Lee
19. Density Functional Theory in Quantum Chemistry by Takao Tsuneda
20. Material Modeling using DFT by Feliciano Giustino

Course Title	**: Quantum Field Theory II**
Course Code	**: P470**
Credits	**: 4**
Course Category	**: Elective**
Course Prerequisite	**: P453 (Quantum Field Theory I)**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by	**: UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in advanced quantum field theory, with the aim to build their background for future research work in this area.

Course Contents:

1. Path-integral formulation of quantum mechanics
2. Path-integral for scalar fields, generating functional, connected Greens functions, Feynman rules, 1 loop diagrams
3. Grassmann variable, path-integral for Dirac field
4. Path-integral for Electromagnetic field, gauge fixing
5. QED, symmetries and Ward identity
6. Renormalization divergences and power counting, Φ4 theory, QED, spontaneous symmetry breaking, Renormalization group basics (running of coupling).
7. Yang-Mills theory, gauge fixing and ghosts, BRST, asymptotic freedom

Text Books (if any) & Suggested References:

1. An Introduction to Quantum Field Theory by M. Peskin and D. V. Schroeder
2. Quantum Field theory: From Operators to Path Integrals, 2nd edition by Kerson Huang
3. Quantum Field Theory by Mark Srednicki
4. Quantum Field Theory by Claude Itzykson and Jean Bernard Zuber
5. Notes from Sidney Coleman's Physics 253a, arXiv: 1110.5013

Course Title : **Quantum Information & Quantum Computation**
Course Code : **P471**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P206 (Quantum Mechanics I)**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in quantum information and computation, with the aim to build their background for future research work in this area.

Course Contents:

1. Introduction to Classical information: Shannon entropy, Mutual Information
2. Quantum Information I: Hilbert space, density matrices, quantum entropy and Holevo bound
3. Quantum Information II: Entanglement, Teleportation, super dense coding & Bell inequalities
4. Quantum dynamics: Two level systems, decoherence and Rabi oscillations
5. Quantum computation: single qubit gates-phase, swap, Hadamard, two qubit gates-CNOT
6. Quantum algorithms: Deutsch, Grover, Introduction to Shor's algorithm
7. Quantum error correction
8. Applications: Quantum simulation and Adiabatic quantum computation
9. Solid state quantum information & computation: Introduction to entanglement in nanostructures, quantum computation with superconducting devices and topological quantum computation

Text Books (if any) & Suggested References:

1. Introduction to Quantum Information Science by V. Vedral (Oxford U. Press)
2. Quantum Information & Computation by M. A. Nielsen & I. L. Chuang (Cambridge U. Press)
3. An Introduction to quantum computing Kaye by P. R. Laflamme and A. M. Mosca (Oxford U. press)

Course Title : **Experimental High Energy Physics**
Course Code : **P472**

Credits : 4
Course Category : Elective
Course Prerequisite : P206 (Quantum Mechanics I), P303 (Special Theory of Relativity)
Contact Hours (28/42/56) (including tutorials) : 56

Proposed by : UGCS, SPS

Outcome of the Course:

This course teaches the students important concepts and methods in experimental high energy physics, with the aim to build their background for future research work in this area.

Course Contents:

1. The interaction of high-energy particles with matter: specific applications related to EHEP. Relativistic kinematics: Detailed derivation of kinematic variables and their transformations whenever needed. Decay kinematics. Rapidity, pseudo-rapidity, space-like and time-like. Some examples where relativistic kinematics play important role for understanding of data.
2. Detectors in High Energy physics: general concept of building a HEp experiment, coverage and option
3. Gas detectors; Semiconductor detector; Scintillator and Cerenkov detectors Specific to EHEP
4. Calorimeter and Pre-shower detectors: principle of electromagnetic and hadronic shower generation. Detector Simulation: need of simulation, various techniques, MC, some general concepts
5. Data analysis in HEP: general approach of data cleanup, calibration, track reconstruction, reconstruction of events Error analysis in EHEP. Computing in EHEP: Basics of OO programming using C++, few applications in EHEP data analysis.

Text Books (if any) & Suggested References:

1. Relativistic Kinematics; a guide to the kinematic problems of High Energy physics by R. Hagedorn
2. The Experimental Foundations of particle physics by R. N. Cahn and G. Goldhaber
3. Techniques for nuclear and particle physics experiments: a How to approach by W. R. Leo (Springer)
4. Experimental Techniques in Hugh Energy Nuclear and Particle physics by T. Ferbel (World Scientific)
5. Introduction to Experimental particle physics by R. C. Fernow
6. Data Reduction and Error analysis for the physical sciences by P. Bevington and D. K. Robinson
7. Data analysis Techniques for High Energy physics by R. Frunwirth, M. Regler, R. K. Bock and H. Grote

Course Title : **Experimental Techniques**
Course Code : **P473**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P305 (Introduction to Condensed Matter Physics) P242 (Basic Electronics Theory & Lab)**

Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in experimental techniques, with the aim to build their background for future research work in this area.

Course Contents:

1. Mechanical drawing and designs: Mechanical drawing tools, basic principles of mechanical drawing, dimensions, tolerances, from design to working drawings
2. Basics tools: hand tools, machines for making holes, lathe & milling machines, grinders, casting
3. Vacuum technology: gases, gas flow, pressure and flow measurement, vacuum pumps, pumping mechanisms, ultrahigh vacuum, leak detection
4. Optical systems: optical components, optical materials, optical sources
5. Charge particle optics: electrostatic lenses, charged-particle sources, energy and mass analyzer
6. Detectors: optical detectors, photoemission detectors, particle and ionizing radiation detectors, signal to noise ration detection, surface barrier detector, Particle detector: interactions of charged particles and photons with matter; gaseous ionization detectors, scintillation counter, solid state detectors
7. Electronics: electronic noise, survey of analog and digital I/Cs, signal processing, data acquisition and control systems, data analysis evaluation
8. Nano- and micro-fabrication: various lithography techniques such as photolithography, nanoimprint lithography, e-beam lithography, ion-ball milling
9. SEM, TEM, X-ray diffraction, SQUID Magnetometry, Magnetotransport, PL/CL time resolved spectroscopy, Rutherford Backscattering spectrometry (RBS), RBS-Channeling, UV-ViS-iR spectrometry.

Text Books (if any) & Suggested References:

1. The art of Measurement, by Bernhard Kramer (V. C. H. Publication)
2. Building Scientific Apparatus by J. H. Moore et al.
3. Experiments in Modern Physics, Second Edition by Adrian C. Melissinos and Jim Napolitano
4. The art of Experimental Physics by Daryl W. Preston,
5. Vacuum Technology by A. Roth (North-Holland publisher)
6. Charge particle Beams by Stanley Humphries (John Wiley and Sons)
7. Principles of Charged Particles Acceleration, by Stanley Humphries (John Wiley and Sons)
8. Radiation Detection and Measurements by G. Knoll (3rd Edition)
9. Techniques for Nuclear and Particles Physics Experiments by W. R. Leo (2nd edition, Springer)

Course Title : **Introduction to Cosmology**
Course Code : **P474**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P457 (General Theory of Relativity & Cosmology)**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This course teaches the students important concepts and methods in introductory cosmology, with the aim to build their background for future research work in this area.

Course Contents:
1. The cosmic history and inventory
2. A sketch of general Relativity.
3. The expanding Universe
4. Friedmann Equations and Cosmological Models
5. The Standard cosmological model.
6. The inflationary Universe.
7. Primordial nucleosynthesis and the thermal history of the Universe.
8. Perturbations in an expanding Universe.
9. Growth of perturbations
10. Dark Matter Halos.
11. Statistical description of gravitational clustering
12. Special Topics: Fluctuations in the CMB, Lensing, Cluster Cosmology, The Lyman-alpha Forest, Re-ionization, Halo Model, Redshift Space Distortions.

Text Books (if any) & Suggested References:
1. Introducing Einstein's General Relativity by Ray D'inverno
2. The Early Universe by E. W. Kolb and M. S. Turner
3. Introduction to Cosmology by Barbara Ryden
4. Modern Cosmology by Scott Dodelson
5. Principles of Physical Cosmology by P. J. E. Peebles
6. Large Scale Structure of the Universe by P. J. E. Peebles
7. Structure Formation in the Universe by T. Padmanabhan

Course Title : **Relativistic Nucleus-Nucleus collision & Quark-Gluon Plasma**
Course Code : **P475**
Credits : **4**
Course Category : **Elective**
Course Prerequisite : **P306 (Nuclei and Particle Physics), P303 (Special theory of Relativity), P301 (Statistical Mechanics), P201 (Classical Mechanics-I)**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **UGCS, SPS**

Outcome of the Course:

This is an advanced course which introduces the students to the field of heavy ion collision in high energy physics, with the aim to build their background for future research work in this area.

Course Contents:
1. Introduction to high energy heavy ion collisions and Quark-Gluon-Plasma, comparison of big bang and the little bang
2. Thermodynamics: Relativisticgas (hadrons, quarks and gluons) and its statistical and thermodynamical properties, MIT Bag model, Hagedorn gas, phase diagram of QCD

3. Relativistic Kinematics: four vectors notation, rapidity variables, pseudo rapidity variables, light cone variables, relativistic invariants, Dalitz plot, cross sections
4. Collision Dynamics: initial state of nuclear collisions, fluid dynamical evolution, kinetic transport model, freeze-out and particle production
5. Experiments: a general overview of different experimental setup related to search for QGP and relevant observables
6. Signatures of QGP: collective flow, J/Ψ suppression, strangeness enhancement, jet quenching, electromagnetic probes, Hanbury-Brown-Twiss measurement
7. Recent progress

Text Books (if any) & Suggested References:

1. Hadrons and QGP by Letterssier and Rafelski
2. Introduction to High Energy Heavy Ion Collissions by C. Y. Wong
3. Phenomenology of Ultra Relativistic Heavy Ion Collissions by W Florkowski
4. Ultra relativistic heavy ion collisions by R. Vogt
5. Introduction to relativistic heavy ion collisions, by L. P. Csernai
6. A Short Course On Relativistic Heavy Ion Collission by A. K. Chaudhuri
7. Extreme states of matter in strong interaction physics by Helmut Satz
8. Relativistic Hydrodynamics by L. Rezzolla and O. Zanotti
9. Finite Temperature Field Theory by J. I. Kapusta and C. Gale
10. The Early Universe by Kolb and Turner
11. Fantastic Realitis by Frank Wilczek
12. Research Reports in Physics, Quark Gluon Plasma, Invited lectures of Winter School, Published by Springer Verlag, Editors - B. Sinha, S. Pal and S. Raha
13. The Physics of Quark Gluon Plasma, Introductory lectures, Lecture Notes in Physics 785, Publisher - Springer, Editor - S. Sarkar, H. Satz and B. Sinha
14. Quark Gluon Plasma - From big bang to little bang, K. Yagi, T. Hatsuda, Y. Miake, Cam- bridge Monograms on Particle Physics, Nuclear Physics and Cosmology
15. Quark Gluon Plasma: Theoretical Foundations, An annotated reprint collection - J. Ka- pusta, B. Muller and J. Rafelski, Publisher - Elsevier Science

PhD course in School of Physical Sciences

Course Title : **Classical Mechanics**
Course Code : **P601**
Credits : **6**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **PGCS, SPS**

Outcome of the Course:

This course reviews the concepts of Masters level classical mechanics with more emphasis on the applied/problem solving aspects. This course is meant to prepare the students for more rigorous analytical treatment of the subject required for research.

Course Contents:

1. Two-body Central force problem (reduced mass), planet orbits,Virial theorem.
2. Collisions and scattering, CM and lab frames, scattering cross section.
3. Motion in non-inertial frames, Coriolis force.

4. principle of virtual work, constraints, D Alemberts principle.
5. Generalized coordinates, velocities and momenta, Lagranges formulation.
6. principle of list action, fomulation by Maupertuls, Euler, Hamilton, Liouvilles theorem.
7. Hamilton's equations, poisson brackets.
8. Canonical transformation, Hamilton-Jacobi equation, Generating functions, Symetries and conservation laws.
9. Small oscillations, Normal modes.
10. Rigid body dynamics, Euler angles, Euler equations (should solve up to rotation of a top)

Text Books (if any) & Suggested References:

1. H.Goldstein-Classical mechanics
2. Morion and Thorton- Introduction to classical mechanics.
3. Landau & lifshitz-Mechanics
4. John R Taylor- classical mechanics

Course Title	**: Mathematical methods**
Course Code	**: P602**
Credits	**: 6**
Course Category	**: Core**
Course Prerequisite	**: None**
Contact Hours (28/42/56) (including tutorials)	**: 56**

Proposed by **: PGCS, SPS**

Outcome of the Course:

This course reviews the important mathematical tools required for physicists for implementation in research work in all specialization of physical sciences.

Course Contents:

1. Vectors and Tensors (index notation,vector analysis in curvilinear coordinates. Cartesian tensors and four vectors, General tensors).
2. Review of Linear Algebra with emphasis on applications to physical problems (linear transformations + Matrix representations, Eigen values + Eigen Vectors, Innner product spaces).
3. Review of complex analysis with applications (Cauchy-Riemann equations, Complex integration, Cauchy theorems, Contour integration, Branch points and branch cuts, Applications to integrals, series etc.)
4. Hilbert Space methods, special functions (hilbert space, Orthonormal series expansions in Hilbert space especially Fourier series, Special functions
5. Ordinary and partial differential equations (Analysis of second order OFE’s Sturm-Liouville system, Boundary value problems for Laplace Diffusion (Heat) and wave equations)
6. Integral transforms, its applications and generalized functions (Laplace and Fourier transform, Dirac delta and other generalized functions, Green’s functions of ODE and PDE)
7. Group theory (introduction using various groups occuring in physics, its algebra, Representation of groups, Characters)
8. Probability and Statistics (probability distributions, Stochastic processes like Brownian motion, Error analysis for experiments, Statistical inference)

Text Books (if any) & Suggested References:

1. Arfken and Weber, Mathematical Methods

2. C.Harper, Mathematical methods
3. T L Chow, Mathematical method for physicists.

Course Title : **Electromagnetism**
Course Code : **P603**
Credits : **6**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **PGCS, SPS**

Outcome of the Course:
This course reviews masters level electricity and magnetism with more emphasis on problem solving and applications. This course is meant to prepare students for taking up realistic research challenges involving one of the most important class of interactions in Physics.

Course Contents:
1. Electrostatics in vacuum, force, field, potentials and enegry.(4 hrs)
2. Electrostatic boundary conditions and conductors. (2 hrs)
3. Solution of Laplace's equation in one, two and three dimensions, uniqueness theorem, methods of images, separation of variables, multipole expansion.(12 hrs)
4. Dielectrics(4 hrs)
5. Current distributions, magnetic fields and magnetostatic boundary conditions(4 hrs)
6. Motion of charges in E & B fields, energy and momentum of electromagnetic fields(8 hrs)
7. Maxwell's equations, EM waves and their propagation in free space and in media(12 hrs)
8. Potential formulation, Coulomb and Lorentz gauge, radiation from an accelerated charge, dipole radiation (10 hrs)

Text Books (if any) & Suggested References:
1. David Griffith, "Introduction to electrodynamic"
2. Reitz, Milford, Christy, "Foundation of electromagnetic theory"
3. J.D.Jackson, "Classical Electrodynamics"
4. M.H Nayfeh, M.K Brussel, "Electricity and magnetism"

Course Title : **Statistical Mechanics**
Course Code : **P614**
Credits : **6**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) : **56**
(including tutorials)

Proposed by : **PGCS, SPS**

Outcome of the Course:
This course reviews masters level statistical mechanics and thermodynamics and prepares students for analyzing research problems/results in a wide variety of situations involving statistical mechanics.

Course Contents:
1. Review of thermodynamics, thermodynamic potentials, thermodynamic equilibrium and stability
2. Gibbs distribution: Ensembles, classical and quantum free particles, systems with continuous and discrete spectrum, degenerate Fermi systems, Bose-Einstein condensation.
3. Interacting system: Cluster an Virial expansions, radial distribution function.
4. Introduction to response, fluctuation and noise, Einstein formula.
5. Phase transition: phenomenology of first order and continuous phase transitions, order parameters, 1D Ising model, Iniversality and scaling, Ginzburg-Wilson theory, Spontaneous symmetry breaking.
6. Fundamentals of statical mechanics: phase space, Liouville theorem, statistical distribution theorem.
7. Probability theory: Probability densities, cumulants and correlations, central limit theorem, laws of large numbers.
8. Brownian motion, Langevin equation, Markov process and Fokker Planck equation.

Text Books (if any) & Suggested References:

1. Kerson Huang - Introduction to statical mechanics
2. Reif - Statistical physics
3. M. Kardar- Statistical physics of particles
4. H.E Stanley - Introduction to phase transitions and critical phenomena

Course Title : **Quantum mechanics**
Course Code : **P615**
Credits : **6**
Course Category : **Core**
Course Prerequisite : **None**
Contact Hours (28/42/56) (including tutorials) : **56**

Proposed by : **PGCS, SPS**

Outcome of the Course:
This course reviews masters level quantum mechanics and prepares students for analyzing research problems/results in a wide variety of situations involving quantum mechanics.

Course Contents:
9. HIlbert space (states, operators, evolution)
10. One dimensional problems & Harmonic oscillator, delta & periodic pots
11. Bound states vs scattering states
12. The central force problem
13. The hydrogen atom, hard and soft sphere
14. Time-independent perturbation theory, WKB approximation, variational method
15. Time-dependent perturbation theory, Heisenberg and interaction represtations
16. Dirac equation
17. Scattering theory/semi classical theory of radiation/identical particles/ angular momentum/ path integrals(depending of available time)).

Text Books (if any) & Suggested References:

1. R. Sankar-principles of Quantum Mechanics
2. Cohen-Tannoudji, Diu and Laloe- Quantum Mechanics I & II
3. J.J Sakurai-Modem Quantum mechanics
4. David Griffiths-Intruduction to Quantum mechanics
5. S.Gasiorowicz-Quantum Physics
6. Eugen Merzbacher-Quantum mechanics
7. Bransden and joachain-Quantum mechanics
8. Richard Liboff-Introductory quantum mechanics

SCHOOL OF HUMANITIES

DETAILED COURSE STRUCTURE

FOR

INTEGRATED M.Sc. COURSE

Revised Jan 2017

National Institute of Science Education and Research (HBNI)

Humanities courses for integrated M.Sc.

Year/Semester	Course no.	Credits	Course Name
CORE COURSES			
1/Semester I	H109	2	Technical Communication I
1/Semester I	H133	2	Introduction to Sociology
1/Semester II	H110	2	Technical Communication
1/Semester II	H101	2	Introduction to Economics
ELECTIVE COURSES			
2/Semester III	H225	2	Introduction to Psychology
	H201	2	Environmental Economics and Environmental Impact Assessment
	H239	2	Introduction to Innovation System
	H238	2	Life and Community in Urban World.
2/Semester IV	H227	2	Organizational Behaviour
	H235	2	Sociology of Science and Technology
	H236	2	Perspectives on Indian Society
	H237	2	Science Communication and Citizen

SEM- I	**H 109**	+	**H 133**
SEM – II	**H 110**	+	**H 101**
SEM – III			**2 Electives**
SEM-I V			**2 Electives**

Economics

H101:Course title: Introduction to Economics

Instructor/Proposed by: Dr Amarendra Das

Prerequisite: None

Course Content:

1.	Role of Government in Organised Society	[1 class]
2.	Expenditure Obligation of Union, State and Local Government	[2 classes]
3.	Sources of Revenue for Union, State and Local Governments	[4 Classes]
4.	Concepts of Budget, and Different deficits	[1 class]
5.	Channels of Resource Transfer from Union to State Governments	[2, classes]
6.	Balance of Payment	[3 classes]
7.	Laws of Demand and Supply	[3 classes]
8.	Equilibrium Price Determination	[1 class]
9.	Exchange rate Determination	[2 classes]
10.	Consumer's Equilibrium	[2 classes]
11.	Producer's Equilibrium	[2 classes]
12.	Current Economic events	[3 classes]

References:

E.Case and R.C.Fair (2006) Principles of Economics, Prentice Hall, USA,

Samuelson, Paul and William D. Nordhaus (1948) Economics, 19th Edition, Mc Graw Hill

Government of India (2017) Union Budget 2017-18

Government of India (2017) Economic Survey-2016-17

H201: Environmental Economics and Environmental Impact Assessment
Instructor/Proposed by: Dr Amarendra Das
Prerequisite: None

Course Content:

12. Definition of Environmental Economics, Ecological Economics and Natural Resource Economics [1 class]
13. Key environmental problems faced by humanity [2 classes]
14. Limits to Growth [2 classes]
15. Sustainable Development: Strong and weak sustainability [2 classes]
16. Indicators of sustainability [1 class]
17. Market Failure: Causes and Remedies [3 classes]
18. Perspective on Environmental Policy/Regulation [2 classes]
19. Informal Regulation [1 class]
20. Population, Poverty and Economic Growth [1 class]
21. Climate Change, Causes and Consequences [2 classes]
22. Principles of using Renewable resources [2 classes]
23. Principles of using Non-renewable resources [2 classes]
24. Environmental Kuznets Curve [2 classes]
25. Mainstreaming of Environment [2 classes}
26. Environmental Impact Assessment [2 classes}
27. Environmental Regulations in India [1 class]
28. Green Accounting, Concepts, Integrated Economic and Environmental
29. Accounting [2 classes]

References:

Report of the World Commission on Environment and Development: Our Common Future

Baumol, W.J. & Oates, W.E. (1975), "The Theory of Environmental Policy: Externalities, Public Outlays and the Quality of Life", Prentice Hall Inc.

Bromley, Daniel W. (1995), "The Handbook of Environmental Economics", Blackwell Publications Ltd.

Pearce, D.W. (1976), "Environmental Economics", Orient Longman Ltd.

World Bank, (1992). "World Development Report, 1992: Development and the Environment", Oxford University Press

Bhatacharya R N (2002) Environemntal Ecconomics: An Indian Perspective, Oxford University Press, New Delhi

<u>English</u>

H109: Technical Communication I

Instructor/Proposed by: Joe Varghese Yeldho

Prerequisite: None

Course Content:

1. **Ideations of Science** (4 classes)
   Categorization and social perspective.

2. **Inscription and the material arts** (4 classes)
   Scientific representation and the figural social.

3. **Mechanics of Writing** (6 classes)
   Structure and compositional logic

4. **The Rhetorical Process** (6 classes)
   Building the argument

5. **Cultural Context and the Sciences** (4 classes)
   Literature and the aesthetic of science.

References

Barrass, Robert (2002). *Scientists Must Write: A Guide to Better Writing for Scientists, Engineers and Students*. London: Routledge.

Booth, Vernon (1993). *Communicating in Science: Writing a Scientific Paper and Speaking at Scientific Meetings*. Cambridge: Cambridge UP.

Cottrell, Stella (2011). *Critical Thinking Skills: Developing Effective Analysis and Argument*. London: Palgrave Macmillan.

Lynn, Steven (2010). *Rhetoric and Composition: An Introduction*. Cambridge: Cambridge UP.

Ranciere, Jacques (1991). *The Ignorant Schoolmaster*.Redwood:Stanford UP.

Ehrlich, Eugene (2011). *Schaum's Outline of English Grammar*, Third Edition. NY: Schaum’s.

H110: Technical Communication II

Instructor/Proposed by: Joe Varghese Yeldho
Prerequisite: None

Course Content:

1. **The logic of Critique** (4 classes)
   Notions of evidence, proof and fact.

2. **Humanities and empiricism** (4 classes)
   Empirical fallacy and social intervention.

3. **Mechanics of Writing II** (6 classes)
   The forms of knowledge production. Understanding readership.

4. **The Rhetorical Process II** (6 classes)
   Staging the argument. Perspective and Institutional / Disciplinary norms.

5. **Narrativizing the Sciences** (4 classes)
   Scientific correspondence and reflections. Popular science and Science fiction.

References

Baudrillard, Jean (2012). *The Ecstasy of Communication*. Cambridge: MIT Press.

Fogelin, Robert (2014). *Cengage Advantage Books: Understanding Arguments*. London: Wadsworth.

Heidegger, Martin (2008).*"The question concerning technology,"Basic Writings.* New York: Harper Collins.

Poovey, Mary (1998). *A History of the Modern Fact*. Chicago: University of Chicago press.

Strunk Jr, William (1767). *The Elements of Style: TheOriginal Edition* (2014). London: Dover.

Psychology

H 225: Introduction to Psychology

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. Introduction: perspectives, methods, issues. (3 classes)
2. Perceptual Process. (4 classes)
3. Learning Process (3 classes)
4. Memory (2 classes)
5. Intelligence (2 classes)
6. Emotion (2 classes)
7. Personality (4 classes)
8. Motivation (4 classes)
9. Attitude (3 classes)

References:

Morgan, C.T., King, R.A., Weisz, J.R., Scopler, J. **Introduction to Psychology** (7th ed). Tata McGraw-Hill.

Baron, R.A. **Psychology** (5th ed) PHI New Delhi

Feldman, R.S. **Introduction to Psychology** (6th ed) Tata McGraw-Hill.

H 226: Applied Behavioural Science

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. Introduction: Personality (1 class)
2. Interpersonal Relationship and Personal Effectiveness (5 classes)
3. Social Perception: errors, biases, impression management (3 classes)
4. Emotional Intelligence: managing emotions. (3 classes)
5. Group and Team Dynamics. (5 classes)
6. Effective Communication. (4 classes)
7. Values and Value System (3 lectures)
8. Stress: coping and managing stress (4 classes)

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Handouts will be given as and when required.

H 227: Organizational Behaviour

Instructor/Proposed by: Rooplekha Khuntia
Prerequisite: None

Course Content:

1. **Introduction to Organizational Behaviour** (2 classes)
   Nature of Organizations, what is OB, contributing disciplines, Functions, role and skills of a manager, environmental challenges.
2. **Individual Decision-making process** (3classes)
   Rational decision-making, creativity, bounded rationality, errors and biases, constraints, ethics in decision-making.
3. **Work attitudes** (2 classes)
   Job satisfaction, job involvement, organizational commitment, cognitive dissonance theory.
4. **Motivation** (3 classes)
   Hierarchy of needs theory, two factor theory, ERG theory, equity theory, goal setting and expectancy theory, MBO in practice, other applications.
5. **Power and Politics** (3 classes)
   Bases of power, the general dependency postulate.
6. **Leadership** (3 classes)
   Behavioural theories, contingency theories, contemporary theories, issues in leadership studies.
7. **Groups and team dynamics** (3 classes)
   Stages of group development, group structure, group decision-making, Types of teams, creating effective teams.
8. **Conflict and conflict resolution** (2 classes)
   Functional and dysfunctional conflict, the conflict process, negotiation.
9. **Organizational Structure** (2 classes)
   Elements of organizational structure, common organizational designs, why do structures differ?
10. **Organizational Culture** (2 classes)
    Functions of culture, creating and sustaining culture.
11. **Organizational Change** (3 classes)
    Forces for change, resistance to change, approaches to managing planned change.

References

Organizational Behaviour by Stephen Robbins, 11th edn, Prentice-Hall India
Understanding Organizations by Udai Pareek, Oxford University Press.
Organizational Behaviour by Steven Mcshane and Mary Von Gilnow, Tata McGraw - Hill

Sociology

H 237: Science Communication & the Citizenship

Instructor/Proposed by: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course content:

1. Introduction, citizenship and Science (4 classes)
2. Science in public, the public understanding of science (4 classes)
3. Public engagement with science (5 classes)
4. Science, communication, ethical codes & scientific norms (4 classes)
5. Patents and dissemination of scientific knowledge (4 classes)
6. Science communication in age of innovation (4 classes)

References

Jane Gregory, J., and Miller, S. *Science in Public: Communication, Culture and Credibility*, New York: Plenum, 2000.

Collins, H., and Trevor Pinch, T. *The Golem: What Everyone should Know about Science*, Cambridge: Cambridge University Press, 1993.

Leach, M., Scoones, I., and Wynne, B. *Science and Citizens: Globalization and the Challenge of Engagement*, London: Zed, 2005.

Irwin, A. *Citizen Science,* London: Routledge, 1995.

Nowotny, H., Scott, P. and Gibbsons, M. *Rethinking Science: Knowledge and the Public in an Age of Uncertainty,* Cambridge: Polity, 2001.

H 238: Life &Community in Urban world

Proposed by: Debashis Pattanaik

Prerequisite: None

Course content:

1. Introduction, urban space and urban thought, urbanization (4 classes)
2. Emergence and evolution of cities (4 classes)
3. Urban life, urban communities (online and offline) (4 classes)
4. The city in context, migration, sorting and niches (4 classes)
5. Markets and networks (5 classes)
6. Urban ecology, suburbia, urban design, policy and planning (4 classes)

References

B. Wellman, *Networks in the Global Village*, Westview Press, Boulder, CO: 1999.

C.S. Fischer, and R.K. Merton, *The Urban Experience,* Houghton Mifflin Harcourt P, Boston: 1984.

E. Ben-Joseph and T. Szold (eds.), *Regulating Place: Standards and the Shaping of Urban America,* Routledge: New York: 2005.

J. Logan and H. Molotch. *Urban Fortunes: Toward a Political Economy of Place,* University of California Press, California: 2007.

R.W. Park, E.W. Burgess and M. Janowitz (eds.), *The City*, University of Chicago Press, Chicago: 1984.

S. Sassen, *Cities in a World Economy*, Pine Forge Press, California: 2011.

S. Zukin, *The Culture of Cities*, Blackwell, New York: 1995.

W.G. Flanagan, *Urban Sociology: Images and Structure,* Rawat Publications, New Delhi: 2011.

H239: Introduction to Innovation System

By: Debashis Pattanaik

Prerequisite: Life & Community in Urban World

Course Content:

1. Nature of innovation (4 classes)
2. The innovative firm (2 classes)
3. Innovation processes (4 classes)
4. Regional innovation system (3 classes)
5. Innovation and IPR (4 classes)
6. Education, universities and national innovation system (2 classes)
7. Multinational enterprises and innovation processes (2 classes)
8. Science and innovation policy (4 classes)

References

B. Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* Pinter, London: 1992.

C. Christensen, *The Innovators Dilemma,* Harvard University Press, Boston: 1997.

E. Dundon, *The Seeds of Innovation: Cultivating the Synergy that Fosters New Ideas,* Amacom Books, New York: 2002.

H. Braczyk, et.al, *Regional Innovation Systems*, UCL Press, London: 1998.

K. Pavitt, *Technology Management and Systems of Innovation,* Cheltenham: 1999.

M. Gibbons et.al, *The New Production of Knowledge – the Dynamics of Science and Research in Contemporary Societies,* Sage, London: 1994.

P. Drucker, *Innovation and Entrepreneurship,* Harper Collins Publishers, New York: 1993.

R. Katz, *The Human Side of Managing Technological Innovation*, Oxford University Press, New York: 2004.

S. Borras, *The Innovation Policy of the EU,* Edward Elgar, Cheltenham: 2003.

H 133: Introduction to Sociology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Origin and Growth of Sociology (2 Lectures)

    Origin and development of sociology as a separate discipline,
    Nature and Scope of Sociology,
    Sociology as a Scientific Discipline.

2. Sociological Perspectives (2 Lectures)

    Conflict, Functionalism and Interactionsim

3. Basic Sociological Concepts (6 Lectures)

Society, Community, Association, Institution, Status and Role,
Types of Society: From early hunting gathering to
industrial development and globalization,
Culture: Components of culture; Norms, values,
folkways, mores, Cultural unity and diversity.
Socialization: Agents of Socialization, Early development
of infant, stages of socialization

4. Social Groups (4 Lectures)

Meaning of Social Groups and Types: Primary Group,
Secondary Group, In-Groups, Out- Group, Quasi- Group,
Reference Group

5. Structure and Stratification (4 Lectures)

Structure, System and Function, caste and class and
Racial and Ethnic group inequalities Social Stratification:
Meaning and Types, Functionalist and Conflict Perspectives
of Stratification, Social mobility: Meaning, horizontal and
vertical mobility

6. Social Institutions (4 Lectures)

Family, marriage and kinship, religion, economy, polity and
education. Functionalist and Conflict Perspectives of institutions.

7. Social processes and Change (4 Lectures)

Social Processes: Co-operation, accommodation, integration,
competition and conflict;
Social Change: Meaning and Definition, Factors of change.

8. Social Problems and Social Control (2 Lectures)

Social Problems and Social disorganization
Social control : Meaning and Types

References

Harlambous, M. (1980) Sociology, Oxford University Press, New Delhi.

Inkeles, A. (1982). What is Sociology, Eastern Economic Edition, New Delhi

Johnson, H.M. (1991). Sociology – A Systematic Introduction, Allied Publishers, New Delhi

Bottomore, T.B. (2000). Sociology: A Guide to Problems and Literature, S Chand Publisher, Dehradun

Gisbert, P. (2004, 3rd edition). Fundamentals of Sociology, Orient Longman

Rao, C.N.(2001) Sociology, Rawat Publication, Jaipur

Giddens, A. (2001). Sociology, Polity Press, UK.

H 235: Sociology of Science and Technology

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content :

1. Social significance of science and technology (4 Lectures)
   a. Contextual nature of science
   b. Scientist as Indexical and Analogical reasoner
2. Robert Merton's approach to science (3 Lectures)
   a. Ethos of science;
   b. Thomas Theorem and Matthew Effect
3. Perspectives on scientific knowledge (8 Lectures)
   a. Karl Marx, Emile Durkheim, Karl Manheim's sociology of knowledge,
   b. Thomas Kuhn's structures of scientific revolutions
   c. Karl Popper's theory of falsification
4. Recent trends in Sociology of Science (8 Lectures)
   a. Science and technology in developing and developed countries,
   b. Indian context,
   c. Information Technology and globalization,
   d. Manuel Castell's network society, internet and social inequality
5. Case Study Discussions (4 Lectures)

References

"The Historian and the History of Science" – Harry Elmer Barnes, *The Scientific Monthly*, Vol 11, No. 2(August 1920!!!), pp. 112-126.

"What is the History of Science?"- *History Today*, pp. 32-53. April 1985. (This article is an interview of six scientists/practitioners of science)

The Structure of Scientific Revolutions, Thomas Kuhn, Chicago: Chicago University Press, 1970. (First Edition 1962). Preface, Chapter, 12,3.

The Sociology of Science – Robert Merton, Chapters, 13,14,20, 21.

"The Scientist as a Practical Reasoner: Introduction to a Constructivist and Contextual Theory of knowledge"-. K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981.

(Chapter I) **A must read, highly recommended.**

"The Scientist as an Indexical Reasoner: The Contextuality and the Opportunism of Research" – K.D .Knorr Cetina *The Manufacture of Knowledge*: An Essay on the Constructivist and Contextual Nature of Science. Oxford: Pergamon Press, 1981. (Chapter II) **A must read, highly recommended.**

"Is Science Losing its Objectivity?" – John Ziman, Nature, Vol.382, pp. 751-756, 1996

Kuhn, Thomas, "Structure of Scientific Revolutions", Chicago University Press. 1996

Merton, Robert K., Social Theory and Social Structure, Amerind. 1981

H 236: Perspectives on Indian Society

Instructor/Proposed by: Pranay Swain

Prerequisite: None

Course Content:

1. Indian Social Structure (2 Lectures)
    - a- Traditional Social Organizations
    - b- Culture and Tradition
2. Caste System and Class Structure (7 Lectures)
    - a- Cultural and Structural Views about Caste System
    - b- Inequality, Differentiation and Hierarchy
    - c- Dominant Caste, Sanskritization
    - d- Change and Persistence of Caste system in Modern India
    - e- Caste in Indian Politics
    - f- Backward Caste Movements
    - g- Social Backwardness and Social Justice
3. Class Structure (3 Lectures)
    - a- Class Structure in India
    - b- Agrarian and Industrial Class Structure
    - c- Emergence of Middle Class and Elites

4. Social Institutions: Marriage, Kinship and Family (2 Lectures)

5. Rural and Urban Social Structure: Poverty, Unemployment, etc. (2 Lectures)

6. Changing faces of Rural society/economy/market, Green revolution (2 Lectures)

6. Political processes: Political system and Governance (2 Lectures)

7. Education (2 Lectures)

8. Religion and Society (2 Lectures)

9. Social Change and Development Sustainable and Inclusive (2 Lectures)
   Development, Basic developmental issues: Health, Education and Livelihood

10. Contemporary Social Issues (2 Lectures)

References:

Mandelbam, D. : Society in India (Part I & II), Popular Prakashan, Bombay, 1970
Srinivas, M.N. : Caste in Modern India and Other Essays, Asia Publishing House, Bombay,1964
Kapadia, K,M, : Marriage and Family in India, Oxford University Press, Calcutta,1981
Srinivas, M.N. : Social Change in Modern India, Orient Longman, New Delhi, 1995
Rao, M.S.A. (ed): Urban Sociology in India, Orient Longman, New Delhi, 1974
Ahuja, Ram : Social Problems in India, Rawat Publications, Jaipur, 1992
Kosambi, D.D. : The Culture & Civilization of Ancient India in Historical Perspective, New Delhi, 1982
Uberoi Patrcia (ed), Family, Kinship And Marriages in India, Oxford University Press, New Delhi.
Omen, T.K. and Mukharjee, P.N. (ed),: Indian Sociology : Reflection and Introspection, Popular Prakashan, Bombay, 1986

SCHOOL OF COMPUTER SCIENCES

A proposal for minor in Computer Science

1 Structure of the curriculum

The curriculum is divided in two category of courses, core courses and optional courses.

1.1 Core Courses

The following courses have been recommended by the steering committee as core courses. The Programming and Data Structure course are proposed to be two lab courses (2 credit each).

1. CS141 and CS142: Programming and Data Structures Lab
2. CS201: Theory of Computation
3. CS202: Discrete Structures and Computation[1]
4. CS301: Design and Analysis of Algorithms

1.2 Elective Courses

For the initial years, we shall offer the following optional courses. A student has to do three courses from the following list to obtain minor.

- CS451: Modern Cryptology
- CS452: Algorithmic Coding Theory
- CS453: Complexity Theory
- CS454: Linear Programming and Combinatorial Optimization
- CS455: Distributed Network Algorithms

In future, more elective courses will be offered based on the interests of the faculties.

1.3 Similarity with other courses

School of Mathematical Sciences offer some courses which are similar to the courses listed above. We make the following observations regarding this.

- Programming and Data Structure course can be merged with the existing Computational Laboratory courses (M141 and M142). I141 and I142 are the two lab courses, which may be offered instead of M141 and M142. The major difference in syllabus is the inclusion of different data structures which are core concepts in Computer Science.

[1]This course was originally titled Discrete Mathematics for Computer Science. We have renamed the course to capture the spectrum of the topics covered, and to avoid any confusion.

- School of Mathematical Sciences also offer Algorithms, Theory of Computation, Cryptology, Information and Coding Theory as PG optional courses. However, in Computer Science, Algorithms and Theory of Computation are fundamental courses, and need to be offered to the undergraduate students. The syllabus of Modern Cryptology, as well as Algorithmic Coding Theory has been designed from Computer Science point of view and significantly different from the SMS courses.

  However, to avoid repetition, we propose, students who take M462 (Cryptology) and M464 (Information and Coding Theory) will not be allowed to take CS451 (Modern Cryptology), and CS452 (Algorithmic Coding Theory) respectively.

2 Syllabi

Syllabi of the courses are given in the following pages. For each subject, the syllabus is organized as follows

1. prerequisite
2. topics
3. references

3 Core Courses

3.1 CS141: Programming and Data Structures Lab-I

Credit : 2

Prerequisite: None

Classes per week: 3P+1L.

Topics Module 0: (6P+2L): Introduction to Computers, Notion of Algorithm, Linux Bash Shell, Simple Shell Programs.
Module 1 (12P+4L): Introduction to Programming: Variables, operators and expressions, input and output statements, Conditions and loops. Functions and recursions.
Module 2 (12P+4L): Arrays, Pointers, Structures, Classes and Objects.
Module 3 (9P+3L): File i/o, command line arguments.
Module 4 (6P+2L). Abstract data type. Linked lists.

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

3.2 CS142: Programming and Data Structures Lab-II

Credit : 2

Prerequisite: CS141 **Classes per week**: 3P+1L. **Topics**

Module 0 (9P+3L): Review of programming, Arrays and Linked List. Bubble Sort and Quick Sort. Binary Search.
Module 1 (12P+4L): Circular Linked Lists, Doubly Linked Lists, Stacks, Queues.
Module 2 (12P+4L): Trees. Binary Search Trees, Tree traversal, Balanced Binary trees. Module 3 (6P+2L): Heap, Priority Queues.

Module 4 (3P+1L). Strings and Searching for Phrases.
Module 6:(Optional) (3P+1L) Dictionaries: universal, k-wise independent, simple tabulation hashing; chaining, dynamic perfect hashing, linear probing, cuckoo hashing

References

- B. W. Kernighan, D. M. Ritchie, The C Programming Language, Prentice-Hall, 2009.
- B. Stroustrup, The C++ Programming Language, Pearson, 2014.
- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- D. Knuth: The Art of Computer Programming. Vol. 1, 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973
- E. Horowitz,S . Sahni, Fundamentals of Data Structures in C++, Universities Press, 2008.

3.3 CS201: Theory of Computation

Credit : 4

Prerequisite: None **Classes per week**: 3L+1T. **Topics**

Module 1 (12L+4T): Introduction to Finite State Automata; DFA,NFA, and their equivalence, Regular Ex- pressions and equivalence with finite state automata.Regular Languages and Properties, Pumping Lemma and applications, Myhill-Nerode Theorem, State Minimization.

Module 2 (12L+4T): Context Free Languages (CFL) and grammars, parse trees, Chomsky Normal Form. Pushdown Automata (PDA), Equivalence of acceptance by final state and empty stack. Equivalence of CFL and PDA, Pumping Lemma for CFL.

Module 3 (12L+4T): Turing Machines and equivalence of different models. Universality. Decidability, Recog- nizability, Enumeration, and Undecidability. Reductions. Rice's Theorem, recursion theorem.

Module 4 (9L+3T): Notions of P,NP,co-NP, hierarchy theorem, NP completeness, Cook-Levin Theorem, NP completeness proofs of some NP complete problems.

References

- J. Hopcroft, JD Ulman. Introduction to Automata Theory, Languages and Computations. Narosa Publishing 2002. (Indian Edition)
- M. Sipser. Introduction to the Theory of Computation. Cengage, 3rd Edition, 2014.
- H. R. Lewis and C. H. Papadimitriou: Elements of The Theory of Computation, Prentice Hall, Englewood Cliffs, 1981
- M. R. Garey and D. S. Johnson: Computers and Intractability: A Guide to The Theory of NP Completeness, Freeman, New York, 1979.

3.4 CS202: Discrete Structures and Computation

Credit 4
Prerequisite: none **Classes per week**:
3L+1T. **Topics**

Module 1 (6L+2T): Review of Sets, Operations, Principles of Inclusion and Exclusion. Functions, relations, Equivalence relations. Countable and uncountable sets. Review of Pigeonhole principle.

Module 2 (6L+2T): Introduction to Propositional Logic, Equivalence and Implications. Truth tables, De Mor- gan's Law, Quantifiers, Inference and Proofs. Introduction to First Order Logic, Syntax and Semantics, Soundeness and Completeness.

Module 3 (6L+2T): Mathematical Induction, Recursions, First order linear recurrence, Geometric series, Re- cursion trees and growth rates of solutions to recurrences, Master Theorem. Generating Functions.

Module 4 (6L+2T): Introduction to counting, sum and product principles, counting subsets. Binomial coefficients and Pascal's triangles. Polya's theory of counting (optional).

Module 5 (3L+1T): Arithmetic Algorithms: Computing GCD, primality testing, RSA.

Module 6 (12L+4T): Graph Theory: Graphs, representations, connectivity, cycles, trees, Spanning tree of a graph, Algorithms to find minimum spanning trees. Eulerian Cycle and Hamiltonian paths, independence number and clique number, chromatic number, Dominating Sets, and Covering Sets. Planar Graphs. Directed Graphs and tournaments.

Module 7(3L+1T) Probabilistic tools, Tail Bounds and Applications.
Module 8 (3L+1T)(optional): Linear Algebraic tools in Combinatorics.

References

- J. Gallier, Logic for Computer Science: Foundations of Automatic Theorem Proving, Wiley.
- Kenneth Rosen. Discrete Mathematics and Its Applications, 7th Edition , McGraw Hill Publishing Co., 2012.
- Ken Bogart. Discrete Mathematics for Computer Science. available at https://www.kth.se/social/files/557ec6b0f27654
- J. L. Mott, A. Kandel and T. P. Baker: Discrete Mathematics for Computer Scientists, Reston, Virginia, 1983
- J. A. Bondy and U. S. R. Murty: Graph Theory with Applications, Macmillan Press, London, 1976.
- F. S. Roberts: Applied Combinatorics, Prentice Hall, Englewood Cliffs, NJ, 1984

3.5 CS301: Design and Analysis of Algorithms

Credit 4
Prerequisite: CS201, CS202
Classes per week: 3L+1T.
Topics

Module 1 (4L+1T). Introduction and basic concepts - mathematics of algorithm analysis, asymptotic notations, worst case and average case complexity. Review of Searching and Union Find.

Module 2 (8L+3T): Divide and conquer- Motivating algorithms that leads into recurrences, solving recurrences, merge sort and its recurrence, Median computation. Analysis of quicksort.

Module 3 (9L+3T). Greedy algorithms- Greedy choice, optimal structure property, minimum spanning tree, knapsack

Module 4 (8L+2T). Dynamic programming- Integral knapsack, longest increasing subsequence, edit distance, independent sets in trees

Module 5 (8L+3T). Graph algorithms- Recall of representation of graphs, BFS, DFS, shortest path, connected components, topological sort of DAGs, biconnected components and strongly connected components in directed graphs

Module 6. (Optional)(3L+1T) Randomization- Median, randomized quicksort, probabilistic primality testing.

Algebraic Algorithms. Karatsuba's algorithm and the Fast Fourier transform

References

- H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, MIT Press, Cambridge, 2009.
- S. Dasgupta, C. Papadimitrou, U. Vazirani, Algorithms, McGraw-Hill Education, 2006.
- A. Levitin, Introduction to Design and Analysis of Algorithms, Pearson 2007 (Lev)
- J. Kleinberg and E. Tardos, Algorithm Design, Pearson, 2005 (KT)
- E. Horowitz, S. Sahni, and S. Rajasekaran, Computer Algorithms, Silicon Press, 2007
- M. Goodrich, R. Tamassia, Algorithm Design, Wiley, 2001.
- D. Knuth: The Art of Computer Programming. Vol. 1 and Vol 3. , 2nd ed. Narosa/Addison-Wesley, New Delhi/London, 1973

4 Optional Courses

4.1 CS451: Modern Cryptology

Credit 4

Prerequisite: CS202, CS301.

Classes per week: 3L+1T.

Topics

Module 1: (3L+1T) Introduction and Classical Cryptography, Perfect Secrecy, One Time Pad.

Module 2: (9L+3T) Symmetric Key Encryption. Computational Security, Concrete vs Asymptotic Approach. Semantic Security. Pseudorandom generators and Stream ciphers, Pseudorandom Functions and Block Ciphers. Practical Constructions.

Module 3: (6L+2T) Hash Functions and Message Authentication Codes. Notions of Security, Generic Attacks, Domain Extension techniques, CBC MAC, HMAC, PMAC, Idea of Authenticated Encryption.

Module 4: (6L+2T) Review of Basic Number Theory. Hardness Assumptions. One-way functions, Trapdoor Permutations, RSA assumptions, Discrete Log and Diffie Hellman Assumptions, SIS and LWE Assumptions. Introduction to Elliptic Curves (Optional)

Module 5. (3L+1T) Key Exchange Protocols and Key Management.

Module 6. (6L+2T) Public Key Encryption, Semantic Security, El Gamal Encryption, Padded RSA PKCS#1 v1.5. Random Oracle Technique, OAEP.

Module 7. (6L+2T) Digital Signatures, Hash and Sign paradigm, Schnorr Signature, Forking Lemma, DSA. SSL/TLS.

Module 8. (6L+2T) (Optional) Idea of some of the following notions, Protocols and Zero Knowledge Proofs, Multiparty Computations and Oblivious Transfers, Secret Sharing. Algorithms for factoring and computing discrete logarithms, Linear and Differential Cryptanalysis, Crypto Currencies.

References

- J. Katz and Y. Lindell, Introduction to Modern Cryptography. CRC, 2014.

Possible Instructor: Rishiraj Bhattacharyya.

4.2 CS452: Agorithmic Coding Theory

Credit 4

Prerequisite: CS202

Classes per week: 3L+1T.

Topics Module 1: (9L+3T) Entropy, Characterization and Properties. Application to Combinatorics. Mutual Information and KL Divergence.

Module 2: (6L+2T) Source coding theorem, lossless compression of data, Lempel-Ziv Algorithm, Optimal lossless coding.

Module 3 (6L+2T) Communication channels (binary symmetric, erasure) and channel capacity, channel coding theorem.

Module 3: (6L+2T) Introduction to Error Correcting Codes. Hamming Codes and Hamming Bounds. BCH Codes, Maximum likelihood decoding and syndrome decoding; coding theory bounds.

Module 4: (9L+3T) Reed-Solomon codes and the Berlekamp-Welch decoding algorithm with Analysis. List Decoding of Reed-Solomon Codes.

Module 5. (6L+2T)Reed-Muller Code and Local decoding. Module 6.

(3L+1T) (Optional) Lovasz Local lemma and proof.

References

- T. M. Cover and J. A. Thomas, "Elements of Information Theory" (Second Edition, Wiley).
- S. Ling C. Xing, "Coding Theory: A First Course", Cambridge University Press.
- J. Radhakrishnan, "Entropy and Counting", http://www.tcs.tifr.res.in/ jaikumar/Papers/EntropyAndCounting.pdf
- V. Guruswami, A. Rudra and M. Sudan, "Essential Coding Theory (Draft of a new book)" available at http://www.cse.buffalo.edu/faculty/atri/courses/coding-theory/book/
- F.J. MacWilliams and N.J.A. Sloane, The Theory of Error-Correcting Codes, North-Holland ML, 1983.

Possible Instructor: Rishiraj Bhattacharyya.

4.3 CS453: Complexity Theory

Credit 4

Prerequisite: CS201, CS202, CS301

Classes per week: 3L+1T.

Topics

Module 1 (9L+3T): Introduction, P and NP - Review of Turing machines, universal Turing machines, and uncomputable functions, P vs. NP, NP vs. co-NP, and NP-completeness, EXP, NEXP

Module 2: (3L) Cook Levin's Theorem

Module 3 (12L+4T): Diagonalization, Space complexity, Polynomial Hierarchy

Module 4 (9L+3T): Interactive Proofs - PCP theorem and its application to approximability Module 5 (4L+1T): Circuit complexity and lower bounds

Module 6 (6L+2T): Hardness vs. Randomness - Randomized Computation, derandomization, Pseudo-random generators

Module 7 (3L+1T): Polynomial identity testing vs Lower bounds for arithmetic circuits

References:

- S. Arora and B. Barak, "Computational Complexity: A Modern Approach", Cambridge University Press.
- O. Goldreich, "Computational Complexity: A conceptual perspective", Cambridge University Press.
- J. Hopcroft, R. Motwani, J. D. Ullman. Introduction to Automata Theory, Languages, and Computation. Pearson Education.
- J. Raddhakrishnan, Graduate course on Computational Complexity, http://www.tcs.tifr.res.in/ jaikumar/Courses/Com

Possible Instructor: Anisur Rahaman Molla.

4.4 CS454: Linear Programming and Combinatorial Optimization

Credit 4

Prerequisite: CS202, CS301
Classes per week: 3L+1T.

Topics

Module 1: (10L+3T) Basic geoemetry and linear algebra related to Linear Programming. Simplex-method and Duality theorem (leading to Von Neumann's minmax principle) and complimentary slackness.

Module 2: (8L+3T) Ellipsoid algorithm. separation oracles.

Module 3: (9L+3T) Semidefinite programming as an extension of linear programming.

Module 4: (9L+3T) LP relaxation. Examples of problems where LP relaxation achieves optimum. Examples where LP/SDP relaxation achieves approximate solution. Integrality gaps.

Module 5: (6L+2T) Rounding, probabilistic roundings, iterative rounding, primal dual methods.

Module 6 (Optional): (3L+1T) Gale-Shapley algorithm, Connection of LP to Cooperative Game Theory core, nucleolus, combinatorial optimization games.

References

- A. Schrijver, "Theory of Linear and Integer Programming", Wiley.
- A. Schrijver, "Combinatorial Algorithm: Polyhedra and Efficiency, Volume A", Springer.
- V. Vazirani, "Approximation Algorithm", Springer.
- S. Chakraborty, M. Mitra, P. Sarkar, "A Course on Cooperative Game Theory", Cambridge University Press.

Possible Instructor: Rishiraj Bhattacharyya, Anisur Rahaman Molla.

4.5 CS455: Distributed Network Algorithms

Credit 4

Prerequisite: CS202, CS301

Classes per week: 3L+1T. **Topics** Module 1: (9L+3T) Foundations of distributed network algorithms - Broad- cast, converge-cast, maximal independent set, coloring, leader election, spanning tree algorithms, shortest paths, and routing.

Module 2:(9L+3T) Fundamental concepts in distributed algorithms - Symmetry breaking, locality, synchronizers Module 3:(9L+3T) Basics of distributed network systems - Communication, synchronization, fault-tolerance,

and resource allocation

Module 4:(9L+3T) Applications to real-world networks - Internet, peer-to-peer networks, wireless networks, sensor networks and dynamic networks

Module 5:(9L+3T) Lower bounds using communication complexity, distributed computation of large-scale data, dynamic network algorithms.

References

- D. Peleg, "Distributed Computing: A Locality-Sensitive Approach", SIAM 2000.
- Distributed Computing: Fundamentals, Simulations and Advanced Topics, by Hagit Attiya, Jennifer Welch, McGraw-Hill Publishing, 1998.
- N. Lynch, "Distributed Algorithms", Morgan Kaufmann 1996.
- G. Tel, Introduction to Distributed Algorithms, Cambridge University Press 2000.
- G. Pandurangan, "Distributed Network Algorithms, a monograph", Department of CS, University of Houston.

Possible Instructor: Anisur Rahaman Molla.

BACK TO MAIN

M.Sc NURSING
(PROGRAM CODE: HLTH15)

09HLTH15-001-C ADVANCED NURSING PRACTICE

Placement: I year

Hours of Instruction
Theory 150 Hours
Practical 200 Hours
Total: 350 Hours

Course Description

The course is designed to develop an understanding of concepts and constructs theoretical basis of advanced nursing practice and critically analyze different theories of nursing and other disciplines.

Objectives:

At the end of the course the student will be able to:

1. Appreciate and analyze the development of nursing as a profession.
2. Describe ethical, legal, political and economic aspects of health care delivery and nursing practice.
3. Explain bio- psycho- social dynamics of health, life style and health care delivery system
4. Discuss concepts, principles, theories, models, approaches relevant to nursing and their application.
5. Describe scope of nursing practice.
6. Provide holistic and competent nursing care following nursing process approach.
7. Identify latest trends in nursing and the basis of advance nursing practice.
8. Perform extended and expanded role of nurse.
9. Describe alternative modalities of nursing care.
10. Describe the concept of quality control in nursing.
11. Identify the scope of nursing research.
12. Use computer in patient care delivery system and nursing practice.
13. Appreciate importance of self development and professional advance

UNIT	HOURS	CONTENT
I	**10**	◆ History of development of nursing profession, characteristics, criteria of the profession, perspective of nursing profession - national, global ◆Code of ethics (INC), code of professional conduct (INC), autonomy and accountability, assertiveness, visibility of nurses, legal considerations. ◆ Role of regulatory bodies. ◆ Professional organizations and unions- self defense, individual and collective bargaining. ◆Educational preparations, continuing education, career opportunities, professional advancement role and scope of nursing education. ◆Role of research, leadership and management. ◆ Quality assurance in nursing (INC). ◆ Futuristic nursing.
II	**5**	**Health care delivery**: ◆ Health care environment, economic constraints, planning process, political process vis a vis nursing profession. ◆ Health care delivery system –nation, state district and local level. ◆ Major stakeholders in the health care system Govt, non government, industry and other professionals. ◆ Patterns of nursing care delivery in India. ◆ Health care delivery concerns, national health and family welfare program, inter- sectoral coordination, role of non-governmental agencies. ◆ Information, education and communication (IEC). ◆ Tele – medicine.

UNIT	HOURS	CONTENT
III	10	**Genetics** ◆ Review of cellular division, mutation and law of inheritance, human genome project, the genetic era. ◆ Basic concepts of genes, chromosomes and DNA. ◆ Approaches to common genetic disorders. ◆ Genetic Testing – basis of genetic diagnosis, pre-symptomatic and predisposition testing, prenatal diagnosis & screening, ethical, legal and psychosocial issues in genetic testing. ◆ Genetic Counseling. ◆ Practical application of genetics in nursing.
IV	10	**Epidemiology** ◆ Scope, epidemiological approach and methods. ◆ Morbidity, mortality, ◆ Concepts of causation of diseases and their screening. ◆ Application of epidemiology in health care delivery, Health surveilliance and health informatics. ◆ Role of nurse

UNIT	HOURS	CONTENT
V	20	**Bio- psycho social pathology** ◆ Pathophysiology and psychodynamic of disease causation. ◆ Life processes, homeostatic mechanism, biological and psycho- social dynamics in causation of disease, life style. ◆ Common problems : Oxygen insufficiency, fluid and electrolyte imbalance, nutritional problems, hemorrhage land shock, altered body temperature, unconsciousness, sleep pattern and its disturbances, pain, sensory deprivation. ◆ Treatment aspects: pharmacological and pre-post operative care aspects. ◆ Cardio pulmonary resuscitation. Care of dying and dead. ◆ Infection prevention (including HIV) and standard safety measures, bio-medical waste management. ◆ Role of nurse –Evidence based nursing practice.
VI	**20**	**Philosophy and Theories of Nursing.** ◆ Values, conceptual models, approaches. ◆ **Nursing theories:** Nightingale's Henderson's, Roger's, Peplau's Abdella's , Lewine's, Orem's Johnson's, King's, Neuman's, Roy's , Watson's, parsce etc. and their applications. ◆ Health belief models, communication and management etc. ◆ Concept of self health. *Evidence based practice model.

UNIT	HOURS	CONTENT
VII	**10**	**Nursing process approach** ◆**Health Assessment**- illness status of patients/ clients (Individual, family, community), Identification of health illness problems, health behaviors, signs and symptoms of clients. ◆Methods of collection, analysis and utilization of data relevant to nursing process. ◆Formulation of nursing care plans, health goals, implementation, modification and evaluation of care.
VIII	25	**Psychological aspects and Human relations** ◆ Human behavior, Life processes and growth and development, personality development, defense mechanisms. ◆ Communication, interpersonal relationships, individual and group, group dynamics, and organizational behavior. ◆ Basic human needs, Growth and development, (Conception through preschool, School age through adolescence, young and middle adult, and Older adult) ◆ Sexuality and sexual health. ◆ stress and adaptation, crisis and its intervention. ◆ Coping with loss, death and grieving, ◆ Principles and techniques of ◆ Counseling.

UNIT	HOURS	CONTENT
IX	**10**	**Nursing Practice** ◆ Framework, Scope and trends. ◆ Alternative modalities of care, alternative systems of complementary therapies. ◆ Extended and Expanded role of the nurse in promotive, preventive, curative and restorative health care delivery system in community and institutions. ◆ Health promotion and primary health care. ◆ Independent practice issues – Independent nurse midwifery practitioner. ◆ Collaboration issues and models within and outside nursing. ◆ Models od prevention. ◆ Family nursing, Home nursing. ◆ Gender sensitive issues and women empowerment. ◆ Disaster nursing. ◆ Geriatric considerations in nursing. ◆ Evidence based nursing practice. ◆ Trans- cultural nursing.
X	**30** **T = 10** **P = 20**	**Computer application for patient care delivery system and nursing practice**. ◆ Use of computers in teaching, learning, research and nursing practice. ◆ Windows, MS office, Word, Excel, Power Point. ◆ Internet, Literature search. ◆ Statistical packages. ◆ Hospital management information system software.

Practicals

Clinical posting in the following areas:

- Specialty area - inpatient unit - 2 weeks
- Community Health Center / PHC - 2 weeks
- Emergency / ICU - 2 weeks

Activities

- Prepare case studies with nursing process approach and theoretical basis
- Preparation of comparative picture of theories
- Family case work using model of prevention.
- Annotated Bibliography.
- Report of field visit (5)

Methods of Teaching

- Lecture cum discussion
- Seminar
- Panel Discussion
- Debate
- Case Presentation
- Exposure to Scientific Conferences
- Field Visits

Methods of Evaluation

- Tests
- Presentation
- Seminar
- Written Assignments

Internal Assessment

Theory

Sl. No.	Techniques	Number	Weightage
1	Tests	2	
	Midterm (50 marks)		50
	Prefinal (75 marks)		75
2	Assignments (25 marks each)	2	50
3.	Seminar (50 marks)	1	50
4.	Presentation (50 marks)	1	50
			275

Internal Assessment Total marks out of 25

External Assessment Total marks out of 75

BIBLIOGRAPHY

1. Potter A. P., Perry A. G.2005 Fundamental of Nursing C. V. Mosby company, Louis 6^{th} edition.
2. Kozier B et al, Fundamentals of nursing concepts, process and practice, Pearson education, inc 2^{nd} Indian print 2004.
3. Brunner and Suddarth Text book of medical surgical nursing 10^{th} edition 2002.
4. Zwemer A. Professional Adjustments and Ethics for nurse in India BI publications, Bangalore 6^{th} edition 1995.
5. Rosdhal, Fundamentals of Nursing, Lippincott Company 2003.
6. Bolander, Fundamentals of nursing, Saunders 1994.
7. Carol Taylor Fundamentals of Nursing, Carol Lillis et al Lippincot, 5^{th} edition 2005.
8. Basavanthappa B T 2007 Nursing Theories Jaypee brothers
9. Pearson Alan , VaughanB. Fitzgerald M (.2005) Nursing models for practice 3 edition Elsevier Limited.
10. Alligood M. R., Tomey A M . (2006) Nursing theory Utilization and Application S T : Louis Mosby.
11. J E Park textbook Preventive and social Medicine17th edition
12. Gulanick, M. & Myers, J.L. (2007) Nursing care plans 6^{th} edition St. Louis: Missouri.

M.Sc Nursing- Advance Nursing Practice
Seminar – Evaluation

Name of the student:____

Batch:-_________________________Date:-_____________________

Topic:-____

Name of the Supervisor:-______________________________________

Total Marks : 25

SN	Criteria	Assigned Marks	Obtained Marks
1	Organization	2	
2	Content	10	
3.	Preparation of environment		
	* Poise	1	
	* Clarity of ideas	1	
	* Modulation	1	
	* Audibility	1	
	* Gestures & mannerism	1	
5	AV aids	2	
6	Class management	1	
7	Group participation	1	
8	Grooming	1	
9	Bibliography	1	
10	Conclusion	1	

Remarks:- Total:-

Date & Signature of the Supervisor: Date & Signature of the student

EVALUATION OF NURSING CARE PLAN

Student's name

Batch | **Name of the patient**

Year | **Diagnosis**

Ward/dept

Supervisor name

Marks 25

SN	Criteria	Assigned Marks	Obtained Marks
1	Elicits relevant history	3	
2	Make quick and valid assessment	4	
3	Identifies problems/needs	2	
4	Formulates nursing diagnosis	4	
5	Prioritizes the nursing diagnosis	2	
6	Plan care for any two priority needs	2	
7	List the outcome criteria	1	
8	Implements care for any two priority needs	5	
9	Evaluates the care (nurses notes based on actual care given every day)	2	
		25 marks	

Remarks:-

Signature of student

Signature of Teacher

M. Sc. Nursing – Advanced Nursing Practice

Evaluation Criteria for Assignment

Total Marks = 25

SN	Criteria	Marks
1.	Content	10
2.	Organization	05
3.	Resources used	03
4.	Completeness	03
5.	Neatness	02
6.	Bibliography	02

09HLTH15-002-C CLINICAL SPECIALITY – I

MEDICAL SURGICAL NURSING

Placement : 1ST Year

Hours of Instruction
Theory – 150 Hours
Practical – 650 Hours
Total : 800 Hours

Course Description

This course is common for the students undergoing clinical speciality-II in neuro science nursing / cardiovascular & thoracic nursing / critical care nursing /oncology nursing / orthopaedica and rehabilitation nursing / nephro & urology nursing, gastroenterology nursing / geriatric nursing.

It is designed to assist students in developing expertise and in depth knowledge in the field of Medical Surgical Nursing. It will help students to appreciate the patient as a holistic individual and develop skill to function as a specialized Medical-Surgical Nurse. It will further enable the students to function as educator, manager and researcher in the field of Medical Surgical Nursing.

Objectives

At the end of the course the students will be able to:

1. Appreciate trends and issues in the field of Medical – Surgical Nursing as a speciality
2. Apply concepts & theories related to health promotion.
3. Appreciate the client as a holistic individual.
4. Perform physical, psychosocial assessment of Medical – Surgical patients.
5. Apply Nursing process in providing care to patients.
6. Integrate the concept of family centered nursing care with associated disorder such as genetic, congenital and long-term illness.
7. Recognize and manage emergencies with Medical – Surgical patient's.
8. Describe various recent technologies & treatment modalities in the management of critically ill patients.
9. Appreciate the legal & ethical issues relevant to Medical – Surgical Nursing.
10. Prepare a design for layout and management of Medical – Surgical Units.
11. Appreciate the role of alternative systems of Medicine in care of patients.
12. Incorporate evidence based Nursing practice and identity the areas of research in the field of Medical – Surgical Nursing.
13. recognize the role of Nurse practitioner as a member of the Medical – Surgical health teams
14. Teach Medical – Surgical Nursing to undergraduate nursing students & in-service nurses.

Course Content

Unit	Hours	Content
I	5	**Introduction** ◆ Historical development of Medical – Surgical Nursing in India. ◆ Current status of health and disease burden in India. ◆ Current concept of health. ◆ Trends & issues in Medical – Surgical Nursing. ◆ Ethical & cultural issues in Medical – Surgical Nursing. ◆ Rights of patients. ◆ National health policy, special laws & ordinances relating to older people. ◆ National goals. ◆ Five years plans. ◆ National health programs related to adult health.
II	20	**Health Assessment of patients** ◆ History taking. ◆ Physical examination of various systems. ◆ Nutritional assessment. ◆ Related investigations and diagnostic assessment.
III	5	**Care in Hospital settings:** ◆ Ambulatory care. ◆ Acute and Critical care. ◆ Long term care. ◆ Home Health Care ◆ Characteristics, care models, practice settings, interdisciplinary team. ◆ Hospitalization- effects of hospitalization on the patient & family. ◆ Stressors & reactions related to disease process ◆ Nursing care using Nursing process approach
IV	10	**Management of patients with disorders of Gastro intestinal tract** ◆ Review of anatomy and physiology. ◆ Disorders-etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up

Unit	Hours	Content
V	**10**	**Management of patients with disorders of nervous system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
VI	**10**	**Management of patients with disorders of respiratory system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
VII	**10**	**Management of patients with disorders of cardio vascular system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up

Unit	Hours	Content
VIII	5	**Management of patients with disorders of blood** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
IX	10	**Management of patients with disorders of genitor urinary system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
X	10	**Management of patients with disorders of endocrine system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up

Unit	Hours	Content
XI	**10**	**Management of patients with disorders of musculo-skeletal system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
XII	**8**	**Management of patients with disorders of integumentory system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
XIII	**5**	**Management of patients with disorders of Eye and ENT** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up

Unit	Hours	Content
XIV	8	**Management of patients with disorders of reproductive system** ◆ Review of anatomy and physiology. ◆ Disorders- etiology, Patho physiology, Clinical manifestations, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
XV	8	**Geriatric nursing** ◆ Nursing Assessment – History and Physical assessment. ◆ Ageing; ◆ Demography; Myths and realities. ◆ Concepts and theories of ageing. ◆ Cognitive Aspects of Ageing. ◆ Normal biological ageing. ◆ Age related body systems changes ◆ Psychosocial Aspects of Ageing. ◆ Medications and elderly. ◆ Stress & coping in older adults. ◆ Common Health Problems & Nursing Management; ◆ Psychosocial and Sexual. ◆ Abuse of elderly. ◆ Role of nurse for care of elderly; ambulation, nutritional communicational, psychosocial and spiritual. ◆ Role of nurse for caregivers of elderly. ◆ Role of family and formal and non formal caregivers. ◆ Use of aids and prosthesis (hearing aids, dentures, ◆ Legal & Ethical Issues. ◆ Provisions and Programmes for elderly; privileges, Community Programs and health services; ◆ Home and institutional care. ◆ Issues, problems and trends.

Unit	Hours	Content
XVI	8	**Management of patients with communicable and sexually transmitted diseases:** ◆ Review of immune system. ◆ Disorders of immune system – HIV / AIDS. ◆ Review of infectious disease process. ◆ Communicable diseases- etiology, Patho physiology, Clinical manifestations complications, prognosis ◆ Health assessment- History taking physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up
XVII	8	**Emergency, trauma and multi-system organ failure** ◆ DIC (disseminated intravascular coagulation) ◆ Trauma, burns, poisoning ◆ Etiology, Patho physiology, Clinical manifestatios, complications, prognosis. ◆ Health assessment- History taking, physical examination, investigation and diagnostic assessment. ◆ Treatment modalities and trends. ◆ Nursing management. ◆ Related research studies. ◆ Evidence based nursing practice. ◆ Rehabilitation and follow-up

PRACTICAL

Total = 650 Hours

1 week = 30 Hours

SN	Dept / Unit	No. of Week	Total Hours
1	OPD	1	30 Hours
2	Eye Ward	1	30 Hours
3	ENT	1	30 Hours
4	Dermatology Ward	1	30 Hours
5	Burn and Plastic Surgery Ward	1	30 Hours
6	Medical Surgical ICU	4	110 Hours
7	Emergency Department	2	60 Hours
8	Cancer Ward	1	30 Hours
9	Cardio-Thoracic Ward	3	90 Hours
10	Neuro	2	60 Hours
11	Orthopaedic Ward	2	60 Hours
12	Nephro-Uro	2	60 Hours
13	GI Units	1	30 Hours
	Total	**22 Weeks**	**650 Hours**

Student Activities:

- Clinical presentations
- History taking
- Health Assessment
- Nutritional Assessment
- Health Education related to disease conditions
- Case studies
- Projects work
- Field visis

Essential Nursing Skills

- Health assessment
- Triage
- CPR
- Pulse oxymetry

EVALUATION BASIS

Theory

1. Test paper -	Mid Term -	=	50 marks
	Pre-final -	=	75 marks
2. Other Assignment	Seminar	=	100 marks
	Project work	=	100 marks
	Total -		**325 marks**

Internal Assessment Total marks out of 25

External Assessment Total marks out of 75

Practical Experience Assignments

Case study :	02	(50 marks each)	50 x 2 =	100
Case Presentation :	02	(50 marks each)	50 x 2 =	100
Care Plan :	03	(50 marks each)	50 x 3 =	150
Clinical Performance Evaluation:	03	(100 marks each)	100 x 3 =	300
				650

Internal Assessment Total marks out of 100

External Assessment Total marks out of 100

M.Sc. **NURSING :** CLINICAL SPECIALITY – I

PROFORMA & GUIDELINE FOR CASE STUDY
Area :- (Maximum Marks – 50)

01. Selection of patient.
02. Demographic data of the patient.
03. Medical history past and present illness.
04. Comparison of the patient's disease with book picture.
    a) Anatomy and physiology.
    b) Etiology.
    c) Patho physiology.
    d) Signs and symptoms.
    e) Diagnosis - provisional & final
    f) Investigations
    g) Complications & prognosis.
05. Management:- Medical or Surgical
    a) Aims and objectives.
    b) Drugs and Medications.
    c) Diet.
06. Nursing Management (Nursing Process approach)
    a) Aims and objectives.
    b) Assessment and specific observations.
    c) Nursing diagnosis.
    d) Nursing care plan (Short term & long term with rationale.)
    e) Implementation of nursing care with priority.
    f) Health teaching.
    g) Day to day progress report & evaluation.
    h) Discharge planning.
07. Drug Study.
08. Research evidence.
09. Summary and conclusion.
10. Bibliography.

EVALUATION CRITERIA FOR CASE STUDY.

(Maximum Marks – 50)

SN	Criteria	Marks allotted.	Marks obtained	Total
01.	Assessment	5		
02.	theoretical knowledge about disease	5		
03.	Comparative study of the patient's disease & book picture.	10		
04.	Management: Medical or Surgical.	5		
05.	Nursing Process.	15		
06.	Drug study.	3		
07.	Summary & conclusion including research evidence.	5		
08.	Bibliography.	2		
	Total	50		

Signature of Student

Signature of Clinical supervisor

M Sc NURSING: CLINICAL SPECIALITY – I

PROFORMA & GUIDELINE FOR CASE PRESENTATION

I] Patient Biodata

Name, Age, Sex, Religion, Marital status, Occupation, Source of health care, Date of admission, Provisional Diagnosis, Date of surgery if any.

II] Presenting complaints

Describe the complaints with which the child has been brought to the hospital

III] Socio-economic status of the family: Monthly income, expenditure on health, food, education etc.

IV] History of Illness (Medical & Surgical)

i) History of present illness – onset, symptoms, duration, precipitating/aggravating factors
ii) History of past illness surgery, allergies, medications etc.
iii) Family history – Family tree, history of illness in the family members, risk factors, congenital problems, psychological problems etc.

V] Diagnosis: (Provisional & confirmed).

Description of disease: Includes the followings

1. Definition.
2. Related anatomy and physiology
2. Etiology & risk factors
3. Path physiology
5. Clinical features.

VI] Physical Examination of Patient (Date & Time)

Physical examination: with date and time.
Clinical features present in the book Present in the patient

VII] Investigations

Date Investigation done Results Normal value Inferences

VIII] Management - (Medical /Surgical)

a) Aims of management
b) Objectives of Nursing Care Plan

IX] Treatment:

S.No Drug (Pharmacological name) Dose Frequency/ Time Action Side effects & drug reaction
Nurse's
responsibility

- Medical or Surgical Management.
- Nursing management

X] Nursing Care Plan: Short Term & Long Term plan.

Assessment Nursing
Diagnosis
Objective Plan of
care
Rationale Implementation Evaluation

XI] Discharge planning:

It should include health education and discharge planning given to the patient.

XII] Prognosis of the patient:

XIII] Summary of the case:

IVX] References:

EVALUATION CRITERIA FOR CASE PRESENTATION

Maximum Marks – 50)

SN	Criteria	Marks Allotted	Marks Obtained	Total
1	Content Subjective & objective data.	08		
2	Problems & need Identified & Nsg. Care Plan	15		
3	Effectiveness of presentation	5		
4	Co-relation with patient & Book i. e. research evidence.	10		
5	Use of A. V. Aids	5		
6	Physical arrangement	2		
7	Group participation	3		
8	Bibliography & references	2		
	Total	50		

CLINICAL EVALUATION: COMPREHENSIVE NURSING CARE

(Maximum Marks – 100 each area.)

Name of the Student

Year: Duration of Experience:

SN	Criteria	1	2	3	4	5
I	UNDERSTANDING OF PATIENT AS PERSON **A. Approach.** 1. Rapport with patient/ family members. 2. Collects significant information. **B. Understanding of patient's health problems.** 1. Knowledge about disease condition. 2. Knowledge about investigations. 3. Knowledge about treatment. 4. Knowledge about progress of the patient.					
II	NURSING CARE PLAN **A. Assessment of the condition of the patient.** 1. History taking – past & present health and illness. 2. Specific observation of the patient. 3. Nursing diagnosis. **B. Development of the short – term & long term Nursing care plans.** 1. Identification of all problems in the patient/ family. 2. Prioritization & implementation of the plans. 3. Evaluation of the care given & replanning					
III	TECHNICAL SKILL 1.Economical & safe adaptation to the situation & available facilities. 2.Implements the procedure with skill speed & completeness.					
IV	RECORDING & REPORTING 1.Prompt, precise, accurate & relevant. 2.Maintenance of clinical experience file.					
V	HEALTH TEACHING 1.Incidental/ planned teaching with principles of teaching & learning. 2.Uses visual aids appropriately					
VI	PERSONALITY 1. Professional appearance (uniform, dignity, tact fullness interpersonal relationship, punctuality etc. 2. Sincerely, honesty & Sense of responsibility.					
	TOTAL MARKS					

Positive & Negative aspects.

Signature of Student Signature of Clinical supervisor

REFERENCES

1. Black M.J., Hawks H.J., “Medical Surgical Nursing, Clinical Management for positive outcome” 7th Ed., Sauders, Elsevier.
2. Smeltzer, Bare Brunner and Suddarths Medical Surgical Nursing.
3. The Lippincott Mannual of Nursing practice, Lippincott.
4. MANN, RUSSELL, WILLIAMS, Bailey & Love’s short practice of Surgery.
5. Potter & Perry Fundamentals of Nursing, Elsevier.
6. Urdan Bavic, Thelan, Essentials of critical care Nursing.
7. Urban, A.N., Greenlac K.K. “Guidelines for critical care Nursing Mosby
8. Wood L.S., Freelicher S.E fetal cardiac Nursing. Lippincott Williams & Wilkings.
9. Gulanic, Klopp, Galnes fetal Nursing care plans nursing diagnosis and intervention.
10. Lewis, Collier & Heitkemper Medical Surgical Nursing assessment and management of clinical problems.

KASTURBA NURSING COLLEGE, SEWAGRAM-WARDHA

EVALUATION CRITERIA FOR *NURSING CARE PLAN*

(Maximum Marks – 50)

Name of the Student : ___________________________

Date : …………………

Field placement : __________

SN	CRITERIA	MARKS ALLOTTED	MARKS OBTAINED	TOTAL
1	1. History taking	6		
2	2. Assessment of needs & problems	10		
3	3. Nursing process	16		
4	4. Implementation of care	10		
5	5. Follow-up care	4		
6	6. Bibliography	4		
	TOTAL	**50**		

N.B. : One Nursing Care Plan : 50 Marks

Remarks

Signature of Students ………

Signature of Supervisor ………

09HLTH15-003-C **NURSING EDUCATION**

PLACEMENT: First Year

HOURS OF INSTRUCTION

Theory : 150 Hours

Practical : 150 Hours

Total : 300 Hours

COURSE DESCRIPTION

This course is designed to assist students to develop a broad understanding of fundamental principles, trends and issues related to education and nursing education. Further, it would provide opportunity to students to understand, appreciate and acquire skills in teaching and evaluation, curriculum development, implementation, maintenance of standards and accreditation of various nursing educational programs.

OBJECTIVES

At the end of the course, students will be able to:

1. Explain the aims of education, philosophies, trends in education and health: its impact on nursing education.
2. Describe the teaching learning process.
3. Prepare and utilize various instructional media and methods in teaching learning process.
4. Demonstrate competency in teaching, using various instructional strategies.
5. Critically analyze the existing nursing educational programs, their problems, issues and future trends.
6. Describe the process of curriculum development, and the need and the methodology of curriculum changes, innovation and integration.
7. Plan and conduct continuing nursing education programs.
8. Critically analyze the existing teacher preparation programs in nursing.
9. Demonstrate skill in guidance and counseling.
10. Describe the problems and issues related to administration of nursing curriculum including selection and organization of clinical experience.
11. Explain the development of standards and accreditation process in nursing education programs.
12. Identify research priorities in nursing education.
13. Discuss various models of collaboration in nursing education and services.
14. Explain the concept, principles, steps, tools and techniques of evaluation.
15. Construct, administer and evaluate various tools for assessment of knowledge, skill and attitude.

COURSE CONTENT

UNIT	TOPIC	THEORY	PRACTICALS	M OT	T/L ACTIVITIES
I	**INTRODUCTION** • Education: definition, aims, concepts, philosophies & their education implication. • Impact of social, economical, political & technological changes on education: - Professional education - Current trends and issue in education - Educational reforms and national educational policy - Trends in development of nursing education India. • Concepts of Nursing education • History of nursing education in India • Philosophy and objectives of nursing education • Purposes of nursing education in India • Scientific approach in Nursing • Current issues and emerging trends in Nursing education Liberal education and nursing education	10		L	• Students to apply various philosophies of educations to nursing education • Present the history of nursing education in India, issues & trends in nursing education
II	**OBJECTIVES AND THEIR CLASSIFICATION** • Meaning of educational objectives. • Formulation and statement of objectives • Classification of objectives • Taxonomy of educational objectives Objectives and learning outcomes	05	04	L/D	• Formulate objectives as per the domains and subject
III	**TEACHING –LEARNING PROCESS** • Concepts of teaching and learning: Definition, theories of teaching and learning, relationship between teaching and learning. • Competency based education (CBE) and outcome based education (OBE) • Instructional design: planning and designing the lesson, writing lesson plan, meaning, its need and importance, formats. • Instruction strategies: Lecture, discussion, demonstration, simulation, laboratory, seminar, panel, symposium, problem based learning(PBL), workshop, project, role play (socio drama), clinical teaching methods, programmed instruction, self directed learning (SDL), micro teaching, computer assisted instruction (CAI), computer assisted learning(CAL) • Sensitivity training and transactional analysis • Training for nursing leadership Development of effective study habits	30	28	L	• In clinicals supervise students prepare rotation plan • Prepare lesson plan, • Carry out practice teaching • Carry out 2 microteaching

IV	**INSTRUCTIONAL MEDIA AND METHOD** • Key concepts in the selection and use of media in education. • Developing learning resource material using different media • Instructional aids- types, uses, selection, preparation, and utilization Teacher's role in procuring and managing instructional Aids- project and non projected aids, multi media, video-tele conferencing etc.	10	06	L/D	• Visit to IEC Bureau • Preparation and utilization of Instructional aids
V	**MEASUREMENT AND EVALUATION** • Concept and nature of measurement and Evaluation, meaning, principles, purpose, problems in evaluation and measurement. • Principles of assessment, formative and summative assessment –internal assessment external examination, advantages and disadvantages • Criterion and norm referenced evaluation **Evaluation process** • Defining objectives for evaluation purposes. • Relating evaluation procedures to objectives. • Formative and summative evaluation • Characteristics of evaluation	10		L/D	• Relate evaluation to educational objective
VI	**STANDARDIZED AND NON STANDARDIZED TEST** • Meaning, characteristics, objectivity validity, reliability, usability, norms, construction of tests. • Blue Print • Essay, short answer questions and multiple- choice questions. • Rating scales, checklist, OSCE/ OSPE • Differential scales, and summated scales, sociometry , anecdotal record, attitude scale, critical incident technique • Question bank-preparation, validation, moderation by panel, utilization Developing a system for maintaining confidentiality	10	15	L/D Work shop	• Prepare blue print • Construct tests • Reliability validity • Prepare question bank • Prepare an aptitude test for entrance examination for B.Sc. Nursing students
VII	**ADMINISTRATION, SCORING AND REPORTING OF TESTS** • Administrating a test, scoring, grading versus marks • Objective tests, scoring essay test, methods of scoring, item analysis	05		L/D	Carry out item analysis
VIII	**STANDARDIZED TOOLS** • Test of intelligence aptitude, interest, personality, achievement, socioeconomic status scale, tests for	05	08	L/D	• Observe various tests - Personality aptitude &

	special mental and physical abilities and disabilities				intelligence Formulate an aptitude test
IX	**NURSING EDUCATIONAL PROGRAMS** • Perspectives of nursing education: Global and national. Patterns of nursing education and training program in India. Non-university and university programs: ANM, GNM, Basic B.Sc. Nursing , Post certificate B.Sc. Nursing , M.Sc. (N) M Phil and Ph D post diploma program, Nurse practitioner programs	05	10	L/D	• Visit to nursing institution s- ANM, GNM, B.Sc., M.Sc. • Critically evaluate any nursing education al program in Maharash tra / India
X	**CONTINUING EDUCATION IN NURSING** • Concepts – Definition, importance, need, scope, principles of adult learning, assessments of learning needs priorities, resources. • Program planning, implementation, and evaluation, of continuing education programs. • Research in continuing education Distance education in nursing	05	15	L/D	• Plan CNE Program me & conduct one workshop (group activity)
XI	**CURRICULUM DEVELOPMENT** • Definition, curriculum determinants, process & steps of curriculum development, curriculum models types and framework. • Formulation of philosophy, objective, Mission statement. Selection and organization of learning experiences, current trends in clinical learning experiences. • Master plan, course plan, unit plan, lesson plan. • Evaluation strategies, process of curriculum change, role of students, faculty, administrators • Statutory bodies, and other stakeholders. • Equivalency of courses: transcripts, credit system • Curriculum committee • Selection of text books • Assignments	10	10	L	• Prepare the mission statement philosoph y, education al objectives for a nursing education program me • Formulate education al objectives for various lessons- eg FON, Medical – Surgical nursing • Select learning experienc es for a specific subject

XII	**TEACHER PREPARATION** • Definition, nature of teaching • Characteristics of good teaching • Communication process in teaching • Principles of teaching • Maxims of teaching • Levels of teaching • Characteristics of an effective teacher • Innovations in teaching • Modification of teacher behaviour • Teacher-roles & responsibilities, function, characteristics, • Competencies, qualities • Preparation of professional teacher • Organizing professional aspects of teacher preparation programs • Questioning technique Evaluation : Self and peer. Critical analysis of various programs of teachers education in India	10	05	L/D	• Application of principles and maxims of teaching • Carry out any one innovative teaching strategy
XIII	**GUIDANCE AND COUNSELING** • Concepts and principles of guidance and counseling • Purpose and phases of counseling • Need for guidance and counseling in nursing education • Types of guidance and counseling • Difference between guidance and counseling • Problems of guidance and counseling • Responsibilities of the nurse administrator in student guidance and counseling • Guidance and counseling services: diagnostic and remedial. • Coordination and organization of services • Techniques of counseling: interview, case work and characteristics of counselor Professional preparation and training for counseling	10	08 + 16	L/D	• Role play • Visit to visually impaired • Deaf and dumb gifted children, slow learner, mentally handicapped
XIV	**ADMINISTRATION OF NURSING CURRICULUM** • Role of curriculum coordinator. Planning, implementation and evaluation. • Evaluation of educational program in nursing course and program • Factors influencing faculty staff relationship and techniques of working together. • Concept of faculty supervisor (dual) position. • Curriculum research in nursing Different models of collaboration between education and service	10	05	L/D	• Evaluate present curriculum of any educational program GNM, B.Sc. Nursing

XV	**MANAGEMENT OF NURSING EDUCATION INSTITUTIONS** • Planning , organizing , staffing budgeting, recruitment, discipline, public relation, performance appraisal, welfare services, library services, hostels • Development and maintenance of standards and accreditation in nursing education programm. • Role of Indian Nursing council, state Registration Nursing councils, board and university. Role of professional association and unions	08	08	L/D	• Visit to educational institutions • Plan to set-up a SON/ CON • Visit to INC/SNC
XVI	**EVALUATION OF CLINICAL PRACTICE IN NURSING** • Clinical evaluation methods • Written communication methods as clinical evaluation Oral communication methods as clinical evaluation	05	08	L/D	• Formulate clinical evaluation criteria: • Conduct practical examination for undergraduate students
XVII	**INTERNAL ASSESSMENT** • Needs for internal assessment • Component of internal assessment system • Validity of internal assessment Advantage and disadvantage of internal assessment	02	04	L/D	• Prepare an internal assessment system for particular education programme
		150	150		

PLANNED ACTIVITIES:

- Panel discussion/group presentation – Educational psychology – Theories and laws of learning and
  teaching, Personality, Intelligence, Individual differences, Motivation, Group Dynamics
- Framing philosophy, aims and objectives of an educational Institution
- Lesson Planning
- Micro teaching –2
- Conduct Practice teaching using different teaching strategies –10 (Classroom – 5,Demonstration
- Construct a written objectives type test for the lessons taken.
- Construct tests, administer and determine reliability and validity.
- Preparation and utilization of instructional aids using different media.
- Design a curriculum for a basic B.Sc. Nursing Programme; Develop course plan, units plan, rotation plans,
- Prepare cumulative records for students.
- Prepare rotation plan for clinical practice

- Planning and organizing field visits
- Plan, conduct and evaluate a continuing nursing education workshop
- Annotated bibliography 10
- Critical evaluation of any nursing education program offered by a selected institution.
- Educational visit – Educational institutions –GNM, B Sc, Diploma course etc
- Field visits (INC/SNC) to get familiar with recognition / registration process.
- Construct, administer and evaluate tools (objective & essay type test, observation checklist, rating scale etc).
- Observe and practice application of various non-standardized tests (intelligence, aptitude, personality, sociometry, physical and mental disabilities tests.)
- Prepare aptitude test for entrance exams of B.Sc nursing students.
- Prepare a plan for evaluation of the students in the B.Sc nursing programme.
- Visit to schools – gifted children, slow learners, mentally handicapped, deaf & dumb & visually impaired

METHODS OF TEACHING

Method of teaching

- Lecture cum discussion
- Demonstration
- Seminar/Presentation
- Project work
- Field visits
- Workshop

Methods of evaluation

- Written Tests
- Class room /Clinical teaching
- Presentation
- Project work
- Written assignments

INTERNAL ASSESSMENT

THEORY

Techniques	**Weight age**	
1. Midterm	50	
2. Prefinal	75	
3. Assignment		
AV Aids	25	
Seminar	25	
	175	**Out of 25**

PRACTICAL

1. Learning resource material	25	
2. Curriculum Planning	25	
3. Practice teaching	50 (total of 10 practice teachings)	
4. Conduct Workshop / Short Term Course	25	
5. Prepare question bank	25	
	150	**Out of 50**

UNIVERSITY EXAMINATION

W RITTEN EXAMINATION - 75 marks

PRACTICAL

1. Practice teaching –I	50	
2. Preparation /use learning resource material-1	25	
3. Construction of tests	25	
	100	**Out of 50**

Total practical examination out of 100

THEORY EXAMINATION - UNIVERSITY

Internal	**University Exam**	**Total**
25	75	100
Practical Internal	**University exam**	**Total**
50	50	100

Books for Reference

1. Aggarwal J.C, " Principles, methods &Techniques of Teaching", Vikas Publishing House PVT Ltd, II Edn.
2. Basavanthappa B.T, "Nursing Education", Jaypee brothers,Edn I, 2005.
3. Bevis, Em Olivia, Curriculum Building in Nursing: A Process, Ed-2, C V Mosby Co, St. Louis. 1978.
4. George Kurian Aleyamma, "Principles of Curriculum Development and Evaluation", Vivekanandha Press, 2002.
5. Bhatia, Kamala & BHATIA,B.D, Principles and methods of teaching, Doabra house, New Delhi, 1970.
6. Billing, Diane M & HALSTEAD, Judith A: Teaching in Nursing: A guide for faculty, W.B. Saunders, Company, Philadelphia, 1998.
7. Bloom, Benjamin S Ed, Taxonomy of educational objectives: cognitive domain I David Mckay CO. Inc. New York. 1956.
8. DOABA guide
9. Fuszard, Barbara: Innovating teaching strategies in Nursing, Aspen Publishers Inc. Maryland.1989.
10. Gay. LR Educational evaluation and measurement Competencies for analysis and Application. Ed-2, Charles E.MERILL publishers Co. Columbus .1985.
11. Guilbert. J J , Educational Handbook for Health Personnel, World Health Organization, Geneva, 1982.
12. Guinee. Kathleen k; Teaching and Learning in Nursing, Macmillan, New York, 1978.
13. Joyce.B, etc, Models of teaching. Ed –4, Prentice Hall Inc, Englewood Cliffs, New Jersey, 1986.
14. Keay,F E, A History of education in India and Pakistan, Ed-4 , Oxford University Press, London, 1964.
15. King, Imogene M, Curriculum and Instruction in Nursing, Concepts and process Appleton – Century crafts, Norwalk., Connecticut, 1986.

16 KrathwohoL, David, R, etc, Taxonomy of educational objectives, Affective Domain I, David Mckay Company Inc., New Yotk, 1956.

17 Mccloskey, Joanne C & GRACE, Helen K, Current issues in Nursing Publishing Company Inc, New York, 1995.

18 Modley, Doris M, etc; Advancing Nursing Education world wide, Springer Publishing Co .New York,1995.

19 Neeraja K.P, " Text book of Nursing Education", Jaypee brothers.

20 O, Connor, Andrea B; Nursing staff development and continuing Education, Little Brown Company, Bonston, 1986

21 Sanatombi Elsa, "Manipal Manual of Nursing Education", CBS Publishers & Distributors, New Delhi, Ist Edn, 2006.

22 Supe, Rege, Bhuiyan, " The Art of Teaching Medical Students", Medical Education Technology Cell, 2nd edn, 2002.

MAHARASHTRA UNIVERSITY OF HEALTH SCIENCES

M.SC. NURSING
PRACTICE TEACHING

PROFORMA FOR LESSON PLAN

Topic :________________________________ Name of the student :________________________________

Sub Topic :_____________________________ Name of the Guide :________________________________

Unit :______________________________ Date :______________________Time:__________________

Venue :____

Class

Taught:____

Method of Teaching

____

Audio Visual Aids

____

Previous Knowledge of the Group ;

General Objective

Specific Objective

Sr. no	Specific objective	Duration	Content	Teacher/ Learner Activity	Audio Visual Aids	B/B Activity	Evaluation
			❖ Introduction ❖ Content ❖ Conclusion ❖ Assignment ❖ References				

MAHARASHTRA UNIVERSITY OF HEALTH SCIENCES

M.SC. NURSING
PRACTICE TEACHING

EVALUATION FOR SEMINAR

Name of the student :______________________________________

Subject :______________________________________

Topic :______________________________________

Group :__________________ **Date:** ___/___/_____ **Time:**_________

Total Marks obtained out of 25:____________

Sr. No	Content	Marks allotted	Marks Obtained
1	Aims & objectives	02	
2	Organization of Content – ▪ Coverage of content ▪ simple to complex ▪ logical	03	
3	Presentation ▪ Introduction ▪ Coverage of subject content ▪ Sequencing ▪ Depth of Knowledge ▪ Integration of subject matter ▪ Explanation and clarification ▪ Use of current literature ▪ Time limit	05	
4	Audiovisual Aids	05	
5	Speaker's Qualities	05	
6	Group Discussion	2.5	
7	References	2.5	
	Total	**25**	

Remarks of the Guide :

Signature of the Guide
Date

Signature of the student
Date

MAHARASHTRA UNIVERSITY OF HEALTH SCIENCES

M.SC. NURSING
PRACTICE TEACHING

PROFORMA FOR EVALUATION

Name of the student :________________________________ **Group** ________________
Topic :____
Place :____
Name of the Evaluator :________________________ **Date:** ___/___/_____ **Time:**________
Total Marks obtained out of 50:___________

Sr. No	Content	Marks allotted	Marks Obtained
1	**LESSON PLAN** ▪ General objectives stated clearly ▪ Specific objectives stated in behavioral terms ▪ Lesson plan followed in sequence ▪ Bibliography upto date and complete	10	
2	**LEARNING ENVIRONMENT** ▪ Physical set up of classroom (seating) ▪ Classroom light adequate ▪ Well ventilated ▪ Motivates students	05	
3	**PREPARATION** ▪ Coverage of subject content ▪ Depth of Knowledge ▪ Integration of subject matter ▪ Speech- Clear, audible, well modulated ▪ Explanation and clarification ▪ Use of current literature ▪ Time limit	10	
4	**USE OF AUDIOVISUAL AIDS** ▪ Relevant , clear and visible ▪ Creativity ▪ Used effectively at the right time	10	
5	**QUESTIONING TECHNIQUE** ▪ Questions equally, addressed to all ▪ Well worded questions, no ambiquity ▪ Thought provoking questions ▪ Sufficient time allowed for answering ▪ Questions relevant and challenging	05	
6	**ASSIGNMENT** ▪ Appropriate to the lesson ▪ Clear ▪ Motivating ▪ Explained to the students ▪ Feedback given to the students	05	
7	**STUDENT TEACHER PERSONALITY** ▪ Appearance grooming ▪ Confidence ▪ Mannerisms	05	
	Total Marks	**50**	

Remarks of the Evaluator / Guide:

Signature of the Evaluator/ Guide:

Signature of the student:

09-HLTH15-004-C NURSING MANAGEMENT

Placement: II year

Hours of Instruction
Theory 150 Hours
Practical 150 Hours
Total : 300 Hours

Course Description:

This course is designed to assist students to develop a broad understanding of Principles, concepts, trends and issues related to nursing management. Further, it would provide opportunity to students to understand, appreciate and acquire skills in planning, supervision and management of nursing services at different levels to provide quality nursing service.

Objectives:

At the end of the course, students will be able to:

1.Describe the philosophy and objective of the health care institutions at various levels.

2.Identify trends and issues in nursing.

3.Discuss the public administration, health care administration vis a vis nursing administration.

4.Describe the principles of administration applied to nursing.

5.Explain the organization of health and nursing services at the various levels / institutions.

6.Collaborate and co-ordinate with various agencies by using multisectoral approach.

7.Discuss the planning, supervision and management of nursing workforce for various health care settings.

8.Discuss various collaborative models between nursing education and nursing service to improve the quality of nursing care.

9.Identify and analyse legal and enthical issues in nursing administration.

10.Describe the process of quality assurance in nursing services.

11.Demonstrate leadership in nursing at various levels.

COURSE – PLAN

UNIT	HRS	CONTENT
I	10	❑ Philosophy, purpose, elements, principles & scope of administration. ❑ Indian Administrative system vis a vis health care delivery system: National, State and Local, Indian Constitution. ❑ Planning Processes: Five year plans, various committee reports on Health State and National Health Policies, National Population Policy on AYUSH & plans.
II	10	**MANAGEMENT: -** ❑ Functions of administration. ❑ Planning and control. ❑ Co- ordination and delegation ❑ Decision making – decentralization basic goals of decentralization ❑ Concept of management. **NURSING MANAGEMENT: -** ❑ Concept, types and principles. ❑ Vision and mission statements. ❑ Philosophy, aims and objectives ❑ Current trends and issues in Nursing administration ❑ Theories and models. Ap application to nursing service and education.
III	15	PLANNING :- ❑ Planning process: concept, principles. ❑ Mission, philosophy, objectives. ❑ Strategic planning ❑ Operational plans. ❑ Management plans ❑ Programme evaluation and review technique (PERT), Gantt chart, management by objectives (MBO). ❑ Planning new venture. ❑ Planning for change Application to nursing service and education
IV	15	ORGANISATION :- ❑ Concept, principles, objectives, types and theories, minimum requirements for organization, developing an organizational structure, levels, organizational effectiveness and organizational climate ❑ Organizing nursing services and patient care : methods of patient assignment – advantages and disadvantages, primary nursing care.

UNIT	HRS	CONTENT
		❑ Planning and organizing : hospital, unit and ancillary services (specially central sterile supply department, laundry, kitchen, lab. Services, emergency etc.) ❑ Disaster management : plan, resources, drill., etc. Application to nursing service and education
V	15	**HUMAN RESOURCES FOR HEALTH :-** ❑ Staffing ❑ Recruitment : credentialing, selection, placement, promotion ❑ Retention . ❑ Personnel policies ❑ Termination ❑ Staff development programme. ❑ Duties and responsibilities of various category of nursing personnel.
VI	15	**DIRECTING :-** ❑ Roles And Functions ❑ Motivation : Intrinsic, extrinsic, creating motivating climate, motivational theories. ❑ Communication : process, types, strategies, interpersonal communication, channels,barriers,problems, confidentiality, public relations ❑ Delegation; common delegation errors ❑ Managing conflicts: process, management, negotiation, consensus ❑ Collective bargaining: health care labour laws, unions, professional associations, role of nurse manager ❑ Occupational health and safety. Application to nursing service and education
VII	10	• Material Management • Concepts, principles and procedures : Specifications • ABC analysis • VED (very important and essential daily use) analysis • Planning equipments and supplies for nursing care : unit and hospital • Inventory control • Condemnation Application to nursing service and education

UNIT	HRS	CONTENT
VIII	15	**Controlling** • Quality assurance Standards Models Nursing audit • Performance appraisal : Tools, formats, Management, interviews • Supervision and management : concepts and principles • Discipline : service rules, self discipline, constructive versus destructive discipline, problem employees, disciplinary proceedings enquiry etc. Application to nursing service and education
IX	15	**Fiscal planning** • Steps • Plan and non-plan, zero budgeting, mid-term appraisal, capital and revenue • Budget estimate, revised estimate, performance budget • Audit • Cost effectiveness • Cost accounting • Critical pathways • Health care reforms • Health economics • Budgeting for various units and levels Application to nursing service and education
X	10	**Nursing informatics** • Trends • General purpose • Use of computers in hospital and community • Patient record system • Nursing records and reports • Management information and evaluation system (MIES) • E-nursing, Telemedicine, telenursing • Electronic medical records
XI	10	**Leadership** • Concepts, Types Theories • Styles • Manager behaviors • Leader behaviors • Effective leader : Characteristics, skills • Group dynamics • Power and politics • Lobbying • Critical thinking and decision making • Stress management Application to nursing service and education

UNIT	HRS	CONTENT
XII	10	**Legal and ethical issues** **Laws and ethics** • Ethical committee • Code of ethics and professional conduct • Legal system : Types of law, tort law, and liabilities • Legal issues in nursing : negligence, malpractice, invasion of privacy, defamation of character • Patient care issues, management issues, employment issues • Medico legal issues • Nursing regulatory mechanisms : licensure, renewal, accreditation • Patients rights • Rights of special groups : children, women, HIV, handicap • Infection control • Standard safety measures

Practical

1. Prepare prototype personal files for staff nurses, faculty and cumulative records
2. Preparation of budget estimate, Revised estimate and performance budget
3. Plan and conduct staff development programme
4. Preparation of Organization Chart
5. Developing nursing standards / protocols for various units
6. Design a layout plan for speciality units / hospital, community and educational institutions
7. Preparation of job description of various categories of nursing personnel
8. Prepare a list of equipments and supplies for speciality units
9. Assess and prepare staffing requirement for hospitals, community and educational institutions
10. Plan of action for recruitment process
11. Prepare a vision and mission statement for hospital, community and educational institutions
12. Prepare a plan pf action for performance appraisal
13. Identify the problems of the speciality units and develop plan of action by using problem solving approach
14. Plan a duty roster for speciality units / hospital, community and educational institutions
15. Prepare : anecdotes, incident reports, day and night reports, handing and taking over reports, enquiry, nurses notes, official letters, curriculum vitae, presentation etc.
16. Prepare a plan for disaster management
17. Group work
18. Field appraisal report.

ESSENTIALS FOR A P. EXP.

1) DEMONSTRATION
2) PREPARATION/STUDY MATERIAL & PRESENTATION
3) ANALYSIS STUDY-REPORT

(GUIDE LINE TO BE PROVIDED) THAT IS

AIMS-OBJECTIVES EVALUATION

AREA FOR EXPERIENCE

- PREPARATION FOR DUTY ROSTER UNIT
- PREPARATION FOR INVENTORY
- PROCESS OF CONDEMNATION
- SUPERVISION FOR NSG/NON NSS STABB ?
- CLINICS FOR TRAINEE NURSES (BEDSIDE)
- OBSERVATIONAL STUDY OF NURSES ADM AREA.

VISIT- APECIFIC Department

C S S D, kitchen

Waste disposal

Special unit

College Demonstration format

- Cumulative Record
- Personal Appraisal
- Various evaluation performe
- Organizational charts
- Job description
- Recruitment Process
- Vision-Mission statement
- Standing orders/protocol
- Staff development programme
- Model budget

Practical Experience:-Observational Study Report Preparation.

SN	Departments/Area	Weeks	Hours
1	Hosptial Administration Nursing service administartion Nursing education administartion	$1^1/_2$	60 hrs.
2	Community Health Administartion	$1^1/_2$	60 hrs.
3	Visit to Specialised Unit /Hosptial	1 (5 hrs. per day)	30 hrs.
	Total		150 hrs.

Hosptial Administration: -

- Account Section
- CSSD
- Dietary Section
- Waste Disposal etc.

Nursing Services Administration:-

- Office of Nursing Superintendent
- Departmental Incharge

Nursing Education Administration:-

- Office of Principal of School/College of Nursing

Community Health Administration: -

- DHS/DHO/CHC/RH/NGO/Govt.Agencies

Assignments: - Theory

- Seminar
- Module Preparation (Staff development programme)
- Vision Mission Statement
- Standing orders
- Job Description
- Cumulative reword
- Evaluation Performa
- Personal Appraisal
- Recruitment process.

Method of Teaching: -

- Lecture Discussion
- Group Discussion
- Field Visit
- Project work
- Seminar Presentation

INTERNAL ASSESSMENT

THEORY

1.	Mid Term -	50
2.	Pre- term -	75
3.	Seminar / Presentation	100
4.	Evaluation for Performance appraisal	50

		275

Practical Experience Evaluation

1. Evaluation Criteria for writing report on Duties and responsibilities of Nursing Personnel — 50 Marks

2. Clinical Performance Evaluation : Nursing Service Administration — 100 Marks

ASSIGNMENT FORMAT FOR SEMINAR

Introduction to the topic__
Unit background
Concept, definition
History
Subject matter
Application in Nursing field
Summary
Conclusion
References

EVALUATION CRITERIA FOR SEMINAR PRESENTATION

Subject
Topic — Date
Name of student — Time
Group — Maximum Marks : 100

SN.	Criteria	Rating					Remarks
		1	2	3	4	5	
1	Introduction						
2	Organization of Content						
3	Presentation of topic						
4	Relevant examples						
5	Relevant statistical data						
6	Group participation						
7	Control of group						
8	Conclusion						
	AV Aids						
9	Appropriate to subject						
10	Proper use of A/V Aids						
11	Self explanatory						
12	Attractive						
13	Planning and preparation						
14	Use of Modern technology						
	Physical facilities						
15	Environment						
16	Classroom preparation						
17	Over lay out						
	Personal Appearance						
18	Voice & clarity						
19	Mannerisms						
20	References						

Remarks & signature of supervisor-
Date :
Signature of student
Date :

ASSIGNMENT FORMAT FOR WRITING PERFORMANCE APPRAISAL :-

Guidelines :-

1 Define the purpose of assessment

2 Decide as to which groups are to be assessed

3 Select and define the qualities to be assessed on a Five point Rating scale.

4 Include the following areas

- Quality of performance
  - Quantity of work
  - Quality of work
- Mental qualities
  - Ability to learn
  - Adaptability
  - Originality
  - Reasoning powers
- Supervisory qualities
  - Leadership
  - Organizing ability
  - Cooperation
- Personal qualities
  - Honesty
  - Self control
  - Initiative
  - Appearance
  - Attitude towards fellow workers
  - Attitude towards work
- Capacity for further development
  - Intelligence
  - Acceptance of responsibility
  - To Lead a group

EVALUATION CRITERIA FOR WRITING PERFORMANCE APPRAISAL

(Maximum Marks : 50)

SN.	Criteria	Marks Allotted	Marks Obtained	Total
1	Preparation of Tool	20		
2	Content	10		
3	Comprehension	10		
4	Conclusion	05		
5	References	05		
	Total	**50**		

Remarks & signature of supervisor-
Date :

Signature of student
Date :

CLINICAL EVALUATION PERFORMS NURSING SERVICE ADMINISTRATION

Name of the student   Field placement
Period :   Name of the supervisor

DECECTION :- To facilitate the use of the clinical evaluation performs, typical activities behavior are described on a five point scale. The direction of all scale is from lowest (1) to highest (5). Mark your evaluation by placing a tick mark in the column, describing the student's standing in relation to other students in the general level experiences :-

1 Poor   2 Fair   3 Good   4 Very good   5 Excellent

Marks : 100

SN	SUPERVISOR TASKS	Rating					Remarks
		1	2	3	4	5	
1	Organizing ability						
2	Leadership						
3	Responsibility for equipments & supplies						
4	Maintenance of cleanliness of ward						
5	Assisting in Ward activity (Pharmacy, Dietary etc)						
6	Written & oral report						
7	Teaching						
8	Supervision of nonprofessional workers						
9	Problem solving ability						
	WORK PERFORMANCE						
1	Knowledge						
2	Skill (Accuracy & speed)						
3	Maintaining nursing & scientific principles						
	PERFSONAL QUALITIES						
1	Communication skill						
2	Attitude towards work						
3	Self confidence						
4	Inter – personal relationship						
5	Emotional stability						
6	Punctuality						
7	Cooperation						
8	Reliability						

Remarks & signature of supervisor-
Date :

Signature of student
Date :

ASSIGNMENT FORMAT FOR WRITING REPORT ON DUTIES AND PESPONSIBLITIES OF NURSING PERSONNEL (NURSING SUPERINTENDENT, WARD IN CHARGES).

Introduction

Aim of the assignment

Objectives of the study

Qualification

Total years of service

Experience in Administration

Date of appointment in the Hospital for the assignment

Write the job description of each of the categories of the above employees in the hospital under Administrative, Supervisory, Clinical, Teaching, Records, Reports & Returns and other duties such as staff welfare, committee procedures ….

Conclusion
References

EVALUATION CRITERIA FOR WRITING REPORT ON

DUTIES AND RESPONSIBLITIES OF NURSING PERSONNEL

(Maximum Marks : 50)

SN.	Criteria	Marks Allotted	Marks Obtained	Total
1	Introduction	10		
2	Organization of content	20		
3	Comprehensive	10		
4	Conclusion	05		
5	References	05		
	Total	**50**		

Remarks & signature of supervisor-
Date :

Signature of student
Date :

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- Keith Davis – Human Relation at Work, the dynamics of organisational behaviour.
- R.D. Agrawal – Organisational Management.
- R.A.Sharma. – Technological Foundation Of Education.

Journals:

1. Registered nurses.
2. Nursing times.
3. Nursing journal of India.
4. Nurses of India
5. Indian journal of medical ethics.
6. Indian journal of holistic nursing.
7. Journal of nursing practice and research.
8. Journal of advance nursing practice.
9. Herald of health
10. Health screen.
11. Health action

09HLTH15-005-C NURSING RESEARCH AND STATISTICS

Placement 1st Year

Hours of Instruction
Theory :150 Hours
Practical :100 Hours
Total: 250 Hours

Part A: Nursing Research

Course Description:-

The Course is designed to assist the students to acquire an understanding of the research methodology and statistical methods as a basis for identifying research problem, planning and implementing a research plan. It will further enable the students to evaluate research studies and utilize research findings to improve quality of nursing practice, education and management.

General Objectives:

At the end of the course, the students will be able to :

1. Define basic research terms and concepts.
2. Review literature utilizing various sources
3. Describe research methodology
4. Develop a research proposal.
5. Conduct a research study.
6. Analyze and interpret the research data
7. Communicate research findings
8. Utilize research findings
9. Critically evaluate nursing research studies
10. write scientific paper for publication

CONTENT OUTLINE

Unit	Hours		Course Content
	Theory	Practical	
I	10 +2		**Introduction :** • Methods of acquiring knowledge – problem solving and scientific method. • Inductive and deductive reasoning • Research – definition, Characteristics, purposes, kinds of research • Historical Evolution of research in nursing • Basic research terms • Scope of nursing research : areas, problems in nursing, health and social research**,** • Role of research in nursing • Evidence based practice • Ethics in research • Overview of Research process
II	5 **(-2)** **3**	5	**Review of Literature** * Importance, purposes, scope, sources, criteria for selection of resources and steps in reviewing literature.
III	12		**Research Approaches and designs** • Type: Quantitative and Qualitative • Historical, survey and experimental – Characteristics, types advantages and disadvantages • Qualitative: Phenomenology, grounded Theory, ethnography • Research designs, its importance , characteristics of good design • Threats to internal and external validity
IV	10	5	**Research problem** : • Identification of research problem, • **Sources of research problem** • Formulation of problem statement and research objectives • Definition of terms • Assumptions and delimitations and **limitation** • Identification of variables • Hypothesis – definition, formulation and types

Unit	Hours		Course Content
	Theory	Practical	
V	5	5	**Developing theoretical / conceptual framework** • Theories: Nature, Characteristics, Purpose and uses • Using, testing and developing conceptual framework, models and theories
VI	**6**	-	**Sampling** • Population and sample • Factors influencing sampling • Sampling techniques • Sample size • Probability and sampling Error • Problems of sampling
VII	20	10	**Tools and methods of Data collection** : • Concepts of data collection • Data sources, methods/techniques quantitative and qualitative • Tools for data collection – types, characteristics and their development • Validity and reliability of tools • Procedure for data collection
VIII	5		**Implementing research plan** • Pilot study, review research plan (design), planning for data collection, administration of tool / interventions, collection of data
IX	10	10	**Analysis and interpretation of data** • Plan for data analysis: quantitative and qualitative • Descriptive and Inferential Analysis • Preparing data for computer analysis and presentation • Statistical analysis • Interpretation of data • Conclusion and generalizations • Summary and discussion

Unit	Hours		Course Content
	Theory	Practical	
X	10		**Reporting and utilizing research findings:** • Communication of research results; oral and written • Writing research report purposes, methods and style-vancouver, American Psychological Association (APA), Campbell etc • Writing scientific article for publication: purposes & style
XI	3	8	Critical analysis of research reports and articles
XII	4	7	Developing and presenting a research proposal

Activities

- Annotated Bibliography of research reports and articles
- Review of literature of selected topic and reporting
- Formulation of problem statement, objective and hypothesis
- Developing theoretical/conceptual framework.
- Preparation of a sample research tool
- Conducting validity and reliability of research tool
- Analysis and interpretation of given data
- Developing and presenting research proposal
- Journal club presentation
- Critical evaluation of selected research studies
- Writing a scientific paper.

Method of Teaching

- Lecture - cum – discussion
- Seminar / Presentations
- Project
- Class room exercises
- Journal club

Methods of Evaluation

- Quiz, Tests (term)
- Assignments / Term paper
- Review of literature of at least 20 Journals and 20 book - 50 marks
- Research Critiques- 50 marks
- Presentations- Presentation of two related researches **50 marks**
- Project Work Project on topic of Interest **100 marks**

PART – B : STATISTICS

Course Description

At the end of the course, the students will be able to develop an understanding of the statistical methods and apply them in conducting research studies in nursing.

Theory 50 Hrs. & Practical 50 Hrs.

General Objectives

At the end of the course the students will be able to

1. Explain the basic concepts related to statistics
2. Describe the scope of statistics in health and nursing
3. Organize, tabulate and present data meaningfully
4. Use descriptive and inferential statistics to predict results.
5. Draw conclusions of the study and predict statistical significance of the results.
6. Describe vital health statistics and their use in health related research
7. Use statistical packages for data analysis.

Unit	Hours		Course Content
	Theory	Practical	
I	7	4	**Introduction :** • Concepts, types, significance, and scope of statistics meaning of data, parameliric and no-paraametrc data • Sample, parameter • Type and levels of data and their measurement • Organization and presentation of data – Tabulation of data: • Frequency distribution • Graphical and tabular presentations
II	4	4	**Measures of central tendency :** • Mean, Median, mode
III	4	5	**Measures of variability**: * Range, Percntiles, average deviation, quartile deviation, standard deviation

Unit	Hours		Course Content
	Theory	Practical	
IV	3 2	2 2	**Normal Distribution :** * Probability , Characteristics and application of normal probability curve; sampling error. Cumulative distribution The cumulative frequency graph, Percentiles and percentile ranks The Cumulative percentage curve or Ogive
V	6	8	**Measures of relationship** : • Correlation – need and meaning • Rank order correlation • Scatter diagram method • Product moment correlation • Simple linear regression analysis and prediction.
VI	4	2	**Designs and meaning:** • Experimental designs • Comparison in pairs, randomized block design, Latin squares
VII	8	10	**Significance of statistic and significance of difference between two statistics (testing hypothesis)** • Non parametric test – Chi – square test, Sign median test, Mann-Whitney test. • Parametric test – 't' test, anova, manova, ancova, Pearson's r
VIII	5	5	**Use of statistical methods in psychology and education:** • Scaling – Z Score , Z Scaling • Standard Score and T score • Reliability of test Scores: test-retest method, parallel forms, spilt half method
IX	4	2	**Application of statistics in health:** • ratios, Rates, Trends • Vital health statistics – Birth and death rates. • Measures related to fertility, morbidity and mortality
X	3	6	**Use of computers for data analysis** Use of statistical package.

Activities

- Exercises on organization and tabulation of data.
- Graphical and tabular presentation of data
- Calculation of descriptive and inferential statistics (Chi, square, t-test, correlation)
- Practice in using statistical package
- Computing vital health statistics

Methods of Teaching:

- Lecture – cum-discussion
- Demonstration – on data organization, tabulation, calculation of statistics, use of statistical package, Classroom exercises, organization and tabulation of data,
- Computing Descriptive and inferential statistics; vital and health statistics and use of computer for data entry and analysis using statistical package.

Methods of Evaluation:

- Test , Classroom statistical exercises

Internal Assessment

Techniques	Weightage 10 marks
Test – (2 tests)	100%

Internal Assessment : Theory

I. Test

	Marks	Research	Statistics
1) Mid term	50	30	20
2) Pre final	75	50	25
	125	80	45

40% of test marks - **10 marks**

II. **Assignments**

i. Review of literature on topic of Interest (At least 20 books and 20 Journals) - 50 marks

ii. Critiquing - 50 marks

Total 100 marks

20% of Assignments – 5 marks

III. Presentation

Presentation of two related researches - 50 marks - **Total 100 marks**

20% of Presentation - **5 marks**

IV. Project work

20% - **5 marks**

References – for Nursing Research and Statistics

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15. Specials & Carpenter Qualitative Research in Nursing Advancing the Hamanistic imperative 4th ed. Lippincott Williams. 2007

Journals:

1 Journal of nursing practice and research.

2 Indian journal of medical ethics.

09HLTH15-006-C **CLINICAL SPECIALITY- II**

MEDICAL SURGICAL NURSING – ONCOLOGY NURSING

Placement: II year M.Sc Nsg.

Hours of Instruction
Theory : 150 hours
Practical : 950 hours
Total : 1100 hours

Course Description:

This course is designed to assist students in developing expertise and in-depth understanding in the field of oncology Nursing. It will help students to develop advanced skills for Nursing intervention in various oncological conditions. It will enable the student to function as oncology nurse practitioner/specialist and provide quality care. It will further enable the student to function as educator, Manager, and researcher in the field of oncology nursing.

Objectives:-

1. Explain the prevention, screening and early detection of cancer.
2. Describe the epidemiology, etiology, pathophysiology and diagnostic assessment of oncological disorders of various body systems.
3. Describe the psychological effects of cancer on patients and families.
4. Demonstrate skill in administrating/ assisting in various treatment modalities used for patients with cancer.
5. Apply nursing process in providing holistic care to patients with cancer.
6. Apply specific concepts on pain Management.
7. Appreciate the care of death and dying patients and value of bereavement support.
8. Describe the philosophy, concept and various dimensions of palliative care.
9. Appreciate the role of alternative systems of medicine in care of cancer patients.
10. Appreciate the legal & ethical issues relevant to oncology nursing
11. Recognize and manage Oncological emergencies.
12. Counsel the patients with cancer and their families.
13. Incorporate evidence based nursing practice and identify the areas of research in the field of oncology nursing.
14. Recognize the role of oncology nurse practitioner as a member of oncology item.
15. Collaborate with other agencies and utilize resources in caring for cancer patients.
16. Teach and supervise nurses and allied health workers.
17. Design a layout and develop standards for management of oncology units/hospitals and nursing care.

COURSE OUTLINE

Unit	Time Hours		Content
	T	P	
I	**4**		**Introduction** • Epidemiology- incidence, Prevalence- Global, National, State and Local • Disease burden, concept of cancer, risk factors • Historical perspectives • Trends and issues • Principles of cancer management • Roles and responsibilities of oncology nurse
II	**5**		**The Nature of Cancer** • Normal cell biology • The Immune system • Pathological and • pathophysiological changes in tissues ○ Biology of the cancer cell ○ Clone formation Transformation ○ Tumors stem lines ○ Structure of a solid tumor ○ Products produced by the tumor Systemic effects of tumor growth
III	**4**		**Etiology of Cancer** • Carcinogenesis • Theories of cancer causation • Risk factors • Carcinogens – genetic factors, chemical carcinogens, radiation, viruses, Immune system failure, rapid tissue proliferation • Hormone changes, diet, emotional Factors.

Unit	Time Hours		Content
	T	P	
IV	**10**	**2**	**Diagnostic Evaluation** * Health assessment: History taking, physical examination * Staging and grading of tumors * TNM classification * Common diagnostic tests • Blood investigation: Haematological, Bio-chemical, Tumor markers, Hormonal assay • Cytology: Fine needle aspiration cytology (FNAC) • Histopathology: Biopsy • Radiological assessment: MRI, Ultrasound, Computed tomography, Mammography, Positron Emission tomography (PET), Radio nuclide imaging, Functional metabolism imaging • Endoscopies Nurses responsibilities in diagnostic measures
V	**10**	**2**	**Levels of prevention and care** * Primary prevention – Guidelines for cancer detection, general measures, Warning signs of cancer. * Self examination – Oral, Breast, Testicular * Secondary prevention – early diagnosis * Screening * Tertiary prevention – disability limitation * Rehabilitation : Mobility, Speech, Bowel and bladder, Ostomies etc. * Patient and family education * Discharge instruction, follow-up care and use of community resources.

Unit	Time Hours		Content
	T	P	
VI	25	4	**Cancer Treatment Modalities and Nurse's Role** **** Surgery*** • Principles of surgical oncology • Current surgical strategy • Determining surgical risk • Special surgical techniques • Pre-intra postoperative nursing care • Acute and chronic surgical complications • Future directions and advances **Chemotherapy** • Principles and classification of chemotherapeutics. • Pharmacology of antineoplastic drugs -Mechanism of action, Absorption, protein binding, Biotrans-formation, excretion common side effects, drug Toxicity. • Calculating drug doses, • Therapeutic response to chemotheraphy-Tumor variables, drug resistance, • Safety precautions **Radiation Therapy** • Physics of radiotherapy • Types of ionizing rays • Radiation equipments : Linear accelerator, cobalt, Implants, Isotopes. • Types of therapies: Oral, Brachytherapy, tele-therapy, selection Therapy.

Unit	Time Hours		Content
	T	P	
			• Effects of radiation on the body Tissue. • Radiation biology-cell damage hypoxic cells, alteration of tumor Kinetics. • Approaches to radiation therapy • External radiotherapy • Internal radiotherapy-unsealed, • Sealed sources. • Effectiveness of radiotherapy-Radiosensitivity, treatment effects • Complications of radiotherapy • Radiation safety : Standards of Bhaba Atomic Research Centre (BARC) **Bone Marrow Transplantation/Stem Cell Transplantation** • Types, indications, t transplantation Procedure and complications. • Types and donor sources • Preparation and care of donor and recipient • Legal and ethical issues **Immunotherapy (Biotherapy)** • Concepts and principles • Classifications of agents • Treatment and applications **Gene Therapy** • Current Concepts and practices **Alternative and Complementary Therapies** • Current practices

Unit	Time Hours		Content
	T	P	
VII	**10**	**4**	**Pain management : Theories, types and** • Nature of cancer pain • Pathophysiology of pain • Pain threshold **Assessment of pain** • Principles of cancer pain control • Pharmacological: Opioid and nonopioid analgesic therapy • Patient controlled analgesia (PCA) • Other invasive techniques of pain control • Recent developments in Cancer pain **Non-Pharmacological pain relief technique.** • Complementary therapies (Music, massage, meditation, relaxation techniques, biofeed back etc) • Psychological intervention in pain control • Alternative system of medicines Role of nurse
VIII	5		**Palliative care** • Definition an scope, philosophy • Concept and elements of palliative care • Global and Indian perspective of palliative care • Quality of life issues • Communication skill • Nursing perspective of palliative care and its elements • Home care • Hospice care Role of nurse in palliative care

Unit	Time Hours		Learning Objectives	Content	Method of Teaching	Evaluation
	T	P				
IX	**2**		Recognize the process of infection and preventive methods	**Infection control** • Process of infection, risk of hospitalization, nosocomial infections-prevention and control of in acute, long term care facility and community based care • Standard safety measure	Seminar Presentation	Essay type questions
X	30		Describe the care of patients with various type of malignancies.	**Nursing Care of Patients With Specific Malignant Disorders** • Malignancies of G.I. system-oral, oesophagus, stomach, rectal, liver & pancreas, care of ostomies/stoma • Respiratory malignancies • Genito urinary system malignancies prostate Bladder, renal testicular malignancies. • Gynecological malignancies-cervix uterus, ovary. • Hematological malignancies-Lymphomas, Leukemias. • Malignancies of musculoskeletal system • Endocrine malignancies • Skin • Head and Neck – brain tumors • Other malignancies – Breast cancer	Clinical presentation Nursing Process Nursing rounds Case conference	Evaluation of case study, care plan
XI	**10**		Provide nursing care to paediatric group of patients	**Paediatric malignancies** • Leukemia, Lymphoma, Neuro blastoma • Wilm's tumor, Soft tissue sarcoma, Retinoblastoma • Nursing Management of children with Paediatric Malignancies	Clinical presentation Nursing Rounds	Assess the skill with evaluation nursing care plan

Unit	Time Hours		Learning Objectives	Content	Method of Teaching	Evaluation
	T	P				
XII	**15**		Recognize the clinical manifestations of cancer patients	**Nursing Management of Physiological Conditions and Symptoms Of Cancer Patient** • Nutrition – effects of cancer on nutritional status and its consequences: Anemia, Cachexia, Xerostomia, mucositis, Dysphagia, Nausea and vomiting, constipation, Diarrhea, electrolyte imbalances, Taste alterations. • Impaired mobility: Decubitus ulcer, pathologic fractures, thrombophlebitis, pulmonary embolism, contractures, footdrop **Other symptoms** • Dyspepsia & hiccup, dyspnoea • Intestinal obstruction • Fungating wounds • Anxiety & depression, insomnia • Lymph edema **Impact of cancer on sexuality** • Effects of radiotherapy/ chemotherapy/surgery on sexuality of the cancer patient • Nursing management of cancer patients experiencing sexual dysfunction • Sexual counseling	Clinical presentation Ward Teaching Nursing Process Guided Group Discussion	Evaluate care plan case study
XIII	**10**			**Cancer Emergencies** • Disseminated intravascular Coagulation (DIC). • Malignant pleural effusion • Neoplastic cardiac tamponade and septic shock spinal cord compression • Superior venacava syndrome		

Unit	Time Hours		Learning Objectives	Content	Method of Teaching	Evaluation
	T	P				
			Appreciate the role of the nurse in cancer emergencies	• Metabolic emergency: hyper and hypo calcemia • Surgical emergency • Urological emergency • Haemorrhage • Organ obstruction • Brain metastasis • Nurses role in managing oncologic emergencies	Lecture Cum Discussion Seminar Presentation	Short Answers
XIV	**8**		Describe the psychosocial aspects of nursing care Explains the ethical, moral and legal issues in caring for the cancer patients	**Psycho-Social Aspects of Nursing Care** • Psychological responses of patients with cancer • Psychosocial assessment • Crisis intervention, coping mechanisms • Stress management, spiritual/ Cultural care and needs. • Counseling: individual and family • Maximizing quality of life of patient and family **Ethical, moral and legal issues** • Care of dying patient • Grief and grieving process • Bereavement support • Care of Nurses who care for the dying	Guided Group Discussion Conducting Guidance and Counseling Group Conference	Short answers checklist
XV	**2**		Design a layout and develop standards for management of Oncology units/hospitals and nursing care	**Layout and Design of an oncology institution/ward, OPD, chemotherapy unit, Bone marrow trans-plantation unit, pain clinic etc.** • Practice Standards of oncology nursing Policies and Procedures • Establishing Sanding orders and Protocols **Quality Assurance Programme in Oncology units** • Nursing audit	Field Trip Presentation of Observation Report	Evaluate the project work and presentation

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26. Yarbro/Frogge/Goodman – Cancer Nursing: Principles and Practice (6thed.)
27. American Cancer Society – A Cancer Source Book for Nurses (8th ed.)
28. Yarbro/ Frogge/ Goodman – Cancer Symptom Management, Patient Self-Care Guides (2)
29. Yarbro/Frogge/Goodman – A Clinical Guide to Cancer Nursing (5th ed)
30. Hassey Dow – Contemporary issues in Breast Cancer, A Nursing Perspective (2nd ed.)
31. Vogel/Bevers – Handbook of Breast Cancer Risk assessment: Evidence based Guidelines for Evaluation, Prevention Counseling & Treatment
32. Johnson/Gross – Handbook of Oncology Nursing (3rd ed) King/ Hinds Quality of Life: From Nursing and Patient Perspectives
33. Brunner/ Siddarth – Text Book of Medical Surgical Nursing. 2004 (10th ed.)
34. Sorresen /Luckman – Medical Surgical Nursing (1994) (5th ed)

Journals:

1 Oncology nursing news letter.

PRACTICALS

1. Clinical practice in the care of patients with various malignant disorders.
2. Assessment of clients suffering with various malignant disorders.
3. Applying Theories and nursing process in the management of patients suffering with various malignancies.
4. Providing care to patients with ostomies and other appliances.
5. Assisting for implantations of radioisotopes.
6. Clinical case presentations of a patient.
7. Projects
8. Clinical and classroom teachings.
9. Health education on related disease conditions.
10. Field Visits Regional cancer centers/ cancer specialty hospitals /unit, Hospice, mobile palliative care, community oncology centers /home care unit, cancer registry, cancer detection centers etc.

Procedures Observed

1. **CT Scan**
2. **MRI**
3. **Ultra sound**
4. **Mammography**
5. **Radio Nuclide Imaging**
6. **Bone Scan**
7. **Thyroid Function Test**
8. **Functional and Metabolic Imaging**
9. **Transportation of radioactive materials**
10. **Others**

Procedures Assisted

1 **IV cannulation –Open method**
2 **Chemotherapy**
3 **Radiotherapy – Brachytherapy – Low Density Radiation, High Density Radiation.**
4 **Interstitial implantation**
5 **Teletherapy – Treatment planning**
6 **Bone marrow aspiration and biopsy**
7 **Biopsy – tissue**
8 **FNAC – Fine Needle Aspiration Cytology & Biopsy**
9 **Advance cardiac life support**
10 **Endotracheal intubation**
11 **Defilbrillation ventilation**
12 **Tracheostomy**
13 **Thoracentesis**
14 **Paracentesis**
15 **Lumbar Puncture**
16 **Arterial Blood Gas**
17 **Nerve Block**
18 **Chest tube insertion**
19 **Intercostal drainage**
20 **CVP monitoring**

Procedure Performed

1. **Screening for cancer**
2. **Assessment of pain**
3. **Assessment of Nutritional status**
4. **Care of Tracheostomy**
5. **Endotracheal intubation**
6. **Gastric gavage**
7. **Pap smear**
8. **IV cannulation**
9. **Care of surgical flaps**
10. **Care of ostomies**
11. **Blood transfusion and component therapy**
12. **Counseling**
13. **Practice standard safety measure**
14. **Care of dead body and mortuary formalities**

Other procedures

1. **Alternative therapies**

Clinical Experience

SN	Department/Unit	No. of Week	Total Hours
1	Medical Oncology Ward	6	180
2	Surgical Oncology Ward	6	180
3	Bone marrow transplantation	2	60
4	Operation Theatre	2	60
5	Radiotherapy Unit	2	60
6	Chemotherapy Unit	4	120
7	Out patient department and pain clinic	2	60
8	Pediatric Oncology Ward	2	60
9	Palliative Care Ward	2	60
10	Community Oncology	2	60
11	Hospice	1	30
12	Other field visits	1	30
	Total	32	960

GUIDELINES TO WRITE CLINICAL PRESENTATION – MSc NURSING

1. Introduction
2. Patient's Profile
3. Health History
   a. Chief complaints on admission
   b. Present & Past illness (Medical surgical, Obstetrics, pediatric, psychiatric, Oncology)
   c. Family History
   d. Specific information of the patient
4. Health Assessment
   a. Physical examination (head to foot & system assessment)
   b. Investigation
   c. Health information from other sources
5. Provisional Medical diagnosis
6. Treatment
7. Correlation of clinical and book picture
   a. Definition
   b. Clinical features
   c. Prognosis
   d. Etiology
   e. Investigation
   f. Complication
   g. Pathophysiology
   h. Treatment
8. Nursing Management – Nursing process
9. Plan of discharge & rehabilitation
10. Conclusion
11. Bibliography

Practical Experience Assignments

Case study	:	02	(50 marks each)	50 x 2 =	100
Case Presentation	:	02	(50 marks each)	50 x 2 =	100
Care Plan	:	03	(50 marks each)	50 x 3 =	150
Clinical Performance	Evaluation:	03	(100 marks each)	100 x 3 =	300
Practical Examination			Mid Term		50
			Pre Term		100
					800

Internal Assessment Total marks out of 100
External Assessment Total marks out of 100

(Theory)

Midterm Exam	**50**
Prefinal Exam	**75**
Seminar	**50**
Project work on planning oncology unit	**75**
	800

M.Sc. **NURSING :** CLINICAL SPECIALITY – II

PROFORMA & GUIDELINE FOR CASE STUDY
Area :- (Maximum Marks – 50)

01. Selection of patient.
02. Demographic data of the patient.
03. Medical history past and present illness.
04. Comparison of the patient's disease with book picture.
    a) Anatomy and physiology.
    b) Etiology.
    c) Patho physiology.
    d) Signs and symptoms.
    e) Diagnosis - provisional & final
    f) Investigations
    g) Complications & prognosis.
05. Management:- Medical or Surgical
    a) Aims and objectives.
    b) Drugs and Medications.
    c) Diet.
06. Nursing Management (Nursing Process approach)
    a) Aims and objectives.
    b) Assessment and specific observations.
    c) Nursing diagnosis.
    d) Nursing care plan (Short term & long term with rationale.)
    e) Implementation of nursing care with priority.
    f) Health teaching.
    g) Day to day progress report & evaluation.
    h) Discharge planning.
07. Drug Study.
08. Research evidence.
09. Summary and conclusion.
10. Bibliography.

EVALUATION CRITERIA FOR CASE STUDY.

(Maximum Marks – 50)

SN	Criteria	Marks allotted.	Marks obtained	Total
01.	Assessment	5		
02.	theoretical knowledge about disease	5		
03.	Comparative study of the patient's disease & book picture.	10		
04.	Management: Medical or Surgical.	5		
05.	Nursing Process.	15		
06.	Drug study.	3		
07.	Summary & conclusion including research evidence.	5		
08.	Bibliography.	2		
	Total	50		

Signature of Student   Signature of Clinical supervisor

M Sc NURSING: CLINICAL SPECIALITY – II
PROFORMA & GUIDELINE FOR CASE PRESENTATION

I] Patient Biodata

Name, Age, Sex, Religion, Marital status, Occupation, Source of health care, Date of admission, Provisional Diagnosis, Date of surgery if any.

II] Presenting complaints

Describe the complaints with which the child has been brought to the hospital

III] Socio-economic status of the family: Monthly income, expenditure on health, food, education etc.

IV] History of Illness (Medical & Surgical)

i) History of present illness – onset, symptoms, duration, precipitating / aggravating factors
ii) History of past illness surgery, allergies, medications etc.
iii) Family history – Family tree, history of illness in the family members, risk factors, congenital problems, psychological problems etc.

V] Diagnosis: (Provisional & confirmed).

Description of disease: Includes the followings

1. Definition.
2. Related anatomy and physiology
3. Etiology & risk factors
4. Path physiology
5. Clinical features.

VI] Physical Examination of Patient (Date & Time)

Physical examination: with date and time.

Clinical features present in the book Present in the patient

VII] Investigations

Date Investigation done Results Normal value Inferences

VIII] Management - (Medical /Surgical)

a) Aims of management
b) Objectives of Nursing Care Plan

IX] Treatment:

S.No Drug (Pharmacological name) Dose Frequency/ Time Action Side effects & drug reaction
Nurse's
responsibility

- Medical or Surgical Management.
- Nursing management

X] Nursing Care Plan: Short Term & Long Term plan.

Assessment Nursing
Diagnosis
Objective Plan of
care
Rationale Implementation Evaluation

XI] Discharge planning:

It should include health education and discharge planning given to the patient.

XII] Prognosis of the patient:

XIII] Summary of the case:

IVX] References:

EVALUATION CRITERIA FOR CASE PRESENTATION

Maximum Marks – 50)

SN	Criteria	Marks Allotted	Marks Obtained	Total
1	Content Subjective & objective data.	08		
2	Problems & need Identified & Nsg. Care Plan	15		
3	Effectiveness of presentation	5		
4	Co-relation with patient & Book i. e. research evidence.	10		
5	Use of A. V. Aids	5		
6	Physical arrangement	2		
7	Group participation	3		
8	Bibliography & references	2		
	Total	50		

CLINICAL EVALUATION: COMPREHENSIVE NURSING CARE

(Maximum Marks – 100 each area.)

Name of the Student

Year: II Year M.Sc Nursing   Duration of Experience:

SN	Criteria	1	2	3	4	5
I	UNDERSTANDING OF PATIENT AS PERSON **A. Approach.** 1. Rapport with patient/ family members. 2. Collects significant information. **B. Understanding of patient's health problems.** 1. Knowledge about disease condition. 2. Knowledge about investigations. 3. Knowledge about treatment. 4. Knowledge about progress of the patient.					
II	NURSING CARE PLAN **A. Assessment of the condition of the patient.** 1. History taking – past & present health and illness. 2. Specific observation of the patient. 3. Nursing diagnosis. **B. Development of the short – term & long term Nursing care plans.** 1. Identification of all problems in the patient/ family. 2. Prioritization & implementation of the plans. 3. Evaluation of the care given & replanning					
III	TECHNICAL SKILL 1.Economical & safe adaptation to the situation & available facilities. 2.Implements the procedure with skill speed & completeness.					
IV	RECORDING & REPORTING 1.Prompt, precise, accurate & relevant. 2.Maintenance of clinical experience file.					
V	HEALTH TEACHING 1.Incidental/ planned teaching with principles of teaching & learning. 2.Uses visual aids appropriately					
VI	PERSONALITY 1. Professional appearance (uniform, dignity, tact fullness interpersonal relationship, punctuality etc. 2. Sincerely, honesty & Sense of responsibility.					
	TOTAL MARKS					

Positive & Negative aspects.

Signature of Student   **Signature of Clinical supervisor**

BACK TO MAIN

Homi Bhabha National Institute (HBNI)
Post Graduate Diploma in Fusion Imaging Technology (PGDFIT)
(PROGRAM CODE: HLTH16)

Syllabus

The **Post Graduate Diploma in Fusion Imaging Technology (PGDFIT)** courses shall have 1 years course. The number of theory papers and practical courses, along with their marking system, are described below. It is necessary to secure minimum 45% pass marks separately in each theory paper and practical courses in each year. It is also necessary to secure minimum 50% marks in aggregate each year to pass.

Code	**Broad topics**	**Details**	**Contact Hours per week**	**Total contact hours (Duration of course 1 year)**	**Hours of workload (Duration of course 1 year)**	**No. of credits**
Paper 1: Basic Sciences in Nuclear Medicine						
09-HLTHI6-001-C	**Basic physics in nuclear medicine**	Atomic structure Radioactivity and radioactive decay and X-rays Electricity, Electromagnetism and Electronics	1 hrs. of class room teaching	22-25	80-90	3
09-HLTHI6-002-C	**Basic chemistry in nuclear medicine**	Periodic table Chemical element, compound & chemical bonding Chemical reaction	1 hrs. of class room teaching	22-25	80-90	3
09-HLTHI6-003-C	**Basic mathematics and statistics in nuclear medicine**	Quadratic Expressions Matrices Calculus Probability Random Variables and Distributions Compartmental analysis Counting statistic Statistical technique used in medical sciences	1 hrs. of class room teaching	22-25	80-90	3

09-HLTHI6-004-C	**Basic computer relevant in nuclear medicine**	Number system & Fundamentals of computer hardware Basics of computer operating system Basics of software programming Networking Computer in nuclear medicine Image formation Hardware and software fusion	1 hrs. of class room teaching	22-25	80-90	3
09-HLTHI6-005-C	**Basic biology in nuclear medicine**	Structure of Cell DNA, RNA and Protein Enzymes Vitamins Cell cycle Tissue, organ and organ system Immunology	1 hrs. of class room teaching	22-25	80-90	3
Paper 2: Radiation Safety, Radiation biology and Radiopharmacy						
09-HLTHI6-006-C	**Radiation Biology**	Radiation Quantities and Units Interaction of Radiation with Matter Biological Effects of Radiation Operational Limits Radiation Detection & Measurement Radiation Hazard Evaluation and Control Radiation Dosimetry	1 hrs. of class room teaching	22-25	80-90	3
09-HLTHI6-007-C	**Radiation protection**	Regulatory Aspects for Nuclear Medicine Laboratories Planning of Nuclear Medicine (NM) Laboratories Transport of Radioactive Material Quality Control for Nuclear Medicine Equipments	1 hrs. of class room teaching	22-25	80-90	3

		Radionuclide Therapy- Radiation Safety Aspects Radiation Hazard Evaluation and Control Emergency Response Plans and Preparedness Radiation Accidents, Case Studies, Lessons Learn Disposal of Radioactive Waste	1 hrs. of class room teaching	22-25	80-90	3
09-HLTHI6-008-C	**Radio pharmacy and radiopharmaceuticals**	**Radio-pharmacy:** good manufacturing practices (GMP) used in hospital radio-pharmacy and cold kit preparation. **Quality Assurance** program in Hospital radio-pharmacy **QC Equipment:** equipments used for Quality control of Radiopharmaceuticals i.e. TLD, HPLC etc. **Radionuclides:** Characteristics of Radio nuclides used in diagnostic and therapeutic nuclear medicine	1 hrs. of class room teaching	22-25	80-90	3
		Production of radionuclide : Reactor produced radionuclide pharmaceutical and cyclotron produced radionuclide **Conventional radio pharmacy:** formulation and quality control of SPECT radiopharmaceuticals **PET radio pharmacy:** formulation and quality control of PET radiopharmaceuticals **Intervention drugs:** used in nuclear medicine **Emergency drugs:** used in nuclear medicine	1 hrs. of class room teaching	22-25	80-90	3

Paper 3: Instrumentation in Nuclear Medicine and Fusion Imaging						
09-HLTHI6-009-C	**Non imaging equipment used in Nuclear medicine**	**Detectors used in nuclear medicine** equipments i.e. gas filled detectors, scintillation detectors, solid state detectors and TLDs. **Detector systems** **Ion Chamber based equipments** used in nuclear medicine i.e. Dose calibrator, Pocket dosimeters, survey meter etc. **Proportional counters**: neutron survey meter **GM tube based equipments:** Survey meter, contamination monitors etc. **Scintillation detector based equipments:** Gamma ray spectrometry and spectrometers, Thyroid uptake probe, liquid scintillation counters etc. **Quality Control** of non imaging equipment Nuclear medicine instrument	1 hrs. of class room teaching	30-32	100-120	4
09-HLTHI6-010-C	**Imaging equipment used in Nuclear Medicine**	**Basics** of detector systems used in imaging. **Instrumentation of Imaging equipments used:** Single Photon Emission Computed Tomography (SPECT) Positron Emission Tomography (PET) Computed Tomography (CT) Magnetic Resonance Imaging (MRI) **Fused Equipments:** SPECT/CT, PET/CT, PET/MRI	1 hrs. of class room teaching	30-32	100-120	4
09-HLTHI6-011-C	**Calibration and Quality Control Of Imaging**	**Calibration and Quality control:** **SPECT :** Calibration and QC	1 hrs. of class room	30-32	100-120	4

	Equipments Used In Nuclear Medicine	of SPECT system **PET:** Calibration and QC of PET system **CT:** Calibration and QC of CT system **MR:** Calibration and QC of MRI system	teaching			
09-HLTHI6-012-C	**Computer and Computer system used in Nuclear Medicine**	**Acquisition system** used in Nuclear medicine **Multi Modality work station:** details of various image processing software **Basics and Architectures of** Picture Archiving and Communication System (PACS), Hospital Informatics system (HIS), Radiology Informatics system (RIS), Electronic Medical Records (EMR)	1 hrs. of class room teaching	22-25	80-90	3
Paper 4: Clinical Nuclear Medicine and Fusion Technology						
09-HLTHI6-013-C	**Human anatomy and physiology relevant in nuclear medicine**	Basic concept of anatomy and physiology Musculoskeletal system Cardiovascular system Lymphatic system Respiratory system Gastrointestinal system Hepatobiliary system Genitourinary system Nervous system Endocrine system Receptor systems	1 hr. of class room teaching	30-32	100-120	4
09-HLTHI6-014-C	**Scintigraphy Study and data processing**	Musculoskeletal system Cardiovascular system Introduction ECG study Lymphatic system Respiratory system Gastrointestinal system Hepatobiliary system Genitourinary system Nervous system Endocrine system	1 hr. of class room teaching	30-32	100-120	4

		Hematology Receptor systems Positron Emission Tomography Computer Tomography Imaging MRI Imaging Therapeutic Nuclear Medicine				
09-HLTHI6-015-C	**Therapeutic Nuclear Medicine technique**	I-131 high dose Therapy I-131 MIBG Therapy Bone Pain Palliation Therapy Somatostatin Receptor Therapy (Lu-177- DOTATOC) Lu-177-PSMA Therapy Trans arterial radioembolization (TARE) (Y-90 microsphere/ I-131-Lepiodol / Re 188-Lepiodo therapy) Radiation Synovectomy	1 hr. of class room teaching	30-32	100-120	4
09-HLTHI6-016-C	**Hospital administration and patient care**	Hospital administration and ethics Departmental procedure Patient Care First aid and Cardio Pulmonary Resuscitation (CPR)	1 hr. of class room teaching	15-18	50-60	2
Practical						
09-HLTHI6-001-P	**Practical in radiation protection, radiopharmacy and instrumentation in Nuclear medicine**	**Radiation Safety** Radiation Exposure – effect of time, distance and Shielding Radiation Survey Decontamination procedure Disposal of Radioactive waste **QC of Non Imaging Equipment** Gamma Ray Spectrometry Operating characteristic (Plateau) of G.M. Counter Dead time of G.M. Counter HVL of aluminum for different isotope and back scatter Identification of half life from a mixture of radionuclide Efficiency of well counter	1 hr. of class room teaching	45-50	80-90	3

		Identification of unknown radionuclide Isoresponse curve of flat field collimators Isotope calibrator / Well counter QC **QC of Imaging Equipment** **SPECT/CT**(Uniformity, Linearity, Spatial Resolution, Energy Resolution, Centre of Rotation, Sensitivity, Detector Shielding, Count Rate Performance, QC of CT- uniformity, contrast test, Registration- SPECT-CT) **QC for PET** (Coincidence timing test, Energy resolution, System correction- normalization, Calibration & Blank Scan) **Radiopharmacy procedures** – Elution of generator QC of eluate Determination of 99Mo breakthrough in 99mTc eluate Chemical tests, Radiochemical test Formulation of Tc-99m compounds from kit and quality control				
09-HLTHI6-002-P	**Practical in clinical Nuclear Medicine and Fusion Technology**	Perfusion/Ventilation quantitation Bone scan, whole-body, planar Bone scan, 3-phase Lymphoscintigraphy/sentinel lymph node localization Tumor imaging, PET Tagged WBC imaging Antibody imaging Renal/Genitourinary Cystogram, direct Effective renal plasma flow (ERPF) Glomerular filtration rate (GFR) Renal anatomy, SPECT Renogram Parathyroid Imaging	1 hr. of class room teaching	45-50	80-90	3

		Thyroid imaging, Thyroid uptake Myocardial perfusion, gated SPECT Gated cardiac blood pool, Esophageal motility/transit Gastric emptying (liquid/solid) Gastroesophageal reflux Gastrointestinal bleeding Hepatobiliary Gall bladder ejection fraction Meckel's diverticulum Brain imaging, SPECT Radionuclide Therapy Thyroid carcinoma Hyperthyroidism Metastatic bone pain Monoclonal antibody therapy TARE				
				527-585 Hrs	**1800-1950 Hrs**	**65 Credit**

BACK TO MAIN

M.Sc. CLINICAL RESEARCH (PROGRAM CODE: HLTH17)

2 year course + 1 year internship

- 1.5 years of teaching: to be tentatively divided into 6 modules (approximately 3 months each). Each module to consist of 10 to 12 teaching sessions and 1 or 2 tests
- Teaching sessions on Wednesdays / Saturdays
- Supervised training on remaining days
- 6 months of project work: this will include 960 hours of field work (5 days a week for 6 months) – one month of this will be spent on epidemiological studies
- 1 year of internship (post-degree): this will include 2 months of epidemiological work

Total: 50 credit hours

INTRODUCTION	
Introduction to the course	1 session
MODULE – 1 (13 SESSIONS)	**10 credit hours**
09-HLTH17-001-C: BASICS OF PHARMACY, DRUG DISCOVERY AND DEVELOPMENT	
• Process of drug development and narrowing down to few molecules • Pre-clinical testing • Phases of trials • Basic principles – Bioavailability, Bioequivalence, Pharmacokinetics	2 sessions
09-HLTH17-002-C: ETHICS	
Ethics Part A (Regulations) • History of Ethics and Evolution of Laws • Declaration of Helsinki • Good Clinical Practice – ICH, Indian GCP, ICMR guidelines, Schedule Y • Brief overview of US-FDA and EMEA	1 session 3 Sessions 1 Session
Ethics Part B (Informed consent) • Informed consent process • Informed consent form	2 Sessions
Presentation by students	1 Session
Recap / Q&A	1 Session
Test	1 Session
Feedback	1 Session
MODULE – 2 (12 SESSIONS)	10 credit hours
09-HLTH17-003-C: CLINICAL TRIAL DESIGN	

• Phases of trials - Review
• Clinical trials
  ○ Study design
  ○ Randomization
	1 Session
	2 Sessions

○ Blinding ○ Placebo ○ *To cover breaking of blind, simultaneous use of blinded and unblinded groups* ○ Basic statistics • Elements of a protocol ○ *To cover protocol violation and deviation*	 2 Sessions 3 Sessions
• Presentation – preparing a protocol	1 Session
• Presentation by students	1 Session
• **Test**	1 Session
• **Feedback**	1 Session
MODULE – 3 (12 SESSIONS)	10 credit hours
09-HLTH17-004-C: CLINICAL TRIALS IN PRACTICE – PART 1	
Roles and Responsibilities • IRB (Ethics committee) ○ *To cover compensation policy* • Investigator • Sponsor • CRA/CRC/Monitor	 1 Session 1 Session 1 Session 1 Session
• **Test**	1 Session
• **Feedback**	1 Session
Safety Reporting • Adverse event / SAE reporting • Data Monitoring and Interim Analysis	 2 Sessions 1 Session
• **Quiz and case scenarios**	1 Session
• **Test**	1 Session
• **Feedback**	1 Session
MODULE – 4 (10 SESSIONS)	8 credit hours
09-HLTH17-005-C: CLINICAL TRIALS IN PRACTICE – PART 2	
Quality control and Quality Assessment • Overview • Essential documents • Study files • Source documentation • Monitoring • Audits and Inspections including preparation • Training records • Standard Operating Procedures • CAPA	 1 Session 1 Session 1 Session 1 Session 1 Session

Recap/presentation by students	2 Sessions
Investigational Product Management • Storage • Temperature • Accountability • Destruction	1 Session
• **Test**	1 Session
• **Feedback**	1 Session
MODULE – 5 (12 SESSIONS)	10 credit hours
09-HLTH17-006-C: CLINICAL TRIALS IN PRACTICE – PART 3	
Data Management • Methods of Data Collection • CRF design and types	4 Sessions 2 Sessions 1 Session
Group project presentation	1 Session
Project Management • Putting it all together – including laboratory management, investigations, processes, recruitment potential, patient recruitment and retention	3 Sessions
• **Test**	1 Session
MODULE – 6 (4 SESSIONS)	2 credit hours
09-HLTH17-007-C: EPIDEMIOLOGICAL STUDIES	
• Basic concepts • Surveillance systems to understand disease burden • Design and planning of Epidemiological studies including field intervention trial • Quality control and good Epidemiological practices • Epidemiology field work in Population Based studies • Ethical aspects of Epidemiological research	3 Sessions
• **Test**	1 Session
SPECIAL MODULE (OTHER TOPICS)	
09-HLTH17-008-C: Medical writing **09-HLTH17-009-C:** Communication **09-HLTH17-0010-C:** Clinical etiquette and Office Practice **09-HLTH17-0011-C:** Investigator-initiated studies – special issues **09-HLTH17-0012-C:** Studies in alternative systems – Ayurveda, Homeopathy	1 Session 1 Session 2 Sessions 1 Session 1 Session

FINAL EVALUATION (3 SESSIONS)	
• Overall recap / Final Q and A	1 Session
• Examination – written and viva	2 Sessions

BACK TO MAIN

GOVERNMENT OF INDIA

BHABHA ATOMIC RESEARCH CENTRE

INTEGRATED Ph.D. (SINGLE DEGREE) ENGINEERING SCIENCE

(PROGRAM CODE: ENGG18)

SYLLABUS

Orientaion Course for Engineering Graduates and Science Post Graduates (OCES)

BARC Training School, Mumbai

HUMAN RESOURCE DEVELOPMENT DIVISION

MUMBAI 400085

PREFACE

The Department of Atomic Energy (DAE) has the multi pronged mandate of the utilisation of the power of the atom towards generation of power, development of advanced technologies, directed research in various scientific and engineering disciplines, production of radioisotopes for societal applications in medicine and agriculture and towards national security. In order to become self reliant and self sustaining in this high technology area, the need for generating highly skilled manpower and ensuring its continuous availability was indispensable. Thus in 1957, the BARC Training School (BARCTS) was established as a centre for in house training of professionals. These professionals today form the backbone of the Nuclear Power Programme. More than 9000 trainees have graduated from BARC TS over the last 61 years and provide the technological leadership in DAE for all its important programmes. Over the last five and a half decades, the BARCTS has grown into a model institute, recognised internationally as a school of excellence.

The academic activities of BARCTS are carried out by the Human Resource Development Division (HRDD) from its campus situated at Anushakti Nagar, well away from the hustle and bustle of Mumbai, nestling between wooded hills and sylvan surroundings, close to the BARC premises. This crucible of learning has been a focus of attraction to many a bright young talent, eager and willing to learn, guided and mentored by an academia drawn from the pool of experts available within DAE. Hailing from some of the best universities in India, they are nurtured with care and concern, by means of a holistic approach to training and personality development. A judicious mix of academics, practical training and soft skills training is imparted at the Training School and at the state of the art laboratories of BARC. A well equipped hostel with sports, recreation, and internet facilities provides the right environment needed for wholesome development. The lure of a professionally challenging career with opportunities for upgradation of skills, an objective merit recognition based career growth pattern and attractive compensation packages have attracted the best talents to BARCTS.

The BARCTS has two principle programmes, the One-Year **Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)** and the **DAE Graduate Fellowship Scheme (DGFS)**

Orientation Course for Engineering Graduates and Science Post-Graduates (OCES)

OCES is the flagship programme of the BARC Training School and its affiliates. Under this scheme, engineering graduates from eight engineering disciplines- Mechanical, Chemical, Metallurgy, Civil, Electrical, Electronics, Instrumentation & Computer Science and Science Post-Graduates from Physics, Chemistry & Biological Sciences are selected and imparted a

rigorous one year training in the field of Nuclear Science and Technology. In addition to the above 11 disciplines, selected post graduate candidates from the Physics and Chemistry disciplines are also inducted into a course specifically designed for the purpose of providing a holistic training in all aspects of radiological safety. This course has been named as "Radiological Safety Engineering' course.

The curriculum provides multidisciplinary training in topics relevant to the nuclear industry, frontier areas of science and technology and some super specialized areas. Training is imparted by adjunct faculty comprising the scientists and engineers working in various projects of DAE. In this manner, not only the objective of training but also the greater task of seamless and effective knowledge transfer from the expert to the acolyte is carried out successfully. The scheme also ensures the retention of the trained manpower within the Department thereby maximising the benefits of the training programme to the Department.

A total of about 150 courses in the above disciplines comprising more than 4000 lectures are delivered by more than 500 adjunct faculty members from BARC and other educational institutes during this period.

OCES Training Objectives: It involves one year of academic and training programme at the BARC Training School. The training programme aims to ensure that the selected candidates are provided with the necessary facilities and opportunities to acquire knowledge and develop skills for meeting the challenging technological goals of the country in the field of nuclear S&T. The training courses are organized in a structured manner as detailed below

- Foundation courses impart multidisciplinary training in the topics relevant to the nuclear industry.
- Core courses bring all selected candidates from different universities to the same or common level of understanding in the core subjects of the respective disciplines.
- Elective courses impart training in few specialized areas in respective disciplines.

OCES graduates are also eligible for the award of Post Graduate Diploma in Nuclear Science/Engineering & Technology of HBNI. After joining the DAE, the eligible OCES graduates can undertake one year project work leading to the award of M.Tech./M.Phil. Degree of the HBNI.

DAE Graduate Fellowship Scheme (DGFS)

In order to meet the requirement of highly specialised professionals in specific areas, DAE initiated the DGFS Programme for inducting engineers at MTech level in collaboration with the six IITs viz. Bombay, Delhi, Kanpur, Kharagpur, Madras, Roorkee and BHU in addition to some other elite institutes such as NIT Rourkela and ICT, Mumbai. The scheme strengthens the research-education linkage with premier institutes of the country in the areas of interest to DAE and provides useful synergy between the nuclear sector and the academia

Under this scheme, trainees selected for the OCES programme as well as one of the above institutes pursue the M.Tech degree under the sponsorship of DAE. On completion of the MTech degree, the candidates are absorbed into DAE as a Scientific Officer with advance increments. These Fellows then undergo a 4-month Orientation Course for DGFS Fellows (OCDF) after successful completion of M.Tech.

Orientation Course for DGFS Fellows (OCDF)

Several topics of interest to the Department do not form part of the MTech curriculum. To provide an exposure to such topics, the DGFS Fellows undertake a four months orientation course in the BARC Training School **(Orientation Course for DGFS Fellows- OCDF)** after successful completion of their MTech. Programme.

This document furnishes the course structures of all disciplines and syllabi of the courses conducted by the BARC Training School under each discipline.

CONTENTS

SYLLABUS

ENGINEERING SCIENCES

Annexure-I

REVISED CREDITS
FOR
COURSES IN ENGINEERING
SCIENCES

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (MECHANICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for PVP	EN610	60	6	250
2	Computational fluid Dynamics and Heat Transfer	EN611	50	6	200
3	Finite Element Method	EN621	30	4	125
4	Fracture Mechanics	EN622	40	4	150
5	Mechanics of Solids	EN624	40	4	150
		Core Total	**220**	**24**	**875**

ELECTIVES (MECHANICAL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Machine Design	EN711	25	2	100
4	Material Science in Nuclear Engineering	EN712	25	2	100
5	Multi-scale material modelling	EN715	30	4	125
6	Nuclear Emergencies	EN716	35	4	150
7	Reliability Engineering	EN718	25	2	100
8	Vibration	EN721	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - CHEMICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CHEMICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25	2	100
2	Advanced Mass Transfer	EN604	25	2	100
3	Code design for PVP	EN610	30	4	125
4	Computational Fluid Dynamics and Heat Transfer	EN611	50	6	200
5	Nuclear Chemical Engineering	EN628	35	4	150
6	Process Dynamics and Control	EN634	45	6	200
7	Process Modeling, Simulation and Optimization	EN635	45	6	200
	CORE TOTAL		**225**	**30**	**950**

ELECTIVES (CHEMICAL) – Any 3 Courses - 9 CREDITS

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Fluid Power Technology	EN709	25	2	100
3	Material Science in Nuclear Engineering	EN712	20	2	75
4	Membrane Technology	EN714	35	4	150
	ELECTIVES TOTAL (APPROX)		**90**	**8-10**	**350**

	THEORY TOTAL	**535**	**62-64**	**2175**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 535; Total Credits: 106-108; Total Marks: 2775

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - METALLURGY

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
		Foundation Total	**220**	**24**	**875**

CORE ENGINEERING (METALLURGY)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	2	75
2	Extractive Metallurgy	EN620	40	4	150
3	Mechanical Metallurgy	EN623	30	4	125
4	Nuclear Materials	EN628	50	6	200
5	Nuclear Metallurgy	EN629	30	4	125
6	Physical Metallurgy	EN630	40	4	150
7	Process Control & Instrumentation	EN631	25	2	100
		CORE TOTAL	**230**	**26**	**925**

ELECTIVES (METALLURGY) Any 3 Courses- 9 Credits

S.No.	Subject Title		Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	4	125
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Image processing and Machine Vision	EN710	30	4	125
4	Materials Characterization	EN713	20	2	75
5	Multi scale Material Modeling	EN715	30	4	125
6	Nuclear Chemical Engineering	EN628	35	4	150
7	Nuclear Emergencies	EN716	35	4	150
8	Welding Science & Technology	EN723	25	2	100
		ELECTIVES TOTAL (APPROX)	**90**	**8-12**	**350**

	THEORY TOTAL	**540**	**58-62**	**2150**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I& VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 540; Total Credits: 102-106; Total Marks: 2750

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Nuclear Fuel Cycle Technology	EN508	35	4	150
5	NPP & Advanced Reactor Concepts	EN509	40	4	150
6	Reactor Physics and Engineering	EN510	55	6	225
	Foundation Total		**220**	**24**	**875**

CORE ENGINEERING (CIVIL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1	30	4	125
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2	30	4	125
3	Design Basis Hazards & Geotechnical Engg	EN621	40	4	150
4	Earthquake Engineeing & Structural Dyanmics	EN609	45	6	200
5	Finite Element Method	EN626	30	4	125
6	Mechanics of Solids	EN624	40	4	150
	Core Total		**215**	**26**	**875**

ELECTIVES (CIVIL)- Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Struct Dynamics & Earthquake Engg	EN724	30	4	100
2	Construction Materials, Management & Quality	EN614	30	4	100
3	Safety & Reliability of Civil Engineering	EN722	25	2	100
4	Project Management	EN717	25	2	100
	ELECTIVES TOTAL (APPROX)		**80**	**8-10**	**300**

	THEORY TOTAL	**515**	**58-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 520; Total Credits: 102-104; Total Marks: 2600

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60

COURSE STRUCTURE - ELECTRICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECRICAL)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	20	2	75
2	Computer Based System Design I	EN612	25	2	100
3	Electrical Systems for Nuclear Power Plants	EN618	30	4	125
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**195**	**22**	**800**

ELECTIVES (ELECTRICAL) Any 3 Courses- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design II	EN702	25	2	100
2	Artificial Intelligence and its Applications	EN703	30	4	125
3	Computer Based System Design II	EN704	25	2	100
4	Digital Signal Processing & Image Processing	EN706	30	4	125
5	Image Processing & Machine Vision	EN710	30	4	125
6	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
7	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**525**	**54-60**	**2100**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-104; Total Marks: 2700

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60(through course work and two viva)

COURSE STRUCTURE - ELECTRONICS ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (ELECTRONICS)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	4	125
2	Advanced Nuclear Instrumentation	EN605	40	4	150
3	Embedded & Computer Based Sys. Design	EN619	45	6	200
4	Modern Control Systems Design and Simulation	EN625	35	4	150
5	Process Control & Instrumentation	EN633	30	4	125
6	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
7	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		**200**	**28**	**825**

ELECTIVES (ELECTRONICS) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Digital Signal Processing & Image Processing	EN706	30	4	125
3	Embedded Electronics Software	EN707	25	2	100
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**60-66**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 104-110; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (INSTRUMENTATION)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40	4	150
2	Computer Based System Design I	EN612	25	2	100
3	Modern Control Systems Design and Simulation	EN625	35	4	150
4	Reactor C&I and Human Machine Interface	EN636	40	4	150
5	Reactor Control Engineering and Instrumentation	EN637-8	35	4	150
6	Reliability Engineering	EN639	20	2	75
	CORE TOTAL		EN639	**20**	**775**

ELECTIVES (INSTRUMENTATION) Any 3 Courses-- 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	125
2	Computer Based System Design II	EN706	25	2	100
3	Digital Signal Processing & Image Processing	EN707	30	4	125
4	Image Processing & Machine Vision	EN710	30	4	125
5	Signal Conditioning, Recovery and EMI Aspects	EN719	25	2	100
6	Software Engineering	EN720	25	2	100
	ELECTIVES TOTAL (APPROX)		**90**	**8-12**	**350**

	THEORY TOTAL	**525**	**54-58**	**2075**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
	TOTAL		**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 525; Total Credits: 98-102; Total Marks: 2675

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40	4	150
2	Engineering Mathematics	EN502-505	30	4	125
3	Health Physics and Rad & Indl Safety	EN506	20	2	75
4	Material Science in Nuclear Engineering (EE)	EN508	20	2	75
5	Nuclear Fuel Cycle Technology	EN509	35	4	150
6	NPP & Advanced Reactor Concepts	EN510	40	4	150
7	Reactor Physics and Engineering	EN501	55	6	225
	FOUNDATION TOTAL		**240**	**26**	**950**

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25	2	100
2	Computer Graphics & Visualisation	EN613	35	4	150
3	Distributed Computing	EN616	45	6	200
4	Networking & Information Security	EN6627	40	4	150
5	Reactor Control Engineering	EN637	15	2	75
6	Software Engineering and Formal Methods	EN640	40	4	150
	CORE TOTAL		**200**	**22**	**825**

ELECTIVES (COMP. SCIENCE AND ENGINEERING) Any 3 Courses— 9 Credits

S.No.	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence & Applications	EN703	30	4	100
2	Data Base Management System & Web Technology	EN705	30	4	100
3	Digital Signal Processing & Image Processing	EN706	30	4	125
4	Embedded Electronics Software	EN707	25	2	100
5	Feedback Control System	EN708	25	2	100
6	Image Processing & Machine Vision	EN710	30	4	125
	3 ELECTIVES TOTAL (APPROX)		**90**	**6-12**	**350**

	THEORY TOTAL	**530**	**54-60**	**2125**

NON-SUBJECT ASSIGNMENTS

S.No.	Subject Title	Course Code	Credits	Marks
1	VivaVoce–I & VivaVoce-II	EN591	2	200
2	Practicals	EN592	1	100
3	MiniProject	EN593	9	300
		TOTAL	**12**	**600**

M.TECH. THESIS WORK (SECOND YEAR)

1	Thesis Work	Dissertation	**32**

Total Contact Hrs: 530; Total Credits: 98-104; Total Marks: 2725

Note: Credit Requirement for M.Tech: 92 (60+32)
Credit Requirement for Non Trg Sch M.Sc.(Engg): 60 (through course work and two viva)

FOUNDATION COURSES

EN501: Accelerator Physics and Technology

Basic Accelerator Physics (5)

- Introduction to accelerators; basic concepts; DC accelerators; Cockcroft – Walton, Van de Graaff and tandem Van de Graaff; linacs; cyclotrons; synchrotrons;
- Ion sources.
- General equations of motion in a combined electric and magnetic field, beam rigidity; relativistic expressions, weak and strong focusing principle; condition for strong focusing.
- Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; betatron frequencies.
- General design of a cyclic accelerator.
- Linear Beam optics, Beam transport systems: bending magnets, quadrupole lenses; Solenoidal lens; drift spaces;
- Matrix techniques in beam optics; first order transfer matrix of dipole, quadrupole, transfer matrix of a drift space; quadrupole doublet;
- Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters
- Introduction of normal (room temperature) DC and pulsed magnets, construction features. Superconducting coils, magnets and their construction features.
- Momentum compaction; Phase stability, phase (synchrotron) oscillations; frequency of synchrotron oscillations.
- Synchrotron radiation sources; spectrum of emitted radiation; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth – Physics of wiggler magnets; undulators.

RF Linacs (12)

Introduction to Linacs

- Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including traveling and standing wave types.
- Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, Isochronism, concept of phase, Wideroe and Alvarez linac
- Transit time factor and the energy gained in a linac.
- Linac focusing devices; quadrupole doublet focusing; stability criteria; phase advance and stability in linacs, etc.
- General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature RF structures.

Proton Linac

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.
- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
- Introduction to Space charge effects.
- Beam diagnostics for measurement of beam current, position, profile, energy and emittance.

Accelerator Driven Systems & RF electron accelerators

Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.

Accelerator Technology (13)

General

- Material selection for Accelerator components
- Mechanical Design and fabrication issues; tolerances, surface finish, etc
- Thermal management in accelerator systems
- Alignment requirements of accelerator magnets and RF structures, methods and instruments for alignment and surveying in accelerators.

Ultra High Vacuum Systems

Basic concepts in Vacuum

- The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
- Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
- Basics of low pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, Sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.

Cryogenics Systems

Introduction to Cryogenic Engineering

- General and basics, Cryogenic properties, Basic cycles
- Large Cryogenic Systems for Accelerators

Cryogenic Equipments

- Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

References

1. Principles of RF Linear Accelerators, T. P. Wangler, (John Wiley & Sons Inc., 1998)
2. Introduction to Accelerator physics – Arvind Jain
3. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer, (John Wiley & Sons Inc., 1982)
4. An Introduction to the Physics of Particle Accelerators - M. Conte, W.W. Mac Kay.
5. Handbook of Accelerator Physics and Engineering - A. Chao, M. Tigner.
6. Particle Accelerator Physics (Vol 1 and Vol 2) - Helmut Widemann.
7. Principles of Charged Particle Acceleration – Stanley Humphries.
8. Fundamentals of Beam Physics - James Rosenzweig.
9. An Introduction to Particle Accelerators - E. J. N. Wilson.
10. Accelerator Physics - S. Y. Lee.
11. The Physics of Particle Accelerators, An Introduction - Klaus Wille.
12. The Principles of Circular Accelerators and Storage Rings - Philip Byrant.
13. Introduction to Vacuum Technology-Compiled by K.G. Bhushan, BARC

EN 502:Engineering Maths-I (15) (All Engg)

- Overview of arithmetic errors in computations
- Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc.
- Linear systems solutions by direct methods, iterative methods and acceleration techniques.
- Linear systems: matrix inverse, ill conditioned matrices, sparse matrices.
- Linear systems: Eigen values.
- Non -Linear systems: Newton-Rapson & Successive Approximation methods
- Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings
- Numerical Integration: Newton Cotes quadratures, Gauss quadratures.
- Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and
   Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 503: Engineering Maths-II (20) (ME Group)

- Introduction to discretization methods and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations, wave equation
- Formulation of the matrix methods by equilibrium concepts (1D-heat conduction, 2D-truss and 1D-hydraulic flow examples).
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's methods, Piecewise approximations. Basis of Finite Element Method, energy principles in structural mechanics and principles of minimum potential energy, assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit methods.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.
- Finite element formulation for laminar and turbulent flows.
- Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning
- Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers
- Interpolation Function, Lagranges interpolation, B-spline, Bezier curves
- Response Surface Method 2K+1, factorial design, 3k factorial design
- Monte Carlo Method
- Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Artificial Intelligence and Genetic Algorithm
- Artificial Neural Network
- Gram-Schmidtt Orthogonalization
- Transformation of matrix

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods".
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
6. Rajaraman V., "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C., "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
11. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G., "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
15. Rajsekaran S., "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987.
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN 504:Engineering Maths-II (20) (MT)

Applications in Materials Science:

- Use of matrix in crystallography. Stereographic analysis, lattice correspondence, orientational relationship, applications to twinning and martensitic. transformations,
- Tensor analysis in phase transformation and deformation studies
- Analysis of diffusion data, Solutions of diffusion equations - error function and Eigen value analysis, Polynomial fitting of diffusion profiles.

Application in thermodynamics of metallurgical systems:

- Temperature dependence of thermodynamic quantities, graphical and analytical integration of Gibbs-Duhem equation. Introduction to database for thermodynamic tables
- Analysis and synthesis of phase diagrams, introduction to first principles calculations of phase diagrams with computer demonstration, cluster variation and Monte Carlo methods

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Methods", Wilev, 1966.
2. Todd R.J. "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Dahlquist et al, "Numerical Methods.
4. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice Hall, 1981.
5. Scheid F., "Numerical Analysis: Schaum Outline Series", McCraw-Hill Book Co. 1983.
6. Rajaraman V,, "Computer Oriented Numerical Methods", Prentice Hall, 1971.
7. Williams P.W., "Numerical Computation", Nelson, 1972.
8. Bajpai A.C. "Numerical Methods for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis

1975.
9. Chapra S.C., "Numerical Methods for Engineers: International Edition", McGraw Hill, 1989.
10. Scarborough J.B,, "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers. 1968.
11. Conte S.D,, "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo,McGraw Hill. 1972.
12. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
13. Salvatori M.G,, "Numerical Methods in Engineering", New Delhi, Prentice Hall, 1952.
14. Gerald C.F., "Applied Numerical Analysis". Addison Wesley, 1984.
15. Rajsekaran S,, "Numerical Methods for Initial and Boundary Value Problems", Wheeler, 1987; •
16. Rajsekaran S., "Numerical Methods in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
17. Jain M.K., "Numerical Methods for Scientific and Engineering Computation' Wiley Eastern, 2nd Edition, 1991.
18. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.-• •
19. Acton, "Numerical Methods That Work"
20. Forsythe et. al,, "Computer Methods for Mathematical Computations"
21. Forsythe et. al,, "Computer Solution for Linear Algebraic Systems"
22. Golub Gene H., "Matrix Computations"
23. Griffiths D. V., "Numerical Methods Engineers: A Programming Approach"
24. Williams P. W,, "Numerical Computation.
25. Strang G,, "Applied Mathematics"
26. Crank J,, "Mathematics of Diffusion"
27. Worked Examples in the Geometry of Crystals: MKDH Bhadesh
28. Materials Science & Technology, Vol.4; Rudman.

EN 505: Engineering Maths-II (20)(EE Group)

- Transforms: Laplace & solution to ODE, Bilinear & Z transforms, Discrete cosine transforms & compression, Entropy & Haufman coding for compression
- Solution of Matrix Differential Equation: Existence & uniqueness of solutions, Solution of Non-Linear continuous time state equation, Solution of Linear time varying continuous time state equation, Solution of linear time invariant continuous time state equations
- Basic Procedure for Designing Conservational Logic: Quine McCluskey method, Iterative consensus method, Design example
- Design of Sequential Circuit Using Sequential Machine Flow Chart: Sequential machine flow chart, Reading reduced dimension maps, Output function synthesis, Next state function synthesis, State assignment & design examples
- Counting Statistics and Error Prediction: Statistical models -Binomial, Poisson and Gaussian distributions, Application of statistical models: Error propagation, Optimization of counting experiments, Limits of detectability, Distribution of time intervals

References:

1. F R Grantmacher, "The Theory of Matrices", New York: Chelsea Publishing Co., 1960.
2. R Bellman, "Introduction to Matrix Analysis", II ed., New York, McGraw Hill, 1970.
3. E Kreyszig, "Advanced Engineering Mathematics, 5th ed., Wiley Eastern Ltd., 1985.
4. Paul R Halmos, "Finite Dimensional Vector Spaces", and New York: D Van Nostrand Co. Inc., 1965
5. Bajpei et.al, "Numerical Methods for Engineers and Scientists"
6. Dahlquist et.al, "Numerical Methods"
7. G Strang, "Applied Mathematics"
8. Golub Gene H, "Matrix Computations"
9. Numerical Methods for Scientists and Engineers, By H.M.Antia, Hindustan Book Agency,New Delhi.
10. Numerical Methods for Mathematics, Science and Engineering, Mathews(IInd Ed), Prentice Hall of India.

EN 506:Health Physics and Radiological & Industrial Safety (20)

Health Physics

Introduction

- Radiation sources, its interaction with matter and units**:** Natural and Induced radioactive sources,
- Units of radioactivity, half-life and decay constant, specific activity.
- Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter.
- Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given).
- Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given),
- Exposure-dose relationship, Bragg-Gray principle.

Biological effects, Radiation Protection and Regulation:

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Importance of radiation protection programme in DAE.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.

- Radiation protection philosophy,
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Fundamentals of ICRP respiratory model, entry through ingestion, GI track model.
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

Principles of radiation detection and monitoring

- Basic operating principles ofa) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type ofRadiation monitors/Radioactivity measurement methods adopted for radiation protection should be taught.

Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management.
- Personal monitoring, area-monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Use of personal dosimeters (TLDs, pocket dosimeters)

Radiation Protection procedures:

- Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper),
- Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation, Protective equipments

Nuclear Accidents, Emergency Preparedness and Management:

- Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

INDUSTRIAL SAFETY ASPECTS

Introduction:

- Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques

Hazards due to physical agents:

- UV and IR radiation, Lasers, Microwave radiation; noise, heat

Chemicals hazards:

- Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer causing chemicals

Evaluation:

- Instrumental methods, air sampling methods, liquid effluent monitoring

Occupational exposure limits:

- Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50

Handling, storage and control:

- Engineering control measures and safety features,
- Safety management techniques such as safety audit, Personal/ administrative control, and Medical control

Fire and explosion hazards:

- Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits,
- USNFPA Classification of Flammable/combustible liquids: flammable gases;
- Engineering safety for prevention of fire and explosion,
- Hazard area classification, selection of equipment, detection and extinguishing systems.

Hazard identification, assessment and control:

- Hazard identification: Concept of risk and Risk management
- Formal methods of hazard identification and assessment:
- Process/ System Check-Lists, Safety Review, Preliminary Hazard Analysis (PHA), "What If" Analysis, Hazard and Operability (HAZOP) Studies
- Relative Ranking - Dow and Mond Indices, Failure Modes, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis, remedial measures and implementation.

Management of major hazard Installations:

- Plant Layout and Engineering Design Consideration
- Leakage of Flammable Material, Explosions, Fires, BLEVE, Toxic Releases,
- Major Hazard Control Plan: Identification, Risk Assessment, Environmental Impact Assessment,
- Emergency Planning Guidelines, Development of Emergency Plan

Health and safety regulatory aspects:

- Statutory bodies, AERB, BSC, CCE, CPCB, State PCB, Electrical Inspectorate, DGFASLI, Boiler Inspectorate.
- EPA-1986 and Rules, Factories Act, Atomic Energy (Factories) Rules 1996, Gas cylinder and SMPV rules, Indian Electricity rules 1956.

References:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection –Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Guide Lines for Hazard Evaluation Procedures – American Institute Of Chemical Engineers
8. Risk Analysis in The Process Industries: The Institute of Chemical Engineers, England.
9. Loss Prevention in The Process Industries: Hazard Identification, Assessment And Control; Vol-1, 1996 2 Edition, Frank P Lees.

EN 507:Material Science in Nuclear Engineering (EE) (20)

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction methods --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices.
- Material characterization techniques --- XRD, RBS, SEM, TEM, EDAX, XPS, IR and Raman Spectroscopy.
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials, mechanical properties and measurement techniques, strength and ductility, creep, fatigue and wear testing
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Reactor core materials, Zircalloys, Zr-Nb alloys --- fabrication, properties and applications in reactors
- Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels) --- fabrication, properties and applications.
- Chemistry of fuel materials: Production of Uranium, Plutonium and Thorium.
- Heavy water: Production process, purification, properties and applications.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)
2. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)
3. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)
4. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)

EN 508: Nuclear Fuel Cycle Technology(35)

An overview (1)

FRONT END

Mining, Milling and Associated Processing of Indian Uranium Resources(1)

- General Introduction
- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.

Case Studies (1)

- Jaduguda and Turamdih Uranium Ore Processing
- Tummalapalle Uranium

Metal Purification using Hydro-Metallurgical Processes (1)

- Process, Equipment, Quality control

Metal Production by Metallothermic Reduction Processes (1)

- Process, Equipment, Quality control

WasteManagement and Safety (1)

- Associated wastes, characterisation and management

BACK END

Reprocessing (4)

- Nuclear fuels and generation of Pu239 & U233
- Spent fuel management options.
- Characteristics of spent fuel (RR, PHWR, AHWR ,FBR&LWR).
- Reprocessing by PUREX -Head end operations, solvent extraction cycles including the conversion of nitrates to oxides.
- Reprocessing of AHWR and FBR spent fuels.
- Prevention of criticality in reprocessing plants.

Waste Management (3)

- Waste sources.
- Radioactive waste classification.
- Management of low and intermediate level wastes.
- Vitrification of high level liquid waste.
- Schemes for partitioning of high level waste including recovery of valuable fission products.
- Storage and disposal of radioactive wastes.
- Various decontamination techniques to address alpha bearing materials.

Instrumentation & Control (3)

- Measurement techniques for level, pressure, temperature, interface density and flow Instrumentation and control associated with transfer devices—steam jets, pumps and air lift pots
- Interlocks related to major equipments like pulse column, dissolver, evaporator, joule melter and ion exchange column
- Computerised data acquisition and control system

Radiation Monitoring System (2)

- Area monitoring instruments, stack monitors, criticality alarm systems, effluent monitors,PCW & steam condensate monitors
- Single line diagram for Class-4, Class-3 and UPS
- Earthing, cabling, lightening protection system, VF drives

Civil (1)

Design aspects of back end technology facilities- Design classification and seismic categorization, considerations for external events, Standards/codes for design

Metallurgy (2)

- Corrosion aspects and material of construction for reprocessing and waste management plants.
- Degradation modes of SS 304L in nitric acid.
- Welding techniques, quality assurance and special requirement for in cell equipment.

Mechanical (7)

- Spent fuel transportation- shipping cask design and regulatory requirement.
- Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
- Remote handling system in reprocessing.
- Automation in plutonium powder handling.
- Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
- Sampling system. Transfer devices and valves for radiochemical plants.

Features of Radiochemical Plant (7)

- Layout considerations and design philosophy for back end operation.
- Control of radiation exposure including shielding and barriers.
- Ventilation aspects and Off gas handling and treatment.
- Utilities requirement for back end.
- Mechanical design aspects of metallic and joule melter.
- Radiation shielding windows.
- Remotisation and remote handling in vitrification plants

EN 509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40)

Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulas gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.

- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

1. Wakil M.EI, "Nuclear Power Engineering", McGraw- Hill.
2. Strosal and Vapet, "Power Plant Engineering & Economics".
3. Lewis E.E., "Nuclear Power Reactor Safety", Wiley Inter Science.
4. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 1977, Von-Nostrand, 1981.

Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time.Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
    - Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio, blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly
    - Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
    - Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination

References:

1. Walter A.E., & Reynolds A.B., "Fast Breeder Reactors", Pergamon Press
2. Yevick J.G., "Fast Reactor Technology", Plant Design, M.I.T, Press.

Module 3:Advanced Reactor Concepts (6)

Introduction(1)

- Need for Advanced Reactors and in what way these are different from conventional reactor
- International initiatives – INPRO, GIF etc.
- Definition of sustainability and INPRO areas of sustainability
- Brief Description of the INPRO Guidelines and Methodology to Evaluate INES
- Basic principles, User requirements, Key Indicators, Allowable parameters etc.

Directions of Development in the World(1)

- GIF and other advanced reactor concepts

Indian Programme on Advanced Reactors and Associated Challenges (2)

- AHWR
- AHWR-LEU
- CHTR, IHTR, MSBR etc.

Reactor Physics Design Challenges(1) ADS and applications(1)

EN 510:Reactor Physics & Engineering (55)

Module 1 :Nuclear Reactor Physics (33)

Properties of Nuclei

Binding energy-formula and interpretation, nuclear forces, nuclear structure.

Fission Process

- Fission rate and reactor power
- Fission neutrons, delayed neutrons, fission gammas, fission products energy balance, photo neutrons
- Fissile, fertile and fissionable materials
- Fission product activity after shut down –decay heat.

Interaction of Neutrons with Matter

- Production of neutrons

Concept of microscopic cross section:

- Inelastic and elastic scattering

Variation of cross-section with energy

- Fast, resonance and thermal ranges
- 1/v law of neuron cross-section
- Resonance absorption, Doppler effect.
- Eta vs E curve conversion & breeding concept
- Thorium utilization

Diffusion of Neutrons

- Fick's law and its validity
- Steady state neutron diffusion equation
- Concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance.

Chain Reaction

- Four Factor formula
- Conceptual treatment of diffusion of one group neutrons in non multiplying and multiplying media Infinite and effective multiplication factors
- Bare homogeneous reactor-concepts of material and geometric buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and lifetime in finite reactor,

Slowing Down Process

- Neutron slowing down
- Slowing down power/ moderating ratio of moderators
- Slowing down with spatial migration
- Fermi age concepts, migration length
- Multi zone reactors
- Ideas of reflectors/blankets, reflector savings, form factor.

Heterogeneous Reactors

- Multigroup neutron diffusion with special reference to 2 group approach
- Heterogeneous reactors, comparison with homogeneous reactors, unit-cell concepts.

Reactor Kinetics

- Time dependent neutron diffusion equation, one group kinetic equation
- Role of delayed neutrons, prompt neutron life time
- Point kinetic model to illustrate importance of delayed neutrons
- Reactor period, reactivity and its units.

Core Burn Up

- Burn up equations including fission products, neutron poisons
- Burnup dependent lattice parameters and their variation.

Neutron Poisons

- Xenon and Samarium Poisons
- Xenon loads (operating and post shutdown), Variation of xenon load with power and enrichment
- Xenon oscillations and their control.

Reactivity Coefficients

- Temperature coefficients of reactivity and void coefficient of reactivity, their relevance to reactor safety.
- Techniques to control reactors, typical reactivity balance, long-term burnup, fuel management. Reactor control system – requirements of physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shut down.
- Approach to criticality, physics measurements and calibrations/validations.
- Physics design aspects of PHWR and AHWR. Differences in the physics design of research reactors, PWRs, BWRs, PHWRs and AHWR

Module 2: Reactor Engineering & Radiation Shielding (22)

Reactor Engineering (14)

- Introduction to reactor system & Indian Nuclear power programme
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems
- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR),
- Fast reactors;
- Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
- Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.

Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.

- Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
- Economic comparison of differ coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.

Nuclear Fuel Cycle (2)

- Concept of Nuclear Fuel Cycle ¾ open and closed fuel cycles.
- Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
- Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
- Advanced fuel cycles

Radiation Shielding (6)

- Source of various neutron & Gamma radiation within the reactor system
- Attenuation of neutrons & gamma rays

- Dose rates for gamma rays for various source geometries
- Buildup factors for homogeneous & multiple layer shields
- Removal diffusion theory for neutron attenuation
- Coolant activation, heat generation
- Streaming of radiation through gaps & void in the shield

CORE COURSES

E601: Advanced Chemical Reaction Engineering (25)

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, application. Micro-mixing and segregated flow, boundaries to micro-mixing, modeling segregation, experimental results, design strategies.
- Non-isothermal effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Heterogeneous reactions, transport and heat effects, reactions in the continuous phase; fluid, solid-fluid reactions, design procedures incorporating flow non-idealities in each phase.
- Reactor design: counter-current moving bed reactors, fluidized bed reactors.
- Advanced topics in reaction engineering- three phase reactors, photochemical reactors, integral reactor-separators, complex systems.
- Examples from nuclear chemical engineering.

References:

1. Chemical Reactor Design and Operation – K.R. Westerterp, W.P.M Van Swaaij, AACM Beenackers, John Wiley & Sons, 1984.
2. Elements of Chemical Reaction Engineering – H.S. Fogler, 2nd ed, Prentice Hall, 1987.
3. Chemical Engineering (vol.3): Chemical Reactor Design, Biochemical Reaction Engineering including Computational Techniques and Control. – Coulson & Richardson 2nd ed., Pergamon Press, 1979.
4. Chemical Reaction Engineering – Octave Levenspeil, 2nd ed., John Wiley and Sons, 1995.
5. Research and Technological Studies on Liquid Phase Oxidation Reaction Process : Hazardous Toxic Chemical Mitigation Techniques. – T.V. Subramanian, Chennai: Emerald Publishers, 1997. (Class No. : 66.094.3-936.35 A97 at Central Library)

EN602: Advanced Electrical Engineering Design-I (20)

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Methods, Finite Element Methods, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Methods: MFL Technique, Eddy current Technique, Remote Field eddy current Methods. (5)

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronics Circuit Design Techniques (30)

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Programmable Logic Devices: PLD, CPLD and FPGA, Technology architecture (4)
- Hardware Description Languages: VHDL – language details (6)
- Digital Circuit Design using VHDL: Design methodology and optimization, Design of a multiplexer, counter, finite state machine etc., test bench (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. Actel HDL Coding Style Guide, 2009 edition, Published by Actel Corporation, Mountain View, CA 94043. Free softcopy available on Actel website (www.actel.com).
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles

10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25)

- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Rate based approaches for design.
- Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors.
- Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors.
- Adsorption and ion exchange equipment.
- Membrane separation and other advanced mass transfer processes.
- Process intensification approaches.

References:

1. L.K. Doraiswamy and Sharma
2. Laddha and Degaleesan
3. Danckwerts
4. Hancook
5. Hansen and Reid
6. Handbook of Membrane Processes
7. Chemical Engg. Journals (By Course Instructors)

EN605: Advanced Nuclear Instrumentation (40)

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and methods of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems ,Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.

Reactor Instrumentation:

- Fundamental Considerations / Philosophies, requirements, and scope.
- Measurement ranges of reactor neutron flux and considerations
- Types of neutron detectors FC,10B, BF3, CIC and SPND for in-core and out-of-core use.
- Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR,LR, Lin, LinR and ρ)
- Noise reduction techniques, considerations and practice: EMI Interference, Grounding and shielding.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma Monitors, Neutron Monitors, Contamination Monitors, including networking and RADAS.

References

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

EN606: Advanced Operating Systems (25)

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Processs Subsystem : Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem : Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Interprocess Communication : Message Queues, Shared Memory, Semaphores, Mailboxes, Sockets, Fundamentals of Socket Programming, Remote Procedure Calls [1][6]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing, Features of distributed Unix, Logical time, Concurrency Control [1][5]
- Unix Shells: Unix Shell Commands & Fundamentals of Shell Programming [1][2]

- Linux: Packaging and Distribution, Loaders, Virtual Terminals, Internal and External Drivers, Threads, Interfaces, X Window System, Hard Disk Partitions, File System Enhancements, Extended File Systems, Virtual File System, System Tuning. [3, 9, 10]

References:

1. The Design of Unix Operating Systems : Maurice J. Bach, Prentice Hall
2. Unix Programming Environment : Kerninghan & Pike, Prentice Hall
3. Linux Internals : Rubini, O'Reilly & Associates
4. Operating Systems Concepts: Silberschatz, Galvin, John Wiley
5. Distributed Operating Systems : Tanenbaum, Prentice Hall
6. Unix Network Programming : W. Richard Stevens, Prentice Hall
7. Xlib Programming : Adrian Nye, O'Reilly & Associates
8. Inside Windows NT , David A. Solomon, Microsoft Press
9. Demblon & Spitzner, http://learnlinux.tsf.org.za/courses/build/internals/internals-all.html
10. Tigran Aivazian, http://www.faqs.org/docs/kernel_2_4/lki.html or http://students.mimuw.edu.pl/SO/Linux-doc/LinuxKernel-2.4.pdf

EN607: Applied Process Instrumentation (40)

- Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables:
- **Flow**: Differential pressure flow elements: Orifices , venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straightners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters. Applications and limitations of various flowmeters. Two phase flow measurements.
- **Pressure**: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezoresistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.
- **Level**: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydrastep level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.
- **Temperature**: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.
- **Temperature transmitters**- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
- **Analytical Instrumentation**: Conductivity, pH, ORP and Turbidity measurement.
- **Other Measurements**: Relative humidity; viscosity and density measurement
- **Control valves:** Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.
- **Instrument Impulse lines and instrument fittings**: Tubes- materials and sizes, tube fittings- materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.
- **P & I Diagrams, loop and hook up diagrams:** P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

EN 608 Civil Engineering Design of Concrete and Steel Structures

EN 608.1Civil Engineering Design of Concrete and Steel Structures-I (30)

Introduction to various structures of nuclear facilities Classification of structure and design basis

Radiation protection objectives, defense in depth, safety functions, safety classification, seismicclassification, quality classification, design classification, design for natural and man induced events.

Design Loads:

- Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
- Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
- Severe Environmental Loads: operating basis earthquake,severe windincluding gust effect and aerodynamic instability, design basis flood load,tsunami.
- Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind- induced missile

Design of RC structures:

- DesignofRC structures as per IS456,AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 ,designloadcombinations,design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies

Design for shrinkage, creep & heat of hydration:

Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies..

Foundation design

- Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
- Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
- Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

EN 608.2 Civil Engineering Design of Concrete and Steel Structures-II (30)

Introduction to Prestressed Concrete structures

Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.

Design of lined and unlined containment structures

Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.

Design of steel structures of nuclear facility

Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections,design of embedded parts and anchor boltsas per AERB and ACI standards, case studies.

Design of water-retaining structures

Design of overhead and underground tanksusingun-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.

Design of cooling towers

Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

References

1. IS 456 (2000) "Plain and Reinforced Concrete – Code of Practice ".
2. ACI 318 (2014) "Building code requirements for structural concrete".
3. ACI 349 (2013) "Code requirements for Nuclear Safety related concrete structures".
4. RCC-G "Code of Practice for Design of Prestressed Nuclear Containment Structures". 5. ISO 14000
6. Raju, N. K. (2006), "Prestressed concrete", Tata McGraw-Hill Education.
7. ACI 207 (1995) "Effect of restraint, volume change and reinforcement on cracking of massive structures".
8. Bowles, J. E. (2001) "Foundation analysis and design", Tata McGraw-Hill Education.
9. Rao, N.S.V.K. (1988),"Vibration analysis & foundations dynamics", Wheeler publishing.
10. IS 2974-1, 1984,"Code of practice for design and construction of machine foundations".
11. Arya, S.C., Oneill, M.W. and Pincus, G. (1979), "Design of structures and foundations for vibrating machines", Gulf Publishing Co.
12. Manohar, S. N. (1984) "Tall Chimneys design and construction", Mcgraw-Hill Book Comp.
13. ANSI/AISC N690 (1984), American and National Standard – Nuclear facilities, "Steel safety related structures for design fabrication and erection".

EN 609 Earthquake Engineering and Structural Dynamics(45)

Introduction to Seismology

- Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA),Design Basis Earthquake,Concept of

Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra
- Seismic instrumentation for micro-earthquake and strong motions.

Structural Dynamics
- Introduction to dynamic loading, different types of dynamic loadings, concept of damping,derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
- Single degree of freedom of system (SDOF)–undamped& damped system, free & forced vibration; Response to harmonic and impulse loading,concept of transmissibility and vibration isolation,estimation of damping of structural system using free & forced vibration approach;response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
- Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
- Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies)& eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
- Introduction to dynamics of continuous system

Seismic Response Analysis of Structures
- Seismic response analysis using response spectrum and time history approach
- Modal superposition method, Modal combinations and spatial combinations, missing mass correction
- Time history analysis using direct time integration,
- Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction

Random vibrations
- Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.

Special Seismic Design Considerations

Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain, curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures;Seismic Design Optimization, Principles of performance based design, dynamic response control techniques such as base isolation, dampers etc.

Seismic Requalification of Existing Installations

Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection, review basis ground motion, evaluation of seismic margin capacity, retrofitting.

Case Studies

Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear installments.

References

1. Chopra, A.K. (2007), "Dynamics of structures: Theory and application to earthquake engineering", Prentice Hall.
2. Clough, R. W. and Penzien, J. (1993). "Dynamics of structures", McGraw Hill, Inc.
3. Mario Paz and William Leigh (2006), "Structural Dynamics-Theory and Computation", Springer.
4. Thompson, W. T. (1972),"Theory of Vibrations with Applications" Prentice-Hall, Englewood Cliffs.
5. ASCE 4-98 (1998), "Seismic Analysis of Safety related Nuclear Structures and Commentary on standard for seismic analysis of safety related nuclear structures".
6. AERB/SG/S-11, "Seismic Studies and Design Basis Ground Motion for NPP Sites".
7. IAEA SAFETY STANDARDS SERIES No. NS-G-3.3 (2002), "Evaluation of Seismic Hazards For Nuclear Power Plants".
8. IS 1893-1 (2002), "Criteria for Earthquake Resistant Design of Structures".
9. IS 13920 (1993),"Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces".
10. Dowrick D.J., "Earthquake Resistant Design"
11. Park and Pauley, "Reinforced Concrete Structures"
12. Pankaj Agrawal, Manish Shrikhande, (2006), Earthquake Resistant Design Of Structures
13. AERB monograph, (2008), SEISMIC SAFETY OF NUCLEAR POWER PLANTS

EN 610: Code Design for PVP (60)

- Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. Dilation of above shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and torispherical end closures.
- Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div - II equations for cylindrical / Spherical shell and conical, ellipsoidal and torispherical end closures.
- Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
- Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin- walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
- Bolted Flanged joints. Types of flange joints. Types of Gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
- Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material

and allowable stresses. Design of saddle supports.
- Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
- Derivation of TEMA Design equation for tube sheets. Background of the ASME Design rules for tube sheets.
- Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
- Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1 code. Non-destructive Examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 and Div.2.
- Difference between metallic pressure vessel and FRP pressure vessels

Nuclear Pressure Vessels and Piping (30)
- Monotonic and Cyclic Stress-Strain Curve, Strain hardening rule, Theory of failure, yield condition and flow rules, Tresca and Von-Mises criterion.
- Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Failure modes of pressure vessels, Ratchetting and shakedown.
- Organization of Boiler and Pressure vessel Sec. Ill code. Safety classification and Criterion for selection of ASME sec. Ill classes. Design loadings and service loadings as per NCA 2140.
- Types of stress, their significance and derivation of stress Intensifies in vessel and piping.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Definition of B, C and K stress indices.
- Design of Nuclear piping as per Sec. Ill div.1. Design rules for standard support as per NF 3400, Design rule for piping support - NF 3600.
- ASME code rule for component support
- Design rule for Plate and shell- Type support as per NF 3200, Design rule for Linear-type support - NF 3300.
- Design rule for component support - NF 3500, Core support structure Design - NG 3300.
- Fracture Toughness requirements for materials for pressure vessels, pipings and boltings.
- Failure Analysis Diagram.
- Protection against Nonductile Failure - Appendix G, Basis of Low Cycle fatigue Design. Fatigue evaluation of vessels.
- Strain concentration factor ' Ke', Local strain approach: Neubar and Zarka rule, Elastic and elastic-plastic fatigue analysis of nuclear pipings, Leak-Before-Break Design Concept.
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec. Ill.
- NDE requirements, Examination of welds, Acceptance standard.

References:

1. Harvey J.F., “Pressure Vessel Design”, CBS Publication
2. Brownell L.E., and Young E.D., “Process Equipment Design” Wiley Eastern Ltd., India
3. ASME” Pressure Vessel and BoilerCode”, Sec. VIII, Div. I and Div. II, 1985
4. American StandardCode for Pressure Piping”, - B31.1, 1972
5. American Standard Code for Pressure Piping”, - Petroleum, Refinery Piping, B31.3, 1972
6. “Standard of Tubular Exchanger Manufactures Association”, 7th Edition, 1988.

EN 611: Computational Fluid Dynamics & Heat Transfer (50)

Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):
- Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction,vorticity and deformation of a fluid element.
- Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
- Classification of Partial Differential Equations (PDEs)
- Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
- Temporal integration: explicit, implicit scheme
- Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
- Discretization of convection-diffusion problem: exponential scheme, power-law scheme
- Laminar Boundary Layer and Forced Convective Heat (5):
- Formulation of differential equation for hydrodynamic and thermal boundary layer
- Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
- Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
- Convective heat transfer for internal and external flows
- Low and high Prandtl number limits and different thermal boundary conditions
- Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

Turbulent Flow and Heat Transfer (5):
- Reynolds decomposition for turbulence
- Prandtl's mixing length theory, Mixing length models
- Structure of turbulent boundary layer over flat plate and through circular cylinder
- Calculation of friction factor and drag coefficient
- Analytical and semi-analytical correlations for calculating heat transfer coefficients
- Analogy between heat and momentum transfer

- Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
- Turbulence Modeling:
- Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
- Reynolds stress models: algebraic and differential models
- Low Reynolds number models
- Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
- **Natural Convection (3):**
- Basic Equations of natural convection
- Boussinesq approximation
- Derivation of Dimensionless groups from basic equations
- Analytical approximations
- Numerical solution of approximate equations

Numerical Solution of Complete Fluid Flow and Energy Equation (10):

- Formulations of governing equations used in numerical simulation:
- Streamfunction-temperature formulation
- Streamfunction-vorticity-temperature formulation
- Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
- Primitive-Variable (P-V-T) formulation
- Pressure velocity coupling for incompressible flow:
- Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
- Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
- Simple grid generation techniques for structured grid:
- Elliptic, parabolic and hyperbolic equation method
- Grid adaptation
- Domain decompositions in CFD and heat transfer
- SIP and preconditioned conjugate gradient methods for solution

Reactor Heat Transfer (12):

- Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.
- Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.
- Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
- low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
- Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
- Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.
- **Heat Transfer With Phase Change (10):**
- Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
- Basic equations of two phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model)
- Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)
- Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
- Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
- Critical Flow: Models for single – phase and two-phase critical flow.

References for CFD:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.
4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.

14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor &Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

EN 612: Computer Based System Design- I (25)

Hardware Design

- Overview of microprocessors and peripherals: 8086, 68000, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications
- Programmable Logic devices: Introduction to PAL, CPLD and FPGA, Introduction to Hardware Description Language (VHDL)
- Case Study: Design of a single board computer with shared memory interface, I/O board design using ADC, DAC etc with emphasis on signal conditioning and isolation
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues

EN 613: Computer Graphics and Visualization (35)

- Introduction overview, Graphics software/hardware and types of graphics applications (1)
- 2D/3D Geometric Transformations, Affined transformations-Translation, Rotation, Scaling, Shear and reflection. (3)
- Homogeneous coordinates, composite transformations, rotation with qutenion, current transformations and matrix stacks. (3)
- Two dimensional viewing 2D viewing – window, viewport, viewport transformations, clipping operations, line clipping algorithms – Cohen-Sutherland, Liang-Barsky, polygon clippimg algorithm – Sutherland-Hodgman. (4)
- Three dimensional graphics – Planer geometric projections – parallel and perspective, Mathematics for projections, classical three-dimensional viewing, specifying views, viewing transformations, 3D clipping operations. (4)
- Hidden surface removal, object space and image space approach, back face culling, z-buffer algorithm, LOD.(2)
- Illumination and shading – Basic illumination models, light sources, material properties, polygon shading methods – flat, gouraud and phong shading, ray tracing methods. (2)
- Color - Color perception, color models – RGB,CMY,HSV (1)
- Visual Realism – Depth cuing, texture mapping, transparency, shadow, steropsis. (2)
- Curves and surfaces – Representation of curves and surfaces, Algebric and geometric form, Blending functions, interpolation, Hermite, Bezier, B-spline curves and surfaces, Rational polynomials, NURBS (5)
- Modern Graphics Architecture – Graphics Pipeline, GPU, PCI Express (2)
- Case Study – Using OpenGL (3)
- Scientific Visualization – Introduction, Geometry (Structured & Unstructured Grids), Data Representation (Scalar, Vectors), Volume Rendering (Marching Cubes, Ray Casting) (3)

EN 614 Construction Materials, Management and Quality Assurance (30)

Construction Materials

- Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
- Reinforcement: Passive and active (Prestressing)
- Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
- Paints
- Water-proofing materials & membranes

Shuttering/Formwork

Design philosophy, different design requirements, climbing shutter design, slip form work.

Prestressing system

Cable ducts, anchorage and grouting, qualification of Prestressing system

Quality Assurance (QA)

- QA in Civil Engineering design
- QA in materials
- QA in construction
- QA in operation & maintenance
- Inspection during construction, Regulatory inspection

Construction Procedure & Construction Safety

- Dewatering, rock excavation, consolidation grouting

- Construction safety, Job Hazard Analysis.

Contract Management

Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication

References:

1. Singh, K. A. N."ISO 9000-Quality Systems", Dolphin books, New Delhi.
2. Quality systems requirements (QS 9000) – Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 3rd edition
3. Quality system assessment (QSA) Chrysler Corporation, Ford Motor Company, General Motors Corporation – 1998, 2nd edition
4. CPWD Works Manual (2012), Central Public Works Department, Government of India, Published by DIRECTOR GENERAL, CPWD, NIRMAN BHAWAN, NEW DELHI-110 011.
5. Manual of Internal Inspection/DAE Works Procedure (2010), Department of Atomic Energy, Government of India.
6. ATOMIC ENERGY (FACTORIES) RULES (1996), Atomic Energy Regulatory Board, Government of India.

EN 615: Corrosion (15)

- Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables, composition and heat treatment. (3 Lectures)
- Forms of corrosion: uniform attack; corrosion rate measurements, Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion, low temperature sensitization, corrosion of weldments; stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen embrittlement, hydrogen attack, corrosion fatigue; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, failure analysis, specification tests, advanced methods for on-line corrosion monitoring. (7 Lectures)
- General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification. (1 Lecture)
- Corrosion in the nuclear industry – Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. corrosion in fluoride and ammonia containing environments; liquid metal corrosion. low alloy steels, stainless steels and Ni and Cu base alloys, protective magnetite formation on carbon steel, stress corrosion cracking of stainless steels and nickel base alloys. high temperature oxidation and hydriding of zirconium alloys, materials for fast breeder reactor system. Effects of radiation on corrosion (4 Lectures).

References:

1. Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. Corrosion – L.L. Shrier (Ed.) Vol.I & II, 1963.
5. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
6. Modern Electrochemistry, Vol. 1 & 2 – J. O.M. Bockris and A.K. Reddy
7. Corrosion of Stainless Steels – A.J. Sedricks.
8. Stress Corrosion Cracking – Materials Performance and Evaluation – Ed. Russel H. Jones, ASM Int., 1993
9. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN 616: Distributed Computing (45)

Advanced Computer Architecture

- Advances in CPU Architecture
  a. Advancements in CPU architecture – Dynamic Instruction level parallelism, Branch prediction, register renaming
  b. Static instruction level parallelism - EPIC, VLIW
  c. Hyperthreading
- Multi core architectureAdvances in Memory
  a. SDRAM, DDR, DDR-2
  b. Registered ECC, FB-DIMM
  c. CPU – Memory Interfacing techniques - FSB, Hypertransport, Quickpath
- Advances in I/O interfaces
  a. Shared I/O bus
  b. Switched I/O fabric
  c. Serial and parallel I/O bus
  d. Case studies - PCI, PCI-X, PCI-Express, PCI-Express Gen2
- Advances in Interconnect techniques
  a. Shared and switched networks
  b. Interconnect fabrics

   c. Approaches for improving interconnect performance
   d. Case studies – Ethernet, Infiniband, SCI
- Cache
   a. Associative, Direct mapped
   b. Write through, Write back
   c. MESI
   d. Shared caches
- Advances in storage systems
   a. Direct attached storage, Network attached storage, Storage Area Networks
   b. File level and block level accesses
   c. Storage protocols
   d. Case studies - ATA, SATA, SCSI, SAS, Fiber channel
   e. Case studies - FC, iSCSI, iSER, SRP

Parallel Computing

- Introduction to High Performance Computing
   a. Need for HPC
   b. Applications of HPC
   c. HPC Overview – Conventional Supercomputers, Parallel Computers, Classification (SISD, SIMD, MIMD)
- Pipelining, Vector processing, SIMD
   a. Pipeline, Speedup and Efficiency of pipeline
   b. Pipeline stalls, out of order execution
   c. Techniques to improve pipeline efficiency
   d. Superscalar, Superpipelined, VLIW, EPIC architecture
   e. Vector processors, vector instruction sets, registers
- MIMD Architecture
   a. Classification of MIMD machines
   b. UMA, NUMA, CC-NUMA, COMA, NORMA
- Interconnection networks and topologies
   a. Interconnection Concepts – Bandwidth, Latency, Network Diameter, Bisection Width, Node degree, Static and Dynamic Networks
   b. Various topologies – Ring, Hypercube, Torus, Mesh, CLOS, Fat tree etc.
- Current Parallel Architectures
   a. Parallel Vector processor
   b. Symmetric Multiprocessors
   c. CC-NUMA
   d. Massively Parallel Computers
   e. Clusters of workstations
- Clusters
   a. Classification of clusters
   b. Cluster software
   c. File systems for clusters
- Software concepts of High Performance Computing
   a. Parallelism – Algorithmic, Geometric, Event, Data
   b. Granularity – Coarse and Fine grains
   c. Speedup, Efficiency, Amdahl's and Gustaffson's Laws
- Parallel Programming Models
   a. Shared Variable Model
   b. Message Passing Model
   c. Threads Model
   d. Data parallel Model
- Design of parallel algorithms
   a. Data dependencies
   b. Data partitioning
   c. Communication patterns
   d. Synchronization
   e. Load balancing
- Parallel Programming Environments
   a. Parallel Languages
   b. Parallel Extensions to Sequential Languages
   c. Parallel APIs – MPI, OpenMP
- Parallelization of example programs – Dot product, Matrix Multiply, etc. at the pseudo code level
- Message Passing Interface (MPI)
   a. Introduction to MPI
   b. MPI constructs
   c. Example programs in MPI
- Benchmarking
- Case studies – ANUPAM series of parallel computers

Grid Computing

- Introduction to Grid Computing
  a. Evolution of Grid Technology comparison with contemporary technologies,
  b. Issues of virtualization, events that have lead to grid computing, client-server, peer-peer, operating system perspective,
  c. Overview of Grids: Formal definition of Grids - how do they work?
  d. How are they different from clusters? Computational Grids, Data Grids, Production Grids worldwide - Applications of Grid.
- Components of Grid
  a. Grid Security- concepts of single sign on, How the security requirements are met?
  b. Concept of Digital certificate- How RSA works? - Working of Kerberos
  c. Concepts of Myproxy services
- Grid Resource management
  a. Issues in Grid Resource management
  b. Abstract model for Grid Resource Management
- Grid Scheduling
  a. Issues in Grid Scheduling
  b. Taxonomy Of Grid Schedulers
  c. Resource Discovery issues
- Visualization and interactivity in Grids, High Performance Computing in Grids- Grid enabled MPI – MPI-G2
- Grids Services
  a. How are they different from Web services?
  b. Concepts and their implementation
- Data Management in Grids
- Information services- Building information services in Grids
- Grid Portals, Their Purpose, Issues in Portal design, discussion on portlets
- Grid Workflow
  a. Concepts
  b. Taxonomy of Grid Workflow
- Semantic Grids
- Virtualization
  a. Concept
  b. Its utility in Grid Computing
- Grid Enabling Applications
  a. Issues
  b. Implementations
- Discussion about GRID standards
  a. OGSA
  b. OGSA-DAI
- Comparative study of different Grid Middlewares
  a. Lacuna in current Grid Architectures
  b. Grid as operating system of operating systems
- Case study of Middlewares:
  a. GT4,
  b. Glite
  c. DAE Grid
- Future of Grids - Concepts of Cloud Computing

References

1. Advanced Computer Architecture, Kai Hwang
2. Scalable Parallel Computing, Kai Hwang, Zhiwei Xu
3. Introduction to Parallel Computing, Ananth Grama, George Karypis, Vipin Kumar and Anshul Gupta
4. High Performance Computing – Paradigm and Infrastructure, Laurence T.Yang, Minyi Guo
5. Storage Networks Explained, Ulf Troppens, Rainer Erkens, Wolfgang Muller
6. Computer Organization and Architecture: Designing for Performance, William Stallings
7. Grid Computing – Making the Global Infrastructure a Reality, Fran Berman, Geoffery Fox, Anthony J. Hey
8. The Grid2 Blueprint for a new Computing Infrastructure, Ian Foster, Carl Kesselman
9. Grid Computing for developers, Silva
10. Current Journal Articles in the area of Parallel Computing, Computer Architecture and Grid Computing

~~EN 617~~

EN 618: Electrical Systems for Nuclear Power Plants (30)

- Interaction of Nuclear Power Station With The Grid Number of evacuation lines; Optimum size of NPP in grid; Brief introduction to Power System Analysis - Short circuit, load-flow and stability studies, Tariff and Capacity factor.
- Ehv Switchyard Design Switching schemes; Clearances; Com parison between types of svvitchyards; Brief introduction to equipments in switchyard and their functions; Lightning arresters and insulation co-ordination; Lightning protection.

- Protection Line protection; Generator protection; Transformer protection; Motor protection.
- Selection of Transformers Accessories; Types; Specifications and testing; Voltage regulation calculations.
- Selection of MV & LV Switchgear Types; specifications and testing, MCCS; Distribution boards; Generator circuit breaker; ELCB.
- Motors In NPP Types of motors; Radiation withstand requirements; Performance requirements.
- Station Auxiliary Systems of NPP Class 1, 11, Ill and IV systems classifications; Nature of electrical loads and supply voltages; Effect of voltage variation on Electrical equipments and remedial measures; Emergency transfer system; Load shedding scheme; Auto transfer schemes; synchronizing schemes.
- Class 1 e requirements Cabling, lighting & grounding Specific requirements for safety related electrical equipments & systems in NPR Cabling, Lighting, Grounding systems in NPP; Bus ducts. Introduction to seismic qualification of electrical equipments., Electrical system control from Control Room. Introduction to [)G sets, UPS & Batteries.
- Billing and metering scheme for a typical NPP. Introduction to brushiess and static excitation systems for Generators. Introduction to SCADA systems.

References:

1. Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity :.CBProblems and Remedial Measures. IAEA Report - Technical Reports Series No. 271.
2. Elements of Power System Analysis - W.D. Stevenson
3. Electrical Transmission & Distribution Hand Book - Westinghouse Electrical Co., USA
4. Protective Relays - Application Guide, GEC Measurements.
5. Manual on Layout of Substations - CBIP, New Delhi
6. The J & P - Transformer Book
7. The J & P - Switchgear Book
8. Utilization of Electrical Energy - E. Openshaw Taylor
9. Cabling - Siemens Hand Book
10. Illumination Engineering Society - IES Lighting Hand Book
11. Modern Power Station Practice - Volume D - Electrical System & Equipment, British Electrical International.
12. Standard Hand Book for Electrical Engineers - Donald G. Fink and H. Wayne Beaty
13. IEEE-80 - IEEE Guide for Safety in AC Substation Grounding
14. IEEE-308 - Criteria for class 1E Equipments for Nuclear Power Generating Stations
15. IEEE-323 - Qualifying class 1E Equipments for Nuclear Power Generating Stations
16. Indian Nuclear Power Programme with PHWR - Published by Directorate of E & P A, NPCIL, Bombay
17. IS-3716 - Application Guide for Insulation Coordination
18. IS-2309 - Code of Practice for the Protection of Buildings and Allied Structures Against Lightning
19. Handbook of Batteries and Fuel Cells - McGraw Hill Book Company

EN 619: Embedded & Computer Based System Design (45)

Module I [22]

Part A - Microprocessor based Design [10]

- 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
- Introduction to Microcontrollers and comparison with Microprocessors
- Introduction to DSP Processors

Part B [12]

- ARM processor: architecture details and introduction to programming
- Board level buses: I2C and SPI
- Introduction to USB

Module II [23]

Part A – Computer based hardware design [8]

- Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
- Industry standard bus systems: ISA, PCI, VME: Mechanical, electrical, functional and procedural specifications
- Multi processing, bus arbitration and Plug and Play
- System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
- Design Case Study:
- I/O Board design, bus interface (ISA, PCI) FIFO and shared memory interfaces.

Part B - Computer Communication and Networks [7]

- Overview of asynchronous and synchronous communication standards
- Encoding (NRZ, Manchester),
- Ethernet, Industrial networks, Field Bus, CAN bus
- Networking hardware: Cables, Hubs, switch and routers.

Part C - Software development for embedded and PC based systems (8)

- Basic RTOS concepts
- C programming for ARM based applications
- Programming for PC based systems:
  - Interface between applications & device drivers
  - Windows: Programming of I/O, ISR, DMA

References:

1. Computer Networks. By: A.Tanenbaum

2. Principles of Communication. By: Taub and Schilling.
3. Microprocessors and Interfacing. By: D.V.Hall
4. CAN Application Note: Robert Bosch GmBH
5. Microcomputer System 8086/8088 family- Architecture, Programming and Design.
Yi -Cheng Liu & Glenn.A.Gibson.
6. The Intel Microprocessors 8086/8088, 80186/80188, 80286, 80386, 80486 and Pentium series: Architecture, Programming and Interfacing. By: Barry.B.Brey.
7. The Scientist and Engineer's guide to DSP. By: Steven.W.Smith
8. High speed digital design: A handbook of black magic. By: Howard Johnson & Martin Graham
9. Interference control in computer and microprocessor based equipment. By: Michel Mardiguian
10. Interfacing to the IBM Personal Computer. By: Lewis C. Eggebrecht
11. PCI bus system architecture – Mindshare publication
12. VME bus standard document
13. USB complete. By: Jan Axelson
14. ARM System Developer's Guide. By: Andrew Sloss, Dominic Symes, Chris Wright
15. Designing Embedded Hardware. By: John Catsoulis

EN 620: Extractive Metallurgy (40)

Principles of Metallurgical Thermodynamics (15)

- Thermodynamic Functions: Enthalpy, Entropy, Free Energy, Chemical Equilibria
- Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Phase Diagrams
- Solution Thermodynamics, Integral and Partial Molar Thermodynamic Properties
- Experimental Methods- Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.
- Computation of predominance area diagram and Phase diagrams

Kinetics(5)

- Principles of Chemical Kinetics, Homogeneous Reactions, Effect of Concentration, Effect of Temperature
- Theory of Reaction Rates, Heterogeneous Reactions, Reaction Models, Mass Transport Phenomena, Heat Transport Phenomena.

Process Metallurgy (25)

- Methods of attaining High Temperatures,Measurement of Temperature,
- Vacuum Metallurgy Principles and Equipments,
- Process Metallurgy of Rare and Refractory Metals,
- Resources of Special Metals, Beneficiation Methods, Physical, Chemical, Separation Methods, Halide Metallurgy, Vacuum Metallurgy, Electro Metallurgy, Reduction Processes, Refining Processes, Ultrapurification Processes,
- Preparative aspects of Special Materials and Alloys,
- Advanced Materials Processing Techniques,
- Reprocessing of irradiated nuclear fuels, Process Metallurgy of - Uranium, Thorium, Plutonium, Beryllium, Zirconium, Hafnium, Niobium, Tantalum, Rare Earths.

EN 621: Finite Element Techniques (35)

- **Introduction to FEM:** Weighted residual method, Galerkin's methods, Weak form formulation, Piecewise approximations. Basis of Finite Element Method, Variational principles, energy principles in structural mechanics, Element libraries 5
- **Element shape functions**: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements. 15
- **Bar element:** Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss
- **Beam element:** Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams.
- **2D plane elements** – 3 noded triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
- **2D isoparametric formulation** – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature.
- **Incompatible displacement model**: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements.
- **Introduction and Application to 3D elements:** Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements.
- Plate bending elements: Thin and Thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration

- **Shell element**: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking.
- **Introduction to Nonlinear problems:** Sources of nonlinearity, Material non-linearity, Geometric non-linearity, Newton-Raphson method
- **Finite element applications for design**:Finite element modelling and discretization criterion, h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.

References:

1. **Bathe K.J., Finite element** procedures in engineering Analysis, Prentice Hall of India, 1990
2. Cook R.D., D.S. Malkus and M.E. Plesha, Concepts and Applications of finite element analysis, John Wiley, 2000.
3. Reddy J.N., An Introductions to Finite Element Method, 4th Edition, McGraw Hill, 1993.
4. Seshu P., Finite Element Method, Prentice Hall of India, New Delhi, Fourth printing, 2006.
5. Zeinkiewicz, O.C., and K. Morgan, Finite elements and approximation, John Wiley, 1983.
6. Zeinkiewicz, O.C., and R.L. Taylor, The Finite Element Method, Vol. 1 & 2, Tata McGraw Hill.
7. M. Asghar Bhatti, Advanced Topics in Finite Element analysis of Structures, John Wiley, 2006.

EN 622: Fracture Mechanics (40)

Linear Elastic Fracture Mechanics (5)

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks and concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture
- Superposition of K
- Plastic zone correction - Irwin's approach
- Basic design principles in LEFM
- **Plane stress vs. plane strain - Variation of toughness (KIc and Kc)**

Elastic-plastic Fracture Mechanics (5)

- J-integral as energy release rate
- J-integral as amplitude of HRR singularity
- J-integral as contour integral
- Laboratory measurement of J-integral - η factor approach
- Fracture resistance of materials – J-R curve and JIc and possible explanation for shape of J-R curve
- Stable and unstable crack growth – Tearing Modulus approach
- J-controlled fracture
- Basic design principles in EPFM
- **J-estimation schemes**

Laboratory measurements of material fracture properties (2)

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- KIc testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of JIc from J-R curve – blunting line equation and SZW

Limit load (2)

- Definitions of limit load
- Global and local limit load
- Basic expressions of limit load of some common geometries

R6 method (2)

- Basic principles of R6 method
- Sensitivity analysis

Fatigue (7)

- Conventional high and low cycle fatigue – S-N diagram, Coffin-mansion relation
- Fatigue crack growth under constant and variable amplitude loading
- Rainflow algorithm
- Environmental effects on fatigue crack growth
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- **Experimental determination of Paris law constants as per ASTM procedure Fracture assessments of welds (2)**
- Basic aspects of fracture assessment of welds – residual stress effect
- Special considerations in fracture toughness determination of welds

PTS and ASME reference/Master curve (6)

- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Warm pre-stress effect

- Reference ASME curve in assessment of PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Computational Fracture Mechanics(4)

- Barsoum's crack tip element and showing the singularity from shape function
- Evaluation of SIF by displacement correlation technique from FEM
- Evaluation of 2-D J-integral by contour integral technique
- Evaluation of 3-D J-integral by domain integral technique

Fracture Mechanism (4)

- Basic mechanism of ductile fracture – Void nucleation, void growth and coalescence
- Cleavage fracture- Mechanism of cleavage initiation
- Mathematical model of cleavage fracture toughness, explanation for scatter in cleavage fracture toughness, RKR model

Application of Fracture Mechanics Principles to Leak-Before-Break (1)

- History of LBB
- Basic concepts of LBB – three levels
- Application to Indian reactors

EN 623: Mechanical Metallurgy (30)

Elasticity and Plasticity

- Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
- Equations of equilibrium.
- Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria

Dislocations:

- Elastic stress field of edge and screw dislocation.
- Self energy of dislocations.
- Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP

Deformation Behaviour

- Single crystal deformation, critical resolved shear stress, Schmidt's factor, Thermally activated deformation, Strengthening mechanisms.

Creep of Metals and alloys

- Various stages of creep and creep laws
- Types of creep tests, evaluation of parameters of a creep test and its use
- Factors influencing creep resistance
- Deformation mechanism map and identification of creep mechanisms, Irradiation creep

Fracture Mechanics

- Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
- Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
- Concepts of R-curves, Evaluation of various fracture parameters, fracture control

Fatigue of Metals:

- High cycle and low cycle fatigue
- Factors contributing to fatigue failure and its mitigation
- Various stages of fatigue damage and Fatigue life improvement
- Fracture mechanics approach to characterize crack growth behavior

References:

1. Engineering Fracture Mechanics - S. A. Meguid.
2. Mechanical Metallurgy - G. E. Dieter
3. Mechanical Behaviour of Materials - T. H. Courtney
4. Elementary Dislocation Theory - J. Weertman & J. R. Weertman
5. Introduction to Dislocations - D. Hull
6. Mechanical Metallurgy : Principles and Applications - M. A. Meyers & K. K. Chawla
7. Deformation and Fracture Mechanics of Engineering Materials - R. W. Hertzberg

EN 624: Mechanics of Solids (40)

Introduction to Theory of Elasticity Mathematical Frame Work (2)

- Illustration of concepts of elasticity, Stress-strain curve, Isotropy, Homogeneity
- Illustration of equilibrium equation, Cauchy equation and stress strain relation in 1-D
- Solution of 1-D boundary value problems using theory of elasticity equations: (a) Natural frequency determination. (b) Solution under external excitation force to show resonance condition, stress wave etc.
- Tensors algebra : Definitions Scalar, Vector, Matrix, Tensor; Index Notations, Kronecker Delta, Permutation symbol ; Coordinate System Transformation, Tensor Algebra, Tensor Calculus.

Analysis of Stress (3)

- Description / Notations of Forces
- Description / Notations of Stress
- Component of stress
- Reciprocity of shear stress in 3D

- Stresses Transformation using direction cosines
- Stress Traction Vectors or Traction Vectors
- Stress component on an arbitrary plane
- Principal stresses
- Stress Invariants
- Mohr's Diagram for 3D state of stress
- Hydrostatic and Deviator components of stress
- Principle planes and their orthogonally
- Octahedral plane, Octahedral stresses
- State of pure shear

Analysis of Strain (2)

- Description / Notation of Strain in 3D
- Components of strain
- Strain Transformation using direction cosines
- Principle Strains, Strain Invariants
- Cubical Dilation
- Strain Deviator Tensor
- Maximum and Octahedral Shear Strains

Principles and Fundamental Equations of Elasticity (8)

- Strain and displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Stress and strain relationship
- Equations of equilibrium (Navier's Equations , Lame's equations)
- Strain Energy
- Uniqueness theorem
- Bounds on elastic constants
- Superposition Principles
- Saint-Venant's Principle
- General Solution Procedures for a elasticity problem

Two and Three Dimensional Formulation (8)

- Elasticity equation for Plane strain
- Elasticity equation for Plane stress
- Biharmonic equations
- Airy's Stress Functions
- Solution for beam bending problems
  a) Special cases by use of polynomials
  b) General solutions using fourier series method
- Solution in polar co-ordinates
  a) Tube subjected to internal and external pressure (Lame's problem) ; shrink fit
  b) Stress Concentration due to a circular hole in stressed plate (Kirsch's problem)
- Stress in spherical shell under internal and external pressure

Thermal Stresses (4)

- Thermal stress definition and their significance
- Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
- 2D thermal stress analysis
  a) The problem of circular disk
  b) The problem of circular cylinder
- 3D thermal stress analysis : The problem of sphere
- Transient thermal stress

Introduction to Plasticity (4)

- Stress-strain curve, Examples of Multiracial stress
- Different Yielding Criteria and their significance
- Yield Surface , Tresca and von-Mises
- Path dependence of Plastic Strains
- Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
- Prandtl-Reuss Equations
- Incremental or flow theory
- Deformation theory of plasticity, Hencky equations
- Plasticity Relations (plastic strain and total strain)

Theory of Plates

- Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
- Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.

- Introduction to analysis of Thick Plates

Theory of Shells

- Introduction to shell theory.
- Classification of shells, Membrane theory of shells of revolution and translation.
- Application to spherical, conical and cylindrical shells.
- Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
- Application to cylindrical shells, spherical and conical shells.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Piblications, Inc.
6. Plasticity Theory and Application, Alexander Mendalson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K .Chandrasekhara, University Press
9. Stresses in shell- W.Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN 625: Modern Control Systems Design and Simulation (35)

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analyti- cal methods of modeling.
- State Space Characterization State 5PaCe representation, solution of state equation, state Transition matrix, properties of STM, computation methods, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kaiman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Control- lability and observability of Discrete data systems.
- Stability liapunov,s stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design Guillemin-Truxal design Procedure, pole placement by state feedback. H,' meth- od, Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kaiman filter as OPtimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency re- sponse methods, Recurise Least square Identification technique.
- Introduction to Adaptive and Robust control.

References:

(Reference materials will be provided during the course)

EN 626 Design Basis Hazards and Geotechnical Engineering (40)

Design Basis Hazards (Natural)

Role of civil engineering in achieving overall nuclear safety: Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.

Introduction to hazard evaluation:

Hazard due to internal and external events, case studies.

Seismic Hazard

Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum

Flood hazard

- Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
- Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
- Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding

Wind hazard

Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India,Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.),

Solar radiation

Temperature map(Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)

Snow hazard

Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides

Design Basis Hazards (Human-Induced)

Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)

Geotechnical Engineering

Soil Mechanics

- Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
- Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
- Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability; Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.
- Bearing capacity – Determination of bearing capacity for soils and Rock.

Geotechnical and Geophysical investigations:

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

Soil Dynamics and Liquefaction

Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

References:

1. Kramer . S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. **IS** 875(Part 3) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. **IS** 875(Part 4) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance”
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – “Basic and applied soil mechanics”.
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities’
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN 627: Networking and Information Security (40)

Networking

General Issues in the transport of data traffic over networks of digital transmission media.

- V.24, V.35, Modems, xDSL, Multiplexing

Circuit switching & Packet switching

- ISDN (BRI), PRI.

Datalink Layer

- Data link layer protocols, Medium access method, Flow control, Error Control
- Ethernet technologies, Bridge, Switching, Analysis of collision domain, Layer 2-based network attacks

Introduction to Satellite communication

- Satellite orbits, VSATs, VSAT network Topologies

Network Layer

- IP, IP Fragmentation, ARP, DHCP, Classes of IP address, CIDR, Layer 3 based network attacks, ICMP
- IP Routing algorithms, RIP, OSPF, BGP.

Transport Layer

- TCP & UDP, TCP Call establishment & Call termination, Sockets, TCP state machine, TCP timers
- RTP, Layer 4 based network attacks

Firewall

- Layer 3 firewall, Layer 4 firewall, Application based firewall

Network Applications

- FTP, DNS, Mail, application based attacks

Network Security

- Data security, type of possible attacks on data etc?
- Ecurity services for secure data communication?
- Like Identification, Authentication, Authorization, Data Integrity, Confidentiality, Non-repudiation, Replay, Availability etc.
- Cryptography and its services Cryptology, cryptanalysis.
- Components of cryptology like algorithms, Keys, Message Digest, Digital signature, Digital Certificates etc. with block diagram.

Types of Algorithms

- Symmetric and Asymmetric.

Symmetric Algorithm

- stream cipher algorithms
- Type of stream ciphers, Unconditional security with stream ciphers, one time pad, LFSRs, Linear complexity in LFSRs, Shanon's concept of perfect secrecy
- Type of possible attacks, Conversion of block ciphers onto stream ciphers etc.

Asymmetric Algorithms

- Diffie-Hellman, RSA with detail mathematics and applications.
- Key management methods for symmetric and asymmetric keys.
- PKI infrastructure, Digital certificates, digital signatures for asymmetric key managements. CRL (certification revocation list)
- Symmetric key certificates. Difference between symmetric and asymmetric key certificates etc.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN 628: Nuclear Chemical Engineering (35)

Intoduction

Role of chemical engineering in the nuclear industry

Recovery & processing of nuclear materials from ores / intermediates (5)

- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources , New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths : Occurrence, importance and separation.

Uranium Conversion / reconversion (6)

- Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF6: choice and problems, Fluorination of UF4, Purification and collection process for UF6, Conversion to UO2.

Isotope Separation (9)

- Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical- exchange: H2S-H20, NH3-H2, monothermal and bithermal process, salient features of equipment like contacting towers, tower internals. Heavy water plants in India. Final enrichment and upgradation plants. Distillation and electrolysis, Tritium removal.
- Laser based separation and new processes (2)
- A brief description of laser based isotopic separation processes.
- Fuel Reprocessing (6)
- Fuel Reprocessing: Introduction to Radiochemistry; Differences between a conventional chemical plant and radio chemical plant- Process and equipment limitations, criticality, safety and other hazards, numerical examples, ventilation, shielding, Typical compositions and burn-up of irradiated nuclear fuels.
- Thermal Reactor Fuel Reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements. Evolution of solvent extraction process fore reprocessing, 'PUREX' and 'THOREX' processes in detail; Head-end process, flow sheet, co-decontamination and partitioning cycles.
- Fast Reactor Fuel Reprocessing and Introduction to reprocessing of Thorium based fuels.

Nuclear Waste Management (7)

- Sources, characteristics and classification of radioactive wastes; general philosophies of management.
- Method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Discussion of the various chemical engineering operations involved. Use of desalination and membrane separation techniques in waste management.
- Conditioning of radioactive waste- cementation, bituminisation, use of polymers and vitrification methods.
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical Engineering in Decommissioning of nuclear facilities.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series,IAEA,Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)

EN 629: Nuclear Materials (50)

Melting & Casting (10)

- Introduction to vacuum measurement units and types of vacuum pumpsincluding diffusion pump & turbo- molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and methods to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits

Mechanical working of Metals (10)

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Methods of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Powder Metallurgy & Advanced Ceramics (30)

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production methods, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.
- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. “Introduction to Ceramics” by Kingery et al.
11. “Ceramics Through Chemistry” by Brinker et al.
12. “Electroceramics” by Buchanan
13. “Ceramics Fabrication Processes” by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman

16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
19. 'Ceramics Fabrication Processes" by Wang.

EN 630: Nuclear Metallurgy (30)

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post- Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradition effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels,definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister fomation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Bengamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brain R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN 631: Physical Metallurgy (40)

- Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor Stereographic projection, X-ray, Electron and Neutron diffraction Common Crystal structures and quasi crystals, Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics
- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation. Ordered omega and Hydride formation.
- Recovery, Recrystalization and Grain Growth

References:

1. Physical Metallurgy Principles - R. E. Reed-Hill
2. Modern Physical Metallurgy - R. E. Smallman
3. Introduction to Metallurgy - A. H. Cottrell
4. Physical Metallurgy - P. Haasen
5. Introduction to Physical Metallurgy - S. H. Avner
6. Structure of Metals - C. S. Barrett & T. B. Massalski
7. Crystallography and Crystal Defects - A. Kelley and G. W. Groves
8. Principles of Phase Diagrams in Materials Systems - P. Gordon
9. Thermodynamics of Alloys - C. Wagner
10. Introduction to Metallurgical Thermodynamics D. R. Gaskel
11. Physical Chemistry of Metals - L. W. Darken and R. W. Gurry
12. Metallurgical Thermochemistry- O.Kubuschewski

13. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering - K. Denbigh
14. Modern Chemical Kinetics - H. Eyring
15. Kinetics of Phase Transformations in Metals - J. Burke
16. Transformation in Metals - P. G. Shewmon
17. Phase Transformations in Metals and Alloys - D. A. Porter and K. E. Easterling
18. Diffusion in Solids - P. G. Shewmon
19. Modern Metallography - R.E. Smallman and K.H.G. Ashbee
20. Electron Optical Applications in Materials Science - L. E. Murr
21. Electron Microscopy and Analysis - P. J. Goodhew and F. J. Humphreys
22. Defect Analysis in Electron Microscopy - M. H. Loretto and R. E. Smallman
23. Thermoanalytical Method of Investigation - P. D. Garn
24. Thermal Analysis - T. Daniels
25. Methods of Surface Analysis - A. W. Czanderna (Ed.)

EN 632: Process Control and Instrumentation (MT)(25)

Principles of Measurement (2)

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.

Sensors, Transducers and Transmission methods for parameters (10)

- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical& Radiation Pyrometers.
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli's Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

Principles of Automatic Control Systems (8)

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doeblin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN 633: Process Control & Instrumentation (EE)(30)

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysterisis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of following process variables
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter, Different types of standard pressure taps for orifices. Variable Area Flowmeters- Glass tube rotameters, armoured rotameters, bypass rotameters,
- Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs- Wire wound and thin film RTDs, self heating error, differential temperature measurement by using RTDs. Thermistors - Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer, two colour pyrometer.
- Pressure and Differential Pressure: Manometers-U tube, well and inclined manometers, mechanical pressure gauges- Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressureTransducers and transmitters, Smart pressure transmitters, Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauges, Mcleod gauge.
- Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass,

Purge system, capacitance probes, displacer type, ultrasonic type, nucleonic type and conductivity type level gauge.

- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- Distributed Control System: Programmable Logic Controllers, Smart Transmitters Control room concepts.
- P & I Diagrams: P &ID symbols, Typical P &ID.
- Class 1E Instruments in nuclear power plant: Definition of Class 1E equipment, various tests for Class 1E equipment qualification.

References:

1. 'Fundamentals of Temperature, Pressure and Flow Measurements" – Bendict
2. "Instrument Technology", Vols. 1 to 5, - E.B. Jones, Butterworth and London
3. "Mechanical and Industrial Measurements" - R.K.Jain, Khanna Publishers, New Delhi
4. "Measurement System, Application and Design", Ernest D. Deophhlin.
5. "Fluid Meters" - ASME Publication
6. "Principles and Practice of Flow meter Engineering" - L.K. Spink, Published by the Foxboro Company
7. "Process Instruments and Control Handbook" - Edited by D.M. Considine, McGraw Hill
8. "Handbook on Applied Instrumentation": Edited by D.M. Considine and S.D. Ross, McGraw Hill
9. "Instrument Engineer's Handbook", Part I & II: Edited by Bela G. Liptak, Chilton Book Company
10. "Instrumentation for Process Measurement and Control", Norman A. Anderson, Hilton Co.
11. "Manual on the use of Thermocouples in Temperature Measurements" (ASME Publication by subcommittee 4).
12. "Process Control Systems: Application Design and Tuning". F.G. Shinskey, Mcgraw Hill.
13. "Fluid Meters - Their theory and Application" Edited by H.S. Bean. ASME Publication

EN 634: Process Dynamics & Control (45)

Instrumentation , Controls & Computers(20)

- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real- time control applications.

Advanced Process Control (25) Background theory

- Introduction to state-space controls, state & measurement equations, general solution **of** the state equation, state- transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.

Introduction to Advanced Process Controls

- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

EN 635: Process Modelling, Simulation & Optimization (45)

Simulation

- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Methods of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent methods.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution methods for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

Optimization:

- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies.Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals,evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.

- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

References:

1. Bisio, A and R.L.Kabel, 'Scale-up of Chemical processes', Wiley-Interscience,NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W.Hoffman, A.I.Johnson, D.R.Woods and P.T.Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Methods and Modelling for Chemical Engineers, Winley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain,A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)
6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs,E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Rekliatis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Methods & applications, John Wiley,N.Y (1983)

EN 636: Reactor Control and Instrumentation and Human Machine Interface (40)

Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package.
- Practical

EN 637: Reactor Control Engineering & Instrumentation -1(15)

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic methods (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant Tav program, constant pressure program, Boiler level and

pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., " Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN 638: Reactor Control Engineering & Instrumentation-2 (20)

- Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.
- Reactor Instrumentation
  - Measurement ranges of reactor neutron flux and considerations
  - Principles of detection and types of neutron detectors: in-core and out – of –core
  - Modes of signal processing: Pulse, Campbell, DC
  - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- Health Physics Instrumentation
  - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
  - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
  - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Contamination Monitors

References:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerl

EN 639: Reliability Engineering (EE)(20)

Introduction: Reliability Engg Applied to C&I Systems

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

Reliability Maths/Statistics

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

Fault Tolerance and Systems Reliability:

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

QA/QC Concepts in Brief:

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.

Environmental Qualification and Reliability Testing:

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

PSA/PRA Concepts in NPPs:

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

Additional safety concepts:

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
- Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc.

References:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
6. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
7. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
8. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
9. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
10. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), ('Formal Methods' has been explained).
11. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
12. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
13. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN 640: Software Engineering and Formal Methods (40)

Software Engineering (20)

- Importance of Software Engineering (1)
- Life cycle, Phases and Work-Products of different Phases, traditional models, agile models, Extreme programming (1)
- Project Management: Relationship to lifecycle, planning, control, Risk Management, Cost Models.(1)
- Requirements: Gathering, Categorization, Analysis, and Specification.(1)
- Software Architecture and Design: Architectural Styles, Design Notation, Design principles. (5)
- Object oriented Design: OOAD, Design Patterns (7)
- Testing: Principles of program Testing, Test Coverage, Static Analysis, and Tools for testing. (2)
- Support Activities: Configuration Management, Verification and Validation, Software Engineering Standards, Documentation formats, Tools and environments for Software Engineering (2)

Formal Methods (20)

- Introduction to Formal Methods, Role of Formal Methods in Software Life Cycle – development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, Statecharts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing - Assertions and their verification (dynamic and Static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)

- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic,, Case study from hardware and software, model cheking tools (SPIN, NuSMV etc.) (4)

References:

1. Software Engineering: Roger S. Pressman McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Adison-Wesley
3. Unified Modeling Language *User Guide*: G. Booch, J. Rumbugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I & II , Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K. McMilan, Kluwer, 1993

ELECTIVE COURSES

EN 701: Advanced Computational Techniques (30)

Programming Language C++

- C: General concepts of programming, Basic data-types and variables, Arrays, Strings, Pointers, Data typecast, Operators, Simple and compound expressions, Simple and compound statements, Functions and arguments, Data scope and lifetime, Dynamic allocation of data, User defined data-types (enum, struct, union), Pre-processor directives and macros, Declaration versus definition of data and functions, Header files and C-library.
- C++: All the features of C++ not available in C, Class and objects, their members, scope and lifetime, Constructors and destructors, Function argument initialisers, Function signatures and overload, Inline functions, Operator functions, Class hierarchy and inheritance, Exception handling, Templates.

Advanced Computational Techniques

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogona Collocation,Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backprogation ANN .
- Optmization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all methods to DAE related problems.

Parallel Programming

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions,parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

Scientific Visualization

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.
- Common pitfalls in programming
- Case Studies

EN 702: Advanced Electrical Engineering Design-I I (25)

Special Electrical Machines

- Special Electrical Machines and their applications :Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

Pulse Power Technology

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

EN 703: Artificial Intelligence Methods & Applications (30)

- **AI Basics**Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert

Systems.

- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence **theorem,** Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification methods, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig
2. Genetic Algorithms in Search, Optimization, and Machine Learning, by David E. Goldberg
3. Neural Networks: A Comprehensive Foundation, by Simon Haykin
4. Reinforcement Learning: An Introduction, by Richard S. Sutton and Andrew G. Barto

EN 704: Computer Based System Design- II (25)

Communication, Networking, Realtime systems, RTOS and Software

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- USB
- Encoding schemes
- Local Area Networks
- OSI 7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Networking hardware – cables, hub, switch, router, etc
- Role of fibre optics in communication
- Fieldbus standards
- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking
- Realtime Systems, their characteristics and applications
- Realtime Operating Systems:
- Concepts of
- Process and threads
- Concurrency
- Latency, context switching
- Scheduling policies
- Inter process communication
- Semaphores
- Priority inversion
- Shared memory
- Common systems calls, Communication features in RTOS
- Comparative study of various RTOSs
- Integrated S/W development environment

EN 705: Data Base Management System and Web Technology(30)

Advanced RDBMS

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

Web Technologies

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

EN 706: Digital Signal Processing and Image Processing (30)

Digital Signal Processing

- **Introduction**

Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.

- **Discrete Fourier Transform**

  Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
- Fast Fourier Transform

Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Efficient computation of the DFT of two real sequences and a 2N-point real sequence, Spectrum analysis using the FFT, Windows in spectrum analysis, Use of FFT algorithm in linear filtering and correlation.

- Digital filters

FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems, Overview of DSP processors.

- DSP Applications

  Applications of digital signal processing in nuclear and other fields.

Image Processing

- **Introduction**

  Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- **Image Enhancement**

  Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- **Image Segmentation andAnalysis**

  Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation; Boundary extraction and representation;
- **Morphological operations**

  Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy- based methods;

  Image Compression Models, Error free compression, Lossy compression, Standards;

References:

1 Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.

1. John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles,
2. Algorithms and Applications, Prentice- Hall of India,1995.
3. Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.
4. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine
6. Vision,Vikas Publishing House,2003.
7. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004

EN 707: Embedded Electronics Software(25)

Programmable Digital System Design, Representation & Synthesis [8]

- Introduction to HDLs, Introduction to PLD, FPGA, ASIC. Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Handel-C, VHDL. Introduction to Design Flows and EDA Design Tools.

Real-time Software [11]

- Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion,

Priority Inheritance
- Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development

Introduction to Microprocessors / Microcontroller and Interfaces [6]
- Introduction to Microprocessor and microcontroller, Synchronous and Asynchronous Standards, RS232C, RS485, FieldBus (Profibus, Foundation FieldBus, CAN, Ethernet , MIL-STD-1553B), TTP

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P.Singh & Renu Singh
3. Fieldbus Technology: by N.P.Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN 708: Feedback Control Systems (25)
- Introduction: The control systems, Basic elements of FIB control systems, Types of FIB control systems.
- Transfer Function: Transfer function of linear systems, Impulse response, Block diagrams, Signal flow graphs, Mason's gain formula, Polar plots, Bode plot.
- State Variable Characterization: State concept, State equation, Standard representation, State transition matrix and solution of state equations, relationship between state equations and transfer functions, Characteristic equation, Illus- trative examples of some electrical, mechanical, electromechanical systems.
- Time Domain Analysis: Test input signals, Time domain perform- ance characteristics, Transient response of a typical second order system, PID controllers
- Stability: Definition, Routh-Hurwitz criterion, Nyquist criterion. Relative stability, Gain and Phase margins.

EN 709:Fluid Power Technology (25)
Basic Fluid Power & Components

Basic principles of Hydraulics and pneumatics
- Fluid power introduction and fundamentals of fluid mechanics
- principle of pneumatics, basic definitions
- pressure – gauge, vacuum, absolute; flow
- Pressure loss, Power, torque, energy – mechanical, hydraulic etc. , power, force, speed, viscosity, hydraulic terms in fluid power, resistances, bulk modulus, Pascal's Law, law of conservation of energy
- Transmission and multiplication of force, Momentum theorem, Angular momentum theorem, continuity equation, Euler's equation of motion, Bernoulli's theorem, laws of compression, forces developed by jets on plates (curved plate, moving plate, etc.) orifice flow formula, flow measurement, pressure measurement, comparison of Pneumatics with Hydraulic power transmissions.

Hydraulic Fluids and pneumatic air
- Basic properties of hydraulic fluids and pneumatic air, compressibility, pour point, flash point, fire point,
- Desirable properties of fluid, undesirable properties of fluids,
- Types of fluid, composition of fluids, effects of additives to hydraulic fluids,
- Advantages of various types of oil.
- Advantages of oil vs. air as working fluid.

Fluid power pumps and compressors
- Function and purposes of pumps and compressors
- Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump. (ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps (iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
- Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
- Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.

Hydraulic and Pneumatic pressure control

Pressure Control Valves, construction and working principles of relief valves- direct acting and pilot operated relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Hydraulic fuse, pressure switch, Pneumatic Pressure regulating valves.

Flow control valves

Basic two way valves, non-compensated flow control valves, throttle valves, restrictor valve, needle valve, ball tip valve, check valves, control valve circuits, pressure compensated flow control valve, demand-compensated flow control, pressure, temperature-compensated, flow control valve, methods of speed regulation in pneumatics.

Directional control valves

Application of directional control valve (DCVs),, designs, construction and operation of check valves, pilot operated check valves, rotary and spool type valves, two way valves, shuttle valves, three way valves, diversion valves, four way valves, solenoid operated, control valves, operation of directional control valves, mounting interfaces, designation, type of actuation of DCVs, pneumatic direction control valves – two way, three way, four way valves, etc., solenoid operated, push button operated, lever operated pneumatic DCVs.

Actuators

Definitions, linear actuators – Hydraulic cylinders, Plunger type, , piston type, Single acting, double acting cylinders, spring return type, tandem and telescopic cylinder, construction of hydraulic cylinders, cylinder seals – piston seal, rod seal, wipes, wear pads, etc. mounting style of cylinders, Pneumatic reciprocating actuators.

Rotary actuators –motors and limited rotation rotary actuators, their types, construction, advantages, vane type single and double vane rotary actuators, rack and pinion type rotary actuators, gear motors – external and internal, gerotor motors, vane motors, Radial piston motors, non-rotating barrel type axial piston motors, advantages of hydraulic motors. Pneumatic rotary actuator, radial piston, vane, and axial piston type air motors etc.

Seals

Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

Pipes, Tubes and Hoses, fittings

Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.

Accessories

Hydraulic and pneumatic filters, their applications, working principles and designs, beta ratio, absolute filtration, nominal filtration, selection of filters, heat exchangers – types, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, types of pneumatic filters, regulators, lubricators, mufflers, dryers, reservoirs etc.

Hydraulic Circuit Design

- Introduction to fluid Power Symbols, Overview of IS 7513,
- Classification of hydraulic circuits, Criteria for designing open loop hydraulic circuits, Analyzing resistive loads, overrunning loads and inertial loads, Heat generation and control.
- Flow control circuits, Pressure control circuits, Direction control & check valve circuits, Cylinder circuits, Pump circuits, Hydraulic motor circuits, Accumulator circuits, Intensifier circuits, Regeneration circuits.
- Sizing of Hydraulic circuit components :
- Reservoir.
- Heat Exchanger: Oil to air heat exchanger, Oil to water heat exchanger.
- Filters: Sizing of suction filter, return line filter, pressure line filter, Beta ratio, Necessary sizing information for filters.
- Fluid Conductors: Flow v/s Pressure drop, Pressure losses, tube/ hose sizing, Pressure rating, Hose/ Tube designation, Calculation of pressure drop in straight lines, bends, fittings etc.
- Pumps: Fixed displacement, variable displacement pumps, Design of suction side and pressure side of pump
- Hydraulic cylinders and motors.
- Accumulator: Isothermal &Adiabatic charging / discharging of accumulator. Sizing of accumulator for various applications i.e. energy storage, shock absorber etc.
- Valves sizing: Direction, pressure & flow control valves.

- Hydraulic Circuit Dynamics considerations: Bulk modulus, Spring rates, natural frequencies, Transmission line dynamics, Pulses in transmissions, Energy controls, Load energy output interaction, system stability, damping, time constant, system response, hydraulic system parameters i.e. resistance, capacitance, impedance.

Advanced Hydraulic Control Circuits

- Various pilot operated valves, construction features, operation, and advantages.
- Modular valves, Stacked type direction control valves, flow control valves, pressure control valves and

combinations.
- Electrically modulated pressure control valves, flow control valves. Pulse width modulation,
- Proportional controls, Servo controls, construction, Uses, differences, operation, advantages and disadvantages.
- Cartridge Valves: Design and construction features of cartridge valves, Types and Operation of cartridge valves, Advantages of cartridge design.
- Advanced pump controls, load sensing, pressure compensation.
- Integrated Hydraulic Circuit:Construction , Advantages of integrated hydraulic circuit, Case study of PVG32 valve, Various modules of PVG 32 valve block, Features of integrated hydraulic circuit of PVG 32, Electronic control capabilities.
- Pneumatic control circuits, proportional and servo valve, proportional and servo actuators

Water Hydraulics and Component Design
- Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals.
- Case Study-1: Differential Pressure Reducing Valve: Conceptual design and sizing
- Case Study-2: Auto Differential Pressure Control Valve - Conceptual design and sizing.
- Case Study-3: Pressure Compensated Flow Control Valve - Conceptual design and sizing.
- Case Study-4: Pilot Operated Pressure Control Valve - Conceptual design and sizing

Electronics and Instrumentation for Hydraulics:
- Current/ Voltage Sources and its measurements, Electronic components –resistance, capacitor, transistors, Opamps etc. Basic circuits for Addition multiplication, division using Opamps. Digital electronics, Logic gates.
- Analog to Digital converters (ADC) and Digital to analog controllers (DAC), Signal conditioning circuits, filters.
- Sensors-Pressure measurement, pressure switches, Position measurement, limit switches-proximity switches, Velocity measurements, Temperature measurement, temperature switches, Viscosity, density measurement, Force, torque, strain measurements.
- Controllers, Closed loop and open loop controllers, Proportional, Integral, derivative controllers and its uses and characteristics. Analog and digital controllers, comparison between digital and analog controllers. Programmable logic controllers, different I/O modules, wiring sensors to PLC. Introduction to microcontrollers, Applications, programming.
- Data Acquisition, Communication buses RS232,RS485, CAN bus, MODBUS, CANOpen bus uses and applications.

Fluid Logic & Control:
- Need for Fluid Control.
- Building Basic Elements for Control Logic (AND, OR, NOT, NAND, NOR).
- Function Implementations using Control Logic.

Experiments :
1. Tuning of PID controller in rotary actuator test facility.
2. Speed control of hydraulic motor using PLC.
3. Measurement of cleanliness level of hydraulic oil samples using particle counter.
4. Qualitative analysis of oil samples using Ferrograph.
5. Establishing position control using frictionless hydraulic linear actuator.
6. Finding characteristics of Differential Pressure Reducing Valve.
7. Finding characteristics of Auto Differential pressure control valve.
8. Finding characteristics of Pressure Compensated Flow Control Valve.
9. Finding characteristics of Pilot Operated Pressure Control Valve.
10. Study of Rexroth/Bemco oil hydraulic power pack and carrying out pressure setting, flow setting etc. in the same.
11. Experiments on ROHYTAM
12. Testing of oil hydraulic filter using filter test set-up.
13. Dismantling & assembling of various valves and actuators.

EN 710: Image Processing & Machine Vision (30)

Image Processing
- Introduction: Digital image model representation, Image sensor, Digitizer, Computer, Standard file format;
- Image Enhancement: Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Colour image processing;
- Image Segmentation and Analysis: Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation;
- Boundary extraction and representation;
- Morphological operations;
- Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy-based

methods;

- Image Compression: Models, Error free compression, Lossy compression, Standards;

Machine Vision

- Imaging model, Scene radiance and image irradiance, Reflectance model of a surface, Lambertian and specular reflectance, Photometric stereo;
- Early Vision: Low level processing for noise suppression, Segmentation by thresholding; Edge detection, Boundary representation,Mathematical Morphology;
- Intermediate Vision: Line, Circle, Ellipse and Polygon detection, Hough Transform for detection, Corner detection, The Generalized Hough Transform;
- High Level Vision: Scene interpretation;
- Texture – Statistical, Structural and Spectral approaches;
- Stereo vision and correspondence problem; Structured light; Optical flow;
- Image representation: Invariants;
- Unstructured objects: Snakes;
- Recognition & Interpretation: Patterns & pattern classes, Classifiers in general, Distance metric, Classification and recognition, Various methods of recognition & interpretation, Template matching and area correlation, Matched filtering;
- Introduction to image understanding;
- Robotic applications of machine vision, Camera calibration;

References:

1. Rafel C Gonzalez, and Richard E Woods, Digital Image Processing, Addison Wesley, 1999.
5. Milan Sonka, Vaclav Hlavac & Roger Boyle, Image Processing, Analysis, and Machine , Vision,Vikas Publishing House,2003.
6. William K Pratt, Digital Image Processing, John Wiley & Sons, Inc. 2004.
7. Davies E.R., Machine Vision Theory Algorithms Practicalities, Academic Press.
8. D.A. Forsyth & J. Ponce, Computer Vision A Modern Approach, Prentice Hall,2003.
9. Horn B.K.P., Robot Vision, The MIT press, 1987.
10. D. Ballard and C. Brown, Computer Vision, Prentice Hall, 1982.
11. Wesley E. Snyder & Hairong Qi, Machine Vision, Cambridge, 2004.

EN 711: Machine Design (25)

Principles of Machine Design:

- Objectives of machine design, general design rules, design methods
- Lightening of' parts and rational design schemes,
- Rigidity of structures, Cyclical/ Contact/ Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs.
- Introduction to inventive problem solving.

Design and Drawing Practices

- Drawing standards, selection of tolerances, fits, and positional tolerances.
- Introduction to Drawing Practices: (matter from various drafting standards),
- Introduction to CAD (including introduction to various drafting and solid modeling softwares)

Sealing Methods

- Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric 'O' rings, mechanical seals, labyrinth, valve packings.
- Methods of sealing for high and ultra high vacuum.

Special Dimensional Inspection Techniques

- Description of special dimensional inspection techniques, gaging techniques including composite and paper gauging, Advanced inspection tools including co-ordinate measuring machines and form measuring machines.

Advanced Manufacturing Techniques:

- Precision machining, super finishing, advanced manufacturing
- Micro machining.

References:

1. "Mechanical Engineering Design" by Joseph E. Shigley.
2. "Machinery's Hand Book" (24th edition)
3. "ISO Standards Hand Book" 18.
4. "SKF Bearing Catalogue."
5. "Relevant IS standards."
6. "Friction, Wear, Lubrication, Tribology Hand Book" edited by Prof. I.V.Kragelsky & V.V Alisim.

7. “Gear Hand Book by” Dudley.
8. “AGMA Standards 218.01” Dec. 1982.
9. “Industrial Sealing Technology” by H.HUGO BUCHTER

EN 712: Material Science in Nuclear Engineering (ME) (20)

- Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.
- Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X- ray Radiography, etc. for welds.

Corrosion

- Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards

Metallurgy of steels

- Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
- Selection and application of advanced alloys.

Nuclear Materials

- Fabrication, properties and application of Zircaloy, Zr-Nb alloys
- Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications.

Advanced Polymeric materials and Composites

- Physical and Chemical Properties, corrosion, mechanicalproperties
- Equipment design with polymeric materials
- Fabrication principles; standards for design, fabrication and testing.

References:

1. “Introduction to Materials Science for Engineers” - James Shackelford
2. “Physical Metallurgy Principles & Practice” - V.Raghavan
3. “Introduction to Solids” - L.V.Azaroff
4. “Structure and Properties of Materials” - Wulff Series, Wiley Eastern, New Delhi
5. “Materials in Nuclear Application” - C.K.Gupta
6. “Nuclear Chemical Engineering” - Benedict and Pigford

EN 713: Materials Characterisation (20)

Microscopy Techniques

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
  - Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
  - Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High reolution electron microscopy
  - Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, Other modes of operation, Applications in failure analysis, fracture surfaces etc.
  - Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

X-Ray Diffraction and Applications

  - Properties of x-rays: continuous and characteristics x-rays, absorption, filter, production and detection of x-rays.
  - Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
  - Experimental methods in x-ray analysis; Laue methods, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates,

crystal size crystal perfection, crystal orientations:

Chemical Analysis (with applications in materials science).

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

Basics of Analytical Transmission Electron Microscopy,

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, llllcorrections
- Cliff Lorimer factor, thin film correction

Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
- Fundamentals of energy filtering and its uses in life sciences
- Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
- Case studies for metallic bulk samples, life science samples, nano-materials

Physical and Thermal Characterization Techniques

- **Thermal expansion**: Methods and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
- **Thermal Conductivity**: Methods and their principle, advantages and limitations of each method, data of nuclear Fuels
- **TGA/DTA/DSC**: Methods and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
- **Elastic Properties**: Methods and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
- **Hardness**: Different methods and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

EN 714: Membrane Technology (35)

Fundamentals and Overview of Membrane Processes: (5)

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Growth Potential, Classification and description of membrane processes
- Pressure driven membrane processes (MF, UF, NF and RO)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

Novel Membranes

- Features, transport mechanism and application areas
- Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Membrane Bio-reactor, Fuel cell membranes, Membrane sensors, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

Membrane Materials, Preparation and Characterization: (10)

- Material selection
- Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity Molecular weight and molecular architecture
- Membrane preparation techniques- Phase-Inversion, In-situ polymerization, Track-etching, Slip-casting, Sintering
- Membrane Casting Aspects for continuous casting
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of charged membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
- Surface characterization -pore size, roughness, in-homogeneities, and hydrophilicity
- Bulk characterization -porosity, permeation study through flux and solute rejection.

Engineering and Design Aspects of Membrane Technology (10)

- Transport through membranes-Preferential sorption-capillary model,Solution Diffusion model, Irreversible thermodynamics model
- Derivation of basic transport equation for RO membranes

- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants
- Pretreatment considerations, Water chemistry- turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control,Scaling assessment parameters (SDI, MFI)
- Materials of construction
- Process design and system design for water desalination-Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices -pelton wheel, turbo-charger and pressure exchanger
- Effect of operating parameters on membrane performance
- Membrane cleaning and protocols
- Trouble-shooting analysis of operating plants
- Post-treatment techniques
- Membrane autopsy, Reject disposal techniques and brine management.

Membrane Technology Applications (10)

- Techno-economics of membranedesalination plant - seawater / brackish water
- Design aspects of water recovery & recycle from spent streams including sewage Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle
- Hybrid membrane systems, Combo systems -membrane + conventional- for separation application
- Nuclear Desalination
- Membrane based water purification systems-RO/UF application in food processing, pharmaceuticals and Bio-technology
- Fractionation & Value Recovery.
- Zero Liquid Discharge (ZLD)

References

1. Membrane Technology & Applications by Richard W Baker (2008)
2. Membrane Handbook by Ho and Sircar (1992)
3. Transport Phenomena in Membrane by K. Lakshminarayanaiah (1970)

EN 715: Multi-Scale Material Modeling (20)

Introduction

- Spatial and temporal hierarchy of microstructure and dynamics in materials
- Types of models: quantum mechanical, atomistic, mesoscopic, continuum
- Multiscale approaches

Short review and elements of differential equations (numerical solution)

- Differential equations in discrete and continuum simulation methods
- Ordinary differential equations for particle dynamics
- Partial differential equations, conduction/diffusion equation

Atomistic models: Molecular dynamics

- The basics of classical molecular dynamics
- Initial conditions, creating lattice structures, introducing defects
- Defining and maintaining temperature and pressure
- Boundary conditions (periodic, stochastic, conducting, non-reflecting)
- Methods for constant temperature or/and pressure simulations
- Tricks of the trade (neighbor lists, force/energy tables, potential cutoffs, etc.)

Monte Carlo methods

- The basics of Monte Carlo
- Monte Carlo integration, thermodynamic averages
- Importance sampling, Metropolis scheme
- Lattice Monte Carlo, Ising model
- Multi-state Potts models (grain coarsening, recrystallization)
- Kinetic Monte Carlo (surface processes, thin film growth)

Interatomic potentials

- Introduction, Born-Oppenheimer approximation
- Pair potentials and their limitations
- Calculation of elastic constants from potential function

- Potentials for ionic systems, ceramics
- Many-body potentials for metals
- Many-body potentials for covalently bounded systems
- Forces from "first principles"

Analysis of the simulation results

- Equilibrium properties (energy, temperature, pressure, velocity distributions)
- Structural properties (geometrical tessellation, pair correlation functions, atomic level stresses)
- Dynamic properties (diffusion, time correlation functions)

Mesoscopic methods

- Discrete dislocation dynamics
- Strain and stress fields for edge and screw dislocations in an isotropic medium
- The equation of motion in Newtonian Dislocation Dynamics
- Examples from 2D and 3D simulations
- Current problems
- Coarse-grained models

Bridging the scale gaps between different simulation levels

- Simultaneous integration of the models
- Sequential integration of the models (hierarchical approach)
- Examples of combined methods (MD-FEM, MD-MC, etc.)

Modeling at microscale

- Mechanism of ductile fracture and cleavage fracture
- Gurson constitutive law for modeling ductile damage
- Roussiler constitutive law for modeling ductile damage
- Beremin's model for cleavage fracture
- Modeling of material under transition temperature
- Case studies

EN 716: Preparedness & Response to Nuclear Emergencies (35)

- Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
- Radiation Shielding & Study of Criticality parameters and control
- Nuclear Waste Management
- Nuclear Accidents/emergencies
- Transport of Radioactive material
- Radiological accidents/emergencies
- Effects of Hiroshima & Nagasaki bombing
- Detection of Nuclear detonation
- Nuclear weapons: effect (Blast, heat, Radiation and EMP)
- Medical decontamination with demonstration
- Nuclear weapon tests (atmospheric)
- Nuclear & Radiological terrorism (Method to contain and control)
- Chemical warfare & Biological warfare (Method to contain and control it)
- Emergency Response methodology/ Philosophy
- Systems and methodology for Radiological impact assessment
- Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities
- Emergency Monitoring & Shelters
- Civil defence WEB plan for Nuclear attack on major cities
- Monitoring of High radiation field area
- Lab Visits

EN 717: Project Management (25)

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
  - Resources of project.
  - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an

activity, earliest start time EST, latest completion time LCT.
- o Scheduling in a project by critical path method, CPM
- o Scheduling in a project by Precedence Diagram Method.
- o Use of Project Management Software for project planning, scheduling & monitoring.
- o Preparation of master control management milestone network, Level-1,2, 3 & 4 network.

- Preparation of Target Plan, updating of progress, monitoring variance & reporting
  - o Constraints of project and its effective management o Development of Six Monthly Plan and its review process o Resource based planning
  - o Physical & Financial Monitoring of project, Use of S-curve
  - o Capital Budgeting & expenditure control in a project
  - o Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis methods, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN 718: Reliability Engineering (ME) (25)

- Reliability Mathematics – Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
- Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
- Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
- Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
- System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
- Application of Reliability - PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

References:

1. Mishra, K.B., “ Reliability Analysis and Prediction”, Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M.,Reliability& Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., “Reliability in Engineering Design”, John Wiley & Sons, 1977.
5. Balaguruswamy, E., “Reliability Engineering” Tata Mcgraw-Hill, 1984.
14. Provan, J.W., “Probabilistic Fracture Mechanics & Reliability”, Martinus Nijhoff, 1987.
15. Nowak, A. S. and Collins, K. R., “Reliability of Structures” McGraw Hill, 2000.
16. Ayyub, B. M. and McCuen, R. H., “Probability, Statistics and Reliability for Engineers”, CRC Press, 1997.
17. Haldar, A. and Mahadevan, S., “Probability, Reliability and Statistical Methods in Engineering Design”,
18. John Wiley and Sons, Inc. 2000.

EN 719: Signal Conditioning, Recovery & EMI Aspects (25)

Review of Analog Signal Conditioning & Recovery Techniques

- Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types ofA/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

Theory of Quantization

- Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti- aliasing filters, fast algorithms for implementation.

Theory of Signal Analysis and Reconstruction

- Function space, orthogonal basis functions, Limitation of Shanon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

Review of EMI Aspects

- Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

EMI Modeling

- Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

EN 720: Software Engineering (25)

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools.(3)
- Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods Testing principles, unit testing, integration testing, acceptance testing Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

EN 721: Vibrations (25)

- Single-degree-of-Freedom (SDOF) Systems: Free vibration - equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations - underdamped, overdarnped and critically damped systems; Material and structural damping - evaluation of damping in SIDOF systems; Response to harmonic loading - complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duharnl's Integral.
    - Multi-Degree-of-Freedom (MDOF) Systems: Equations of motion - Lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
- Response of Systems To Ground Motion: Earthquake motion - Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake - Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis - Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
    - Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft - Jeff Cott rotor;

Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating rnachinary.

- Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
- Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
- Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, aperiodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross - Correlation and significance of these parameters; Application of vibration for condition monitoring and diagnostics; Vibration standards for acceptance.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Methods in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN 722: Safety and Reliability of Civil Engineering Structures (25)

Introduction to Probability Theory

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, ProbabilityDistributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

Structural Reliability

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment Method, Hasofer Lind Reliability Index, Rackwitz Fiesseler Method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

Probabilistic Safety Assessment

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

Industrial Safety

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

Safety assessment of existing structures:

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

Introduction to decommissioning of structures

References:

1. Hahn, G. J.and Shapiro, S. S. (1994), “Statistical Model in Engineering” Wiley-Interscience.
2. Ranganathan, R. (2000), “Reliability analysis and design of structures”,Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), “A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”, The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety Standard No. AERB/SS/CSE.
6. AERB (1996),“Atomic Energy (Factories) Rules”.

7. AERB (1991), “Safety Guide for Works contract”, Safety Guide No. AERB/SG/IS-1
8. AERB (1996), “The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex”, Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”.
10. Regulatory Guide 1.165 (1997), “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion”, U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (25)

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- BeamWelding Processes
- Arc-Beam Hybrid WeldingProcesses
- Study of welding arc characteristics
- Metal transferduringarcwelding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on themacro-andmicro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high coolingrates
- Phenomena of hot-crackingand coldcracking
- Residualstresses anddistortion duringand afterwelding
- Residual stressmeasurements
- Application ofaboveprinciplesto welding ofcarbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

EN724: Advanced Structural Dynamics and Earthquake Engineering(CE) (30)

I. Introduction to Structural Dynamics and Earthquake Engineering

II. Performance Based Design of structures, systems and components subjected to earthquake loading

Concepts of performance bases, Seismic demand, Capacity of structures, systems and components, performance levels, energy dissipation and damping.

II. Seismic and Vibration Control

Concepts of seismic and vibration control, Passive control using Yielding dampers, friction dampers, tuned mass dampers, Tuned liquid damper, etc., Semi active and active control strategies.

III. Base Isolation Techniques

Concepts of vibration and seismic isolation, laminated rubber bearings, Lead plug bearings, Friction Isolation System etc.

V. Testing and Modal analysis

Need of testing, Methods of testing, qualification of systems by testing, data processing using FFT and Wavelets, modal analysis for frequency, mode shapes and damping. Causes and types of experimental error, statistical analysis of data.

VI. Seismic and Vibration Instrumentation

Measurement Methods and Applications: Measurement of displacement, velocity, acceleration, pressure, forces, strain and optical methods of measurements; Data Acquisition and Processing.

Types of inputs: analog and digital signals, calibration and uncertainty, Measurement System: Performance characteristics, linearity, dynamic range, sensitivity, stability, accuracy, bandwidth, noise, repeatability, hysteresis- threshold- resolution, readability and span.

VII. Fluid-structure interaction techniques

Coupling of fluid with structure, Dimensionless numbers in fluid-structure interactions, Added mass and added stiffness, Fluid sloshing, Flow induced vibration, Flow over bluffed bodies, Vortex shedding.

VIII. Multibody Dynamics

Rigid-Body Kinematics, Kinematics for General Multibody Systems, Modelling of forces in multibody systems, contact forces, friction effect, Equations of Motion of Multibody Systems.
Numerical integration methods for free standing objects, spring-mass system with friction, Runge Kutta methods, error estimation, Computer programs.

Text / Reference Books

1. A. K. Chopra, “Dynamics of structures”, Prentice Hall, 4th edition, 2007.
2. S. S. Rao, “Mechanical vibration”, Prentice Hall, 5th edition, 2014.
3. Holman, “Experimental Methods for Engineers”, 6e, McGraw-Hill, 1994.
4. Doeblin, Engineering Experimentation, McGraw-Hill, 1995.
5. Hans-Joachim Bungartz Michael Schäfer, “Fluid-Structure Interaction Modelling, Simulation, Optimization”, Springer-Verlag Berlin Heidelberg 2006.
6. Soong, T.T. and G.F. Dargush, “Passive Energy Dissipation Systems in Structural Engineering”, Wiley & Sons, New York, 1997
7. Farid Amirouche, “Fundamentals of Multi Body Dynamics, Theory and Applications”, Springer Science, 2006

NON-SUBJECT ASSIGNMENTS

EN 591: Viva Voce

In addition to the formall assessment carried out by the mehod of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.

EN 592.1: Process Control Trainer (15)

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

Expt 1

Introduction to typical process under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.

Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

Expt 2

Optimisation of process control - using ultimate sensitivity method.

Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.

Optimum gain and integral / differential time constants are calculated using empirical formulae.

Expt 3

Feed forward control configuration - study of process response in comparison with normal feedback control.

Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

Expt 4

Smart Differential Pressure transmitter.

Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.

Re range transmitter using HART communicator.

Re configure transmitter for linear and square root characteristics.

Expt 5

Final control element - Linear pneumatic control valve.

Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.

Virtual instrumentation and wireless data communication between controller and PC.

EN 592.2: Nuclear Detectors (15)

A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.

NaI(Tl) γ- Ray Scintillation Detector

This experiments imparts training on the use of NaI(Tl) detector using known γ- Ray sources (Co^{60} & Cs^{137}) , plotting of calibration curves and identification of unknown sources.

α-Particle spectroscopy using a Solid State Detector

This experiment imparts training on the use of the Solid State Detector using known α-Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup. **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter , testing counting statistics of the counter and studying absorption behaviour of β-rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN 593: Mini-Project Work (300)

The 11 week Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses. The principle objective of carrying out a Mini- Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists.

The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 225 being awarded by the expert committee and 75 by the guide.). Project runs on a part time basis for 11 weeks from mid May to Mid July.

BACK TO MAIN

IGCAR

INTEGRATED Ph.D. (SINGLE DEGREE)
ENGINEERING SCIENCES

(PROGRAM CODE: ENGG18)

MECHANICAL ENGINEERING

NUCLEAR ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
	Total	**230**	**25**

CORE ENGINEERING

(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
ME1	Code Design for Pressure Vessels and Piping	30	4
ME4	High Temperature Design and Inelastic Analysis	25	2
ME6	Computational Fluid Dynamics	30	4
ME8	Finite Element Method	30	4
ME10	Advanced Heat and Mass Transfer	30	4
ME13	Reliability Engineering	20	2
ME14	Manufacturing Technology	40	4
	Total	**205**	**24**

SPECIALISED/ELECTIVE COURSES

(Any three of the seven listed courses)

Course Code	Course Name	Hours	credits
ME3	Machine Design	25	2
	Structural Integrity Assessment Methods and NDE	30	4
	Vibration Engineering and condition Monitoring	20	2
ME5	Seismic Design of Nuclear Reactors and Facilities	20	2
	Plant Dynamics	20	2
	Experimental Mechanics	20	2
ME15	Process Control and Instrumentation	20	2

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-001-P	Project	Duration : 9 Weeks	
2.	02ENGG04-001-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

1. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
2. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
3. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
4. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
5. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
6. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
7. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity

2 **Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor

3 **Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors

4 **Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation

5 **Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions

6 **Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization

B BASIC REACTOR PHYSICS-STATIC

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety
Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down
Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
7. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

   Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. **Thermal Power Reactors :**

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. **Fast Power Reactors :**

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology (NRST)**

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flowmeter: Electromagnetic pumps and flowmeter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6.	Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7.	Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Code Design for Pressure Vessel & Piping (ME1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3
11.	Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , ‘Pressure vessel design’ CBS publication
2. Brownell. L. E & Young. E. D , ‘Process equipment design’, Wiley Eastern Ltd., India

3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Finite Element Method (ME8) (30 hours)

S.No.	Course content
1.	Introduction to FEM as applied to solid mechanics. Energy principles in structural mechanics and principles of minimum potential energy
2.	Element Shape and Shape Functions: Generalised co-ordinates. General requirements of shape functions; Lagrangian and Hermitian interpolation functions – CO, C1 continuity; Natural coordinate system; Derivation of shape functions for Bar, Beam, Plane, Brick and Plate elements.
3.	Bar Element: Derivation of elemental stiffness matrix and load vector; Transformation from element to global coordinate system; Assembly of Global stiffness matrix and load vector; Solution of typical 2D-plane Truss problems to evaluate Displacements and Member forces/stress; Thermal stress evaluation in Bars/Truss.
4.	Beam Element: Derivation of elemental stiffness matrix and load vector; Solution of simple Beam problems to evaluate Deflections/rotations; BM/SF distribution and determination of stresses, Shear deformation in beams. Curved Beam Element: Derivation of elemental stiffness matrix and load vector; Derivation of stiffness matrix for elbow.
5.	Axisymmetric Thin Shell Element: Strain-displacement and stress-strain relationship; Derivation of stiffness matrix and load vector for 2 noded axisymmetric thin shell element. 2D Plane Elements – 3 Noded Triangular Element: Derivation of elemental stiffness matrix and load vector, Plane Stress/Plane Strain & Axisymmetric elements: Evaluation of Strain/Stress.
6.	2D Isoparametric Element – 4, 8 and 12 noded quadrilateral Element: mapping of parent element to global space; Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of stiffness matrix for plane & axisymmetric elements; Evaluation of strain/stress at Gauss points.
7.	Introduction and Application of 3D Elements: Strain displacement and stress-strain relationship; Tetrahedron, Triangular prism and Hexahedron elements.
8.	Plane Bending Elements: Thin and Thick plate theory; Elements based on Kirchoff's Theory; Elements based on Mindlin Theory; Shear locking and Reduced Integration.
9.	Shell Element: Strain-displacement and stress-strain relationship; Flat plate and curved shell elements; 4 and 8 noded degenerated thick shell Elements, basic assumptions, degree of freedom, shape functions and shear locking.
10.	Incompatible Displacement Model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral element.
11.	Introduction to Nonlinear Problems. Meshing and Errors: Finite Element Modeling and Discritization Criterion, Adaptive meshing, classification of FEM stresses per ASME code, sources of potential error in the finite element solution

Books Suggested:

1.Finite Element Procedures-K.J.Bathe, Prentice Hall, 1996.
2.Concepts and Applications of Finite Element Analysis, R.D.Cook,D.S.Malkus & M.E.Plesha, 4th Ed., Prentice-Hall India, 2003.
3.An introduction to the Finite Element Method-J.N.Reddy, 2nd Ed., McGraw Hill Education (ISE editions)-1993.
4.Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.1, Butterworths-Heinemann,2000.
5. Finite Element Method-O.C.Zienkiewicz & R.L.Taylor, 5th Ed., Vol.2, Butterworths-Heinemann,2000.

6.The Finite Element Methods: its basics and fundamentals- O.C.Zienkiewicz ,R.L.Taylor &J.Z.Hu, Elsevier,2005.
7.The Finite Element Method: Linear,Static and Dynamic Finite Element analysis-T.J.R.Hughes, Dover Publication,2000.
8.Fundamentals Finite Element Analysis and Applications-M.Ashghar Bhatti, John-Wiley & Sons, NJ,2005.

3. Advanced Heat and Mass Transfer (ME10) (30 hours)

S.No.	Course content
1.	**Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes & Bemoulli equations.
2.	**Laminar Boundary Layer and Forced Convective Heat:** Formulation of differential equation for hydrodynamic and thermal boundary layer. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory. Convective heat transfer for intemal and extemal flows. Low and high Prandtl number limits and different thermal boundary conditions Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method.
3.	**Turbulent Flow and Heat Transfer:** Reynolds decomposition for turbulence**.** Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical. correlations for calculating heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
4.	**Turbulence Modeling:** Eddy diffusivity models: k-£ and k-w) models, RNG based k- £ model. Reynolds stress models: algebraic & differential models. Low Reynolds number models Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models
5.	**Natural Convection:** Basic Equations of natural convection. Boussinesq approximation. Derivation of Dimensionless groups from basic equations. Analytical approximations
6.	**Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Moment, porosity, permeability etc.., homogenization method, continuity equation & energy equation, introduction to 2 phase flows & heat transfer in fluid flows.
7.	**Heat Transfer With Phase Change** : Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post dryout heat transfer. Various models available for calculation of heat transfer coefficient.. Critical Flow. Models for single - phase and two-phase critical flow.
8.	**Radiation heat transfer:** Radiation heat transfer. Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies.

Books suggested:
1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.

3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

4. Computational Fluid Dynamics (ME6) (30 hours)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme
B.	**Numerical Solution of Complete Fluid Flow and Energy Equation:**
1.	Formulations of governing equations used in numerical simulation:
2.	Stream function-temperature formulation
3.	Stream function-vorticity-temperature formulation
4.	Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5.	Primitive-Variable (P-V-T) formulation
6.	Pressure velocity coupling for incompressible flow.
7.	Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8.	Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9.	Simple grid generation techniques for structured grid:
10.	Elliptic. parabolic and hyperbolic equation method
11.	Grid adaptation
12.	Domain decompositions in CFD and heat transfer
13.	SIP and preconditioned conjugate gradient methods for solution

14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.

15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.

16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Books suggested:

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

5. Reliability Engineering (ME13) (20 hours)

S.No.	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.
2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.
4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.\
5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.
6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.
7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987
8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.
9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY.

6. Manufacturing Technology (ME14) (40 hours)

S.No. **Course content**

Curriculum for Metal Forming

1. **Uniaxial tensile test**:
   a. Engineering stress, engineering stain, true stress, true strain;
   b. Extraction of plastic stress-plastic strain data from load – elongation data of uniaxial tensile tests; Hollomon type and Voce type constitutive relations;
   c. Tensile instability and significance of strain harkening exponent;
   d. Determination of strain rate sensitivity index and the significance of strain rate sensitivity;
2. Stress matrix and the derivation of the Cauchy relation from the law of conservation of linear momentum; concept of principal stress;
3. Small strain matrix and rotation matrix obtained from the displacement functions;
4. **Elements of the theory of plasticity**:
   a. Decomposition of stress matrix to hydrostatic and deviatoric matrices;
   b. Yield surfaces as a function of the second and third invariants of the deviatoric matrix with von Mises and Tresca criteria being examples; concept of equivalent stess;
   c. Normality flow rule and convexity of the yield surface; concept of equivalent strain

Curriculum for Materials Joining

1. **Welding Processes**
   a. Fusion Welding Processes: Arc Welding Processes like SMAW, GTAW, GMSE, GVSE etc. and Beam welding process like EB welding and Laser Welding
   b. Solid state Welding Process like Friction Welding, Friction Stir Welding, Diffusion bonding, Explosive welding
   c. Resistance Welding Processes
2. **Thermal Cycle during welding**
   a. Weld Thermal Cycle, Dependence of bead shape with welding speed, prediction of weld thermal cycle
3. **Residual Stress and Distortion**
   a. Generation of residual stress, Effect of residual stress on performance, removal of residual stresses, measurement of residual stresses
   b. Origin of Distortion, Control of distortion

7. High Temperature Design & Inelastic Analysis ME4: (25 hours)

S.No. **Course content**

1. Introduction: Modes of failure, material selection, criteria to assess creep effect, creep law, creep-fatigue interaction, thermal striping
2. Design Practice: Loading category, primary, secondary and peak stress intensity, allowable stress intensity (S_m), assessment of basic wall thickness, strain limits

3. Analysis: strain range under multi axial state of stress, Nuber’s rule, triaxiality, elastic followup, fatigue damage, allowable numbers of cycle, creep damage, creep life prediction, creep rupture strength, creep fatigue interaction, ratcheting, efficiency diagrams and creep buckling
4. Fracture mechanics, creep crack growth, introduction to RCC-MR A16
5. In elastic Analysis: General principles for constitutive models, non unified model (plastic + creep), flow rule, creep strain hardening, classified models, viscoplastic material model, non-linear kinematic hardening, isotropic hardening, plastic strain memory, finite element Implementation, automatic time integration

Books Suggested:

1.Creep Analysis – H.Krauss
2.Mechanical Metallurgy-G.E. Dieter
3.Creep in Structures-A.R.S.Ponder and Drkhayhurst
4.Advances in Creep Design-Ed.A.I.Smith and A.M.Nickelson
5.ASME Section3 Subsection NH-1
6.French Design Code-RCCMR-Subsection RB

SPECIALISED/ELECTIVE COURSES

1. Machine Design (25 hours)

S.No.	Course content
1.	Principles of Machine Design: Objectives of machine design, general design rules, design methods, variable loads, Lightening of parts and rational design schemes, Rigidity of structures, Cyclical/Contact/Thermal strengthening, Surface finish, special machine elements bearings. Expansion bellows and springs. Introduction to inventive problem solving.
2.	Design and Drawing Practices: Drawing standards, selection of tolerances, fits, and positional tolerances. Introduction to Drawing Practices: (matter from various drafting standards), Introduction to CAD (including introduction to various drafting and solid modelling softwares)
3.	Sealing Methods: Static, dynamic, metallic and non-metallic seals, pipe threads, seal materials and their selection, elastomeric `O’ rings, mechanical seals, labyrinth, valve packings. Methods of sealing for high and ultra high vacuum.
4.	Special Dimensional Inspection Techniques: Description of special dimensional inspection techniques, gauging techniques including composite and paper gauging, advanced inspection tools including co-ordinate measuring machines and form measuring machines.
5.	Advanced Manufacturing Techniques: Precision machining, super finishing, advanced manufacturing, Micro machining.

Books suggested:

1) Mechanical engineering design (In SI Units) - Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2) Design Of Machine Elements Edition 7 - Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3) Machine Elements in Mechanical Design - Mott (R L), Columbus, Charles E Merril, 1985.
4) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.

5) Mechanical Engineering Design (In SI Units) – Joseph E Shigley & Charles R. Mischke, New Delhi, Tata Mcgraw Hill, 2001.
6) Design of Machine Elements - Ed. 7 – Spoots M F, Shoup T E, New Jersey, Prentice Hall 1998
7) Machine Elements in Mechanical Desgin – Moot R L, Columbus, Charles E Merril, 1985.
8) Design of machine elements – V B Bhandari, Tata Mcgraw Hill.
9) Fundamentals of machine design – Oriov, Mir Publishers, Moscow.
10) Fluid power applications – Anthony Esposito, Pearson education
11) Precision engineering manufacturing – Murthy R.L., New Age International
12) MEMS and Microsystems design and manufacture – Tai-Ram Hsu, Tata McGraw Hill.

2. Structural Integrity Assessment Methods and NDE (ME3) (30 hours)

S.No.	Course content
1.	Fracture Mechanism in Metals
2.	Linear Elastic Fracture Mechanics
3.	Elastic Plastic Fracture Mechanics
4.	Low Cycle Fatigue
5.	Assessment of Creep damage and creep-fatigue interaction
6.	Creep crack growth models
7.	Experimental determination of fatigue and creep curve CTOD, KIC, KIa, J-R curve and C*
8.	Basis of ASME Sec. XI Reference Curve and its use in Pressurised Thermal Shock
9.	CTOD design method
10.	J-Estimation Schemes and J-based failure assessment diagram
11.	Net Section Collapse Criteria and Reference Stress approach
12.	R-6 method and its application
13.	Thermal background of international assessment procedure
14.	RCCMR code/A-16 method and its application
15.	CEGB codes
16.	Application of R-5/R-6 for design of high temperature components
17.	Failure Assessment Diagram of PD-6493 and BS-7910
18.	J-Estimation Schemes and J-based failure assessment diagram
19.	Leak-Before-Break design method
20.	Analysis of numerical techniques/Computational fatigue, Fracture and creep
21.	Probabilistic Fatigue, Fracture and creep
22.	Bench Mark solutions
23.	Manufacturing and process-induced defects that influence structural integrity -
24.	Principles, capabilities and applications of surface examination NDE techniques
25.	Principles, capabilities and applications of volumetric examination NDE techniques
26.	Quality assurance of nuclear components with relevant codes and standards and quality concepts
27.	Structural integrity, in-service inspection and life assessment of nuclear components using NDE
28.	NDE Lab visit and Practicals

Books Suggested:

1. Practical Non-destructive testing- Baldev Raj, Jayakumar.T. and Thavasimuthu. M., Narosa publishing house, New Delhi, 1997
2. Advances in NDE for structural integrity, - Nichols. R.W., Applied Science Publishers, London, 1982.
3. Non destructive Evaluation: A tool in Design, Manufacturing and Service and Francis – Don E.Bray and Roderick K. Stanley, Taylor, CRC Press, New york, 1996.
4. Non-destructive testing, R. Halmshaw, Edward Arnold, 1991.
5. Electrical and Magnetic Methods for Non-destructive testing, - J. Bllitz, Adam Hilger, Bristol, 1997.
6. Ultrasonic testing of materials, - Josef Krautkramer, Herbert Krautkramer, Springer-Verlag. January 1983.

3. Vibration Engineering and Condition Monitoring (20 hours)

S.No.	Course content
1.	Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2.	Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3.	Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; Aseismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4.	Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5.	Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6.	Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.
7.	Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum,

coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

4. Seismic Design of Nuclear Reactors and Facilities (ME5) (20 hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson’s ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
7.	**Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.

Books Suggested:

1. Chopra, A.K., "Dynamics of Structures, Theory and applications to Earthquake Engineering", Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures", New York, McGraw-Hill Book Company.
3. Mariopaz, "Structural Dynamic (Theory and Computation)", CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., "Numerical Methods in Finite Element Analysis", Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, "Engineering Seismology", IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, "Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites". AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design", BIS, New Delhi.

5. Plant Dynamics (20 hours)

S.No.	Course content
1.	**Pressure drop** in fuel Subassembly, friction, local acceleration and elevation pressure drop in wire-wrap. Flow zoning
2.	**Hot spot factors**: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors. Subchannel analysis of fuel subassemblies, mixing parameters, introduction to computer codes.

3. **Event analysis**: General safety features, General Considerations on Design Basis Events, Thermal and Hydraulic Modeling for Analysis, Safety Criteria, Design Criteria for Selection of SCRAM Parameters, Sympathetic Safety Actions, Primary Sodium Flow Halving Time, Maximum Permissible Absorber Rod Speed.

4. **Results of Analysis of Major DBE:** One Primary Sodium Pump Acceleration, Both Primary Sodium Pumps Acceleration, One Secondary Sodium Pump Acceleration, Both Secondary Sodium Pumps Acceleration, Feed water Flow Increase Events, Continuous Withdrawal of One CSR, One Primary Sodium Pump Trip, One Primary Sodium Pump Seizure, Off-Site Power Failure with Emergency Backup for PSP, Primary Pipe Rupture, One Secondary Sodium Pump Trip, One Secondary Sodium Pump Seizure, One Boiler Feed Pump Trip, Loss of Feed Water Flow to Steam Generator, Intermediate Heat Exchanger Sleeve Valve Closure, Loss of Heating in High Pressure Feed water Heaters, Spurious SCRAM. Reactor start-up, BFP Trip and over speeding at full power, Turbine Generator -Trip and subsequent plant operating actions, power setback.

5. **Decay Heat Removal:** Decay Heat Removal through OGDHRS, Decay Heat Removal through SGDHRS, Need for Forced Convection Core Flow, Decay Heat Removal during Station Blackout Situation, Adequacy of SGDHRS Capacity.

6. **Energy Release In Beyond Design Basis Events:** Local Events: Subassembly Accident, Whole Core Events: Pre – disassembly Phase, Disassembly Phase, Mechanical Energy Release / System Response Phase, Analysis of Transient Over Power Accident, Computer Codes, Analysis of Loss of Flow Accident (LOFA), Sodium Void Worth, Consequences of Fuel - Coolant Interaction

Books Suggested:
Material will be provided during the course

6. Experimental Mechanics (20 hours)

S.No.	Course content
1.	Stress & Strain: State of stress, strain, plane stress, plane strain, Thermal stress, Hydrostatic & Deviatoric Component of stress, Elastic stress-strain relationship, Elastic-Plastic strain relations, Von-mises plasticity criteria, plastic flow rule, strain hardening law, perfectly plastic material, Isotropic strain hardening material, kinematic strain hardening, combined strain hardening stress concentration, cyclic stress, Fatigue, Endurance limit, Creep, Larson Miller parameter.
2.	Photo elasticity: Polarisation, polariscope, diffused light and lense polariscope, stress optics law, plane polariscope, circular polariscope, criteria for model material selection, Isochromatic fringe pattern, Iso fringe pattern, scaling model to prototype stress.
3.	3D photo elasticity: locking of model deformations, scaling model and interpretation of the resulting fringe pattern, effective stresses, Birefringent coating, scattered light and its relation to photo elasticity, scattered light polariscope.
4.	Strain measurement methods: strain gage, basic characteristics, types of strain gages, factors in gage selection, electrical resistance strain gage, potentiometer for strain measurement, strain gage circuit, wheat stone bridge

5. Recording Instrument: galvanometer with oscillograph, transient response galvanometer, frequency response of the wheatstone bridge and galvanometer, cathode ray oscilloscope and potentiometer recorder.

Books Suggested:

1.Mechanical engineering design (In SI Units)', Joseph E Shigley & Charles R Mischke, New Delhi, Tata Mcgraw Hill, 2001.
2.Design Of Machine Elements Edition 7, Spoots (M F), Shoup (T E), New Jersey, Prentice Hall, 1998.
3.Machine Elements In Mechanical Design, Mott (R L), Columbus, Charles E Merril, 1985.
4.Experimental methods for engineers- J.P.Holman, McGraw Hill.
5.Theories of engineering experimentation-Hilbert Schenck, McGraw Hill.

7. Process Control & Instrumentation (Co-ordinator: A. Venkatesan) (20 hours)

S.No.	Course content
1.	Basic Concepts
2.	Units of measurements, Definitions (accuracy, precision, repeatability, span, range, hysterisis, drift, sensitivity, resolution, lag etc.) -- Sensors, transducers, Transmitters, PI diagrams, Symbols., Digital and analog devices.
3.	Sensing, Transmission, Receiving of the following Process Variables
4.	Temperature: classification, thermocouples, RTD, Thermistors, Pyrometers.
5.	Flow: Direct type, inferential type, constant area sensors, differential pressure meters, variable area meters, magnetic, ultrasonic, vortex type flow meters, and mass flow meters.
6.	Level: Direct type (Float, gauge glass, torque tube, piston tube, reflex etc) indirect type (Pressure gauge, purge, d/p with open/closed tanks, Ultrasonic, nucleonic, capacitance & conductivity).
7.	Pressure: Manometers, Bourdon, bellows, diaphragms, D/P Tx, (electronic & pneumatic), strain gauges, load cells.
8.	Analytical: pH, viscosity, conductivity, humidity, isotopic purity, and turbidity.
9.	Control System: Feedback Control theory, Modes of control, generation of control modes, Controllers, feedback & feed forward control, final control elements and valve positioners.
10.	Safety principles: Trip logic, annunciators, simple logic circuits, and smoke/fire detectors.
11.	Current Trends In Instrumentation: Smart transmitters, Instrumentation for a process loop, Paperless recorders, DAS, PLC, DRS, etc.

Books Suggested:

1. Instrument Technology Vol. I to V E.B. Jones.
2. Mechanical & Industrial Measurements, R.K. Jain
3. Automotive Process Control, Donald P. Eckman
4. Measurement Systems Application & Design, Ernest Doebelin.
5. Process Instrument & Control Handbook, Douglas Considine.
6. Instrument Engineers Handbook, Vol. I&II, Dela G. Liptak
7. Instrumentation for Process Measurement & Control, N.A. Anderson

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
ELECTRONICS AND INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
Total		**230**	**25**

CORE ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
EL2	Reactor Control Engineering	20	2
EL3	Nuclear Instrumentation	20	2
EL4	Reliability Engineering	20	2
EL5	Software Engineering	20	2
EL8	Human Machine Interface for Reactor Control Instrumentation	45	6
EL10	Modern Control of Dynamic Systems	30	4
Total		**155**	**18**

SPECIALISED COURSES

Course Code	Course Name	Hours	Credits
EL6	Artificial Intelligence and Digital Signal Processing	40	4
EL7	Process Instrumentation	35	4
EL9	Embedded and Computer based systems Design	45	6
EL11	Analytical Instrumentation	25	2
Total		**145**	**16**

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-002-P	Project	Duration : 9 Weeks	
2.	02ENGG04-002-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers B-splines, Bezier curves, Response surface method, different levels of factorial design.

Book suggested

8. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
9. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
10. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
11. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
12. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).

13. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
14. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

Sl.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

13. Introduction to Materials Science for Engineers - James Shackelford
14. Physical Metallurgy Principles & Practice - V.Raghavan
15. Introduction to Solids - L.V.Azaroff
16. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
17. Materials in Nuclear Application - C.K.Gupta
18. Nuclear Chemical Engineering - Benedict and Pigford
19. Physical Metallurgy, Reed - Hill
20. Heat treatment of steel - Avener
21. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
22. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
23. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
24. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Fast Reactor Physics and Shielding (RP) (35 hours)

S.No.	Course content
A	NUCLEAR THEORY BASICS :
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick’s law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units
2	**Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

8. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
9. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
10. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
11. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
12. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
13. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
14. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics and Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

13. Introduction to Health Physics – Herman Cember
14. Introduction to Radiation Protection – Alan Martin
15. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
16. Nuclear Radiation Detection - W.J. Price
17. Radiation Detection and Measurement - G.F. Knoll
18. Biological Effects of Radiation – J.E. Coggle
19. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
20. Atoms, Radiation and Radiation Protection by James E. Turner 1986
21. Problems and solutions in Radiation Protection by James E. Turner, 1988
22. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
23. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
24. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) – (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :**
	Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR’s, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D **Sodium Technology (NRST)**

1 **Properties of Sodium:** Physical and chemical properties, (hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

11. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
12. Steam Power Station, G.A. Gassort.
13. Power Plant Engineering & Economics, Strosal & Vapet.
14. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
15. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
16. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
17. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
18. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
19. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
20. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.
B.	**Coolant circuits**
1.	Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2.	Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3.	Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4.	Design criteria, Loadings to be considered, Analysis method and validation methodology
5.	Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Reactor Control Engineering (EL2) (20 hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (EL3) (20 hours)

S.No.	Course content
1.	Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2.	Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3.	Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4.	Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5.	Introduction to various reactor instrumentation and radiation monitors:
6.	Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (EL4) (20 hours)

S.No.	Course content
12.	**Introduction: Reliability Engg. Applied to C&I Systems** Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors. Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems. Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
13.	**Reliability Maths/Statistics:** • Mathematical and statistical expressions required for reliability study. • Types of failures in electrical, electronic and computer components • Failure probability concept, statistical distribution models_ • Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions • Chi-square distribution and its use in confidence and risk factors • Baye’s theorem • Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software. • Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions. • Derivation of exponential reliability expression_ • R(t)=[exp-(lt)] for electronic components and systems. • Examples to solve

14. **Fault Tolerance and Systems Reliability:**

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance methods for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis methods:
- Boolean logic
- Digraph, cutest-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model

Example from C&I system in the NPPs

15. **QA/QC Concepts in Brief:**

- QA/QC Concepts in the components, systems procurement, manufacture and
- Site installation for C&I systems in the NPPs.

16. **Environmental Qualification and Reliability Testing:**

- Environmental qualification, testing of the C&I systems.
- Effects of various environments on the electrical/ electronic components
- Climatic Qualification tests: Temperature, Humidity
- Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
- Reliability Testing of the electronic components, equipment and C&I systems.
- Reliability screening tests for electronic components
- Accelerated environmental tests
- Failure terminated and time terminated tests
- Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
- Few examples to solve

17. **PSA/PRA Concepts in NPPs:**

- Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs.
- Explain Event Tree
- Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
- Level-1, Level-2, Level-3 PSA studies (Brief introduction only).

18. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), (‘Formal Methods’ has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Software Engineering (EL5) (20 hours)

S.No.	Course content
1.	Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work- products of different phases
2.	Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics, CASE tools.
3.	Analysis and Design II: Object oriented methods, Unified Modeling Language (UML), notion of objects, classes, attributes, methods, interfaces, associations, generalization, composition, polymorphism. Modeling structure and behavior, Use case diagrams, class diagrams, state diagrams, sequence diagrams, architectural and detailed design., Modeling real-time software. Introduction to Object Oriented Languages. CASE tools.
4.	Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities.
5.	Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal methods. Testing principles, unit testing, Integration testing, acceptance testing., Unit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing.
6.	Software Configuration Management: Configuration items (with examples), baselines, libraries, version control
7.	Software Engineering Standards

Books suggested:
1. Software Engineering by Roger S. Pressman, McGraw Hill International Students Edition
2. Software Engineering by Ian Sommerville, 5th Edition, Addison Wesley
3. An Integrated Approach to Software Engg. by P. Jalote, Springer/Narosa Publishers
4. Unified Modeling Language User Guide by G. Booch, J. Rumbaugh, I. Jacobson, Addison Wesley
5. Real-time UML, second edition, Bruce P. Douglass, Addison Wesley

5. Human Machine Interface for Reactor Control Instrumentation (EL8) (45hours)

S.No.	Course content
A .	**Reactor Instrumentation:**
1.	Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification
2.	RPS & RRS for FBRs : Core Temperature Monitoring System, Diversified Safety Logics, Control Logics for CSRDM & DSRDM
3.	Supervision Systems : Startup systems, Discordance supervision systems for SCRAM signals & CSRs, Alarm Generation system, ESR & PDA
4.	Component Handling Systems: I & C for Rotatable plugs, Transfer Arm, IFTM, CTM, Under Water Trolley and Storage Bays, HMI in HCR for Component handling and fuel movement monitoring.
5.	Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, low selector, high selector, median selector, voting logics, Interfaces with electrical Control gear.
6.	C & I Cables : Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.
7.	Incident monitoring & mitigation systems : RCB Isolation, I&C for SGDHR, Seismic Instrumentation, Post Accident monitoring system, Video monitoring system
8.	Special systems: Fire Alarm System, Physical protection systems, Biometric Sensors, etc.
9.	Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station, DDCS for PFBR. Programmable Controllers (PLC) - Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards, PLCs for package systems.
10.	PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.

11. Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.

B. Human Machine Interface (HMI)

1. Overview of plant automation.
2. Design of HMI, Soft Console versus Conventional control panels.
3. Guidelines for design of HMI displays.
4. Case study of a commercially available Professional HMI package.
5. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package
6. Practical.

Books suggested:

1. Intellution Ifix documentation
2. NPC Guidelines for development of soft consoles.

6. Modern Control of Dynamic Systems (EL10) (30 hours)

S.No.	Course content
1.	**1.** State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	**.** Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	**.** Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

SPECIALISED COURSES

1. Artificial Intelligence & DSP (EL6) (40 hours)

S.No.	Course content
	A. Introduction to Artificial Intelligence
1.	Introduction – Nature of AI problems
2.	Search – State space search
3.	Robotics – Kinematics and dynamics
4.	Knowledge Representation – Predicate logic
5.	Neural Networks – Feed forward vs Feedback
6.	Fuzzy Logic – membership functions
7.	Reinforcement Learning – Intelligent agents
8.	Genetic Algorithm – Solution representation
9.	Engineering applications including in Robotics
	B. Digital Signal Processing
1.	Introduction: Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, convolution, correlation, sampling theory, aliasing, anti-aliasing filter, quantization noise, signal reconstruction.
2.	Discrete Fourier Transform: Interpretation of DFT, properties of DFT, DFT of real signals, periodic & linear convolution and correlation using DFT.
3.	Fast Fourier Transform: Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, computation of Inverse DFT using FFT algorithm, efficient computation of the DFT of two real sequences and a 2N-point real sequence,

spectrum analysis using the FFT, windows in spectrum analysis, use of FFT algorithm in linear filtering and correlation.

4. Digital filters: FIR and IIR filters, design techniques for FIR and IIR filters, realization of FIR and IIR systems, overview of DSP processors.
5. DSP Applications: Applications of digital signal processing in nuclear and other fields.

Books suggested:

1.Johnny R. Johnson, Introduction to Digital Signal Processing, Prentice- Hall of India,2000.
2.John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing- Principles, Algorithms and Applications, Prentice- Hall of India,1995.
3.Allan V. Oppenheim and Ronal W. Schafer, Digital Signal Processing, Prentice- Hall of India,1988.

2. Embedded & Computer based systems Design (EL9) (45 hours)

S.No.	Course content
A.	**Microprocessor Based Hardware Design:**
1.	Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16 bit Micro-controllers (e.g. 80196), DSPs (e.g. TMS320, SHARC family) and ARM processor.
2.	Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3.	Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play.
4.	Design Case Study: Single board computer architectures, circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.
5.	IO board design, bus interface (ISA, PCI), FIFO and shared memory interfaces, Analog and Discrete IO interfacing, signal conditioning, isolation and protection issues, testability.
6.	Embedded computer system design example.
B.	**Computer Communication and Networks**
	Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Field bus standards, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.)

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.

2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Real-Time System Design

1. Real-time system concepts, Timeliness Vs speed, hard Vs soft real time systems, scheduling methods, concurrency, process and thread concepts, inter process communication and synchronisation, Case study of Real Time Operating Systems, development tools, real time programming, device drivers. Validation and performance evaluation of Real-time systems.

2. Overview of LINUX and Embedded NT.

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons
7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek & R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.

3. Process Instrumentation (EL7) (35 hours)

S.No.	Course content
7.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors,

flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.

8. Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors -performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques.

   Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.

9. Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

10. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

11. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

12. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type-Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

    Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

13. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

    Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.

14. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

    Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.

15. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication
3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrment Engineer’s Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Fieldbus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

4. Analytical Instrumentation (EL11) (25 hours)

S.No.	Course content
	Measurement related issues
1.	Sensitivity, detection limit, signal-to-noise ratio enhancement
2.	Absorption and Emission Spectroscopy
3.	UV-VIS-IR Spectrophotometry
4.	Atomic Absorption Spectrophotometry
	IR absorption methods for detection of Carbon, Sulphur, Oxygen, Nitrogen
5.	**Fluorescence Spectrometry**
6.	Generation of X-Rays
7.	X-Ray Fluorescence Spectrometry
8.	X-Ray Diffraction Spectrometry
9.	Laser florescence
10.	**Mass Spectrometry**
	Applications and importance of mass spectrometry
	Various types of ion sources
	Various types of mass analysers
	Various methods of detection
	Computer based automation and measurements
11.	**Thermo analytical methods**
	Thermal analysers-DTA and TG
	Differential Scanning Calorimeters
12.	**Electro analytical instruments**
	Voltametry, amperometry and Coulometry
	Conductivity and pH

Books Suggested:

1. Instrumental methods of analysis, - Willard & Others, Pub: CBS, New Delhi, 7th Ed.
2. Principles of instrumental analysis, - Douglas A.Skoog and James J. Leary, Saunders College Publishing, Harcourt Brace College Publishers. (IGCAR Acc. No. 063944)

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
CHEMICAL ENGINEERING

NUCLEAR ENGINEERING
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
NR	Nuclear Reactors	50	6
EM	Engineering Mathematics	35	4
MM	Materials and Metallurgy	25	2
RP	Fast Reactor Physics and Shielding	35	4
RE	Reactor Engineering	40	4
HP	Health Physics and Radiological Safety	25	3
PM	Project Management	20	2
	Total	**230**	**25**

CORE ENGINEERING (CHEMICAL)
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE1	Nuclear Chemical Engineering	35	4
CE2	Chemical Engineering Thermodynamics	40	4
CE3	Transport Phenomena	40	4
CE4	Multi Phase Flow Systems	40	4
CE5	Code Design for Pressure Vessels and Piping	25	2
CE6	Computational Fluid Dynamics and Heat Transfer	40	4
CE7	Advanced Chemical Reaction Engineering	25	2
	Total	**245**	**24**

SPECIALISED COURSE
(All subjects are Compulsory)

Course Code	Course Name	Hours	Credits
CE8	Process Analysis and Control	25	2
CE9	Advanced Mass Transfer	25	2
	Total	**50**	**4**

ELECTIVE COURSES
(One course amongst the three to be chosen)

Course Code	Course Name	Hours	credits
CEEL	Preparedness &Response to Nuclear Emergencies	30	4
	Artificial Intelligence Methods &Applications	30	4
	Membrane/ Separation Process and Technology	30	4

PROJECT /SEMINAR

	Course Code	Course Name		
1.	02ENGG04-003-P	Project	Duration : 9 Weeks	
2.	02ENGG04-003-S	Seminar -1,2,3		
		Total		12

NUCLEAR ENGINEERING

1. Engineering Mathematics (EM) (35 hours)

Sl.No.	Course content
1	Computer arithmetic and errors . Types of errors, error estimates and its propagation, Data analysis : Difference tables, Interpolation methods of Lagrange and Hermite, Chebyshev polynomials and Pade's approximation with rational functions. Numerical differentiation of interpolating polynomials. Numerical Integration : Trapezoidal, Monte-Carlo and Gaussian Quadrature methods Solution of algebric and transcendental equations, Newton-Raphson method, Graffe's root squaring method; Data approximation by method of least square, curve fitting
2	Linear vector space and subspaces, Basis, Gram-Schmidt orthogonalization, Linear system of equations: LU decomposition, Cholesky factorization and Gauss-Jordan technique. Iterative techniques using the methods of Jacobi, Gauss-Seidel and over relaxation. Convergence criteria and error estimation. Matrix inverse, Ill conditioned and sparse matrices. Bilinear forms, Principal axes transformation and eigen values, Determination of eigen values and eigen vectors. LU and QR algorithms, Singular matrices and singular value decomposition.
3	Ordinary differential equations, Different types of differential equations, Lipschitz theorem and conditions for existence and uniqueness of solutions, Numerical methods for solving differential equations. Method of Euler, Adams and Runge Kutta, Predictor corrector method, Solving stiff equations
4	Probability and Statistics:Probability and Random variables, Binomial, Poisson and Normal distributions, Moments of a distribution, Counting experiments Estimation of model parameters, Confidence intervals, Testing of hypotheses, Goodness of fit, Chi-square test.
5	Integral Transforms: Laplace transform, Linearity of LT, LT of derivatives and integrals, Solution of differential equations using LT, Response of electric circuits, Response of damped oscillator to a square wave, Differentiation and integration of LT.Periodic functions, Fourier series representation of functions, Even and odd functions, Determination of coefficients, Fourier integrals. Data compression, Hauffman coding and wavelet transforms.
6	Partial Differential Equations, Finite difference method in one and two dimensions, Solution of steady and transient heat conduction and diffusion equations.
7	Finite element method, Energy Theorem and integral equations, Weighted residual approximations, Point and subdomain collocation. Galerkin method, Variational principles and Lagrange multipliers. B-splines,Bezier curves, Response surface method, different levels of factorial design.

Book suggested

15. Davis, H. T. and Thompson, K., Linear Algebra and Linear Operators in Engineering: with Applications in Mathematica, Academic Press, 2000.
16. Chapra, S.C. and Canale, R.P., Numerical Methods for Engineers, McGraw-Hill, 1985.
17. R. L. Burden and J. D. Faires, Numerical Analysis, 6th ed., PWS-Kent Publishing, 1997.
18. Krishnamurthy, E. V., Computer based numerical algorithms, East West Press, 1976
19. Gupta, S.K., Numerical methods for Engineers, Wiley (1995).
20. Press, W.H.; Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P., Numerical Recipes in Fortran (or C), Cambridge University Press (1992).
21. Scarborough, J. B. Numerical Mathematical Analysis, Oxford and IBH Publishers, 1968

2. Materials and Metallurgy (MM) (25 hours)

S.No.	Course content
9.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
10.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
11.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
12.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
13.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
14.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
15.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
16.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

25. Introduction to Materials Science for Engineers - James Shackelford
26. Physical Metallurgy Principles & Practice - V.Raghavan
27. Introduction to Solids - L.V.Azaroff
28. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
29. Materials in Nuclear Application - C.K.Gupta
30. Nuclear Chemical Engineering - Benedict and Pigford
31. Physical Metallurgy, Reed - Hill
32. Heat treatment of steel - Avener
33. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
34. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
35. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
36. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

3. Introduction to Fast Reactor Physics (RP) (35 hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect
	Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	BASIC REACTOR PHYSICS-STATIC
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance
2	**Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor
3	**Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor
C	TIME DEPENDENCE
1	**Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

15. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
16. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
17. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
18. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
19. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
20. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc.
21. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press.

4. Health Physics & Radiological Safety (HP) (25 hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)

5. **Radiation Protection procedures:**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

6. **Nuclear Accidents, Emergency Preparedness and Management:**

Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.

7. **Radiological aspects and Environmental Impact of FBRs**

Radiological aspects of Fuel Cycle Facilities

8. **Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996,ndustrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

25. Introduction to Health Physics – Herman Cember
26. Introduction to Radiation Protection – Alan Martin
27. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
28. Nuclear Radiation Detection - W.J. Price
29. Radiation Detection and Measurement - G.F. Knoll
30. Biological Effects of Radiation – J.E. Coggle
31. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
32. Atoms, Radiation and Radiation Protection by James E. Turner 1986
33. Problems and solutions in Radiation Protection by James E. Turner, 1988
34. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
35. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
36. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

5. Nuclear Reactors (NR) (50 hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:**
	Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.

B. Thermal Power Reactors :

Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR

C. Fast Power Reactors :

1 Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.

2 Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.

3 Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.

4 Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.

5 Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.

D Sodium Technology

1 **Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals

2 **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.

Impurities in Sodium, Purification Methods: Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors)

Sodium System: Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control

Sodium Pumps and flow meter: Electromagnetic pumps and flow meter for sodium systems

Electrical Systems for Sodium Loops: Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

21. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
22. Steam Power Station, G.A. Gassort.
23. Power Plant Engineering & Economics, Strosal & Vapet.
24. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
25. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
26. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
27. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
28. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
29. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
30. Material for Sodium Technology portion will be provided during the course.

6. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.

9. Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.

10. Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.

11. Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.

12. Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements

2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.

3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types

4. Design criteria, Loadings to be considered, Analysis method and validation methodology

5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.

6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features

7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

CORE ENGINEERING

1. Nuclear Chemical Engineering (CE1) (30 Hours)

S.No.	Course content
1.	**An Introduction to Nuclear Chemical Engineering** General Introduction and course schematics
2.	**Production of Nuclear Materials** Production of nuclear fuels (i.e.)uranium, thorium and zirconium form ores. Alternate sources for uranium Isotope separation technologies for uranium and water Fuel fabrication technologies for various types of reactors Less common nuclear materials like Zr, Hf, Th, Be,V, Nb and Ta
3.	**Solvent Extraction of Nuclear Materials** Introduction to archival extractants and flowsheets Science and technology of primary extractant (TBP) Alternate extractants for fuel reprocessing applications Extractants for nuclear waste management applications Classical and novel nuclear solvent extraction equipment Criticality and its prevention. Other safety aspects
4.	**Nuclear Fuel Reprocessing** PUREX, Advanced PUREX, SuperPUREX processes Reprocessing of thermal reactor (PHWR and AHWR) Fuels Reprocessing of fast reactor (FBTR & PFBR) Fuels UREX process and its variants Supercritical Fluid Extraction based Superdirex Process Pyrochemical and other non-aqueous processes for reprocessing
5.	**Nuclear Waste Management** Characterization of nuclear wastes Conditioning and remediation. Post-PUREX and Post-UREX processes for isolation of important radionuclides (TRUEX, UNEX, ARTIST, SETFICS, SESAME etc.) Decontamination and decommissioning
6.	**Modeling and Simulation in Nuclear Chemical Engineering** Generation of SX data by conventional & **AKUFVE** techniques Modeling of solvent extraction data Computer codes for simulation of nuclear SX Simulation of solvent extraction process flowsheets Experimental design based variation analysis of flowsheets

Books Suggested:

1. Benedict M., Pigford T.H. and Lewi H. Nuclear Chemical Engineering, McGraw Hill. 2nd ed. (1981)
2. Long, J.T. , Engineering for Nuclear Fuel Reprocessing, American Nuclear Society, IL (1978)

3. Schulz. W.W, Navratil, J.D. and Talbot A.E., Science and Technology of Tributyl Phosphate, Vol.1, CRC Press Inc., Boca Raton, FL (1984)
4. Schulz. W.W, Burger, L.L.,Navratil, J.D. and Bender K.P., Science and Technology of Tributyl Phosphate, Vol.3, CRC Press Inc., Boca Raton, FL (1984)
5. Knief, R.A. Nuclear Energy Technology, Hemisphere Publishing corporation, NY, (1981)
6. Vilani, J., Isotope Separation, (IGCAR library)
7. Selected IGCAR Reports Concurrent literature on AFCI, UREX and allied processes

2. Chemical Engineering Thermodynamics (CE2) (30 Hours)

S.No.	Course content
1.	Classical thermodynamics - the scope of classical thermodynamics, basic concepts and definitions. Laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures.
3.	Multicomponent systems: the chemical potential, fugacity, activities, and activity coefficients.
4.	Solubilities of gases in liquids, solids in gases and in liquids.
5.	Vapour liquid equilibria at low and high pressure. (Van Laar, Peng-Robinson equations). Thermodynamics of super critical fluid
6.	Liquid-Liquid equilibria.
7.	Models for Non ideal, Non-electrolyte solutions and ionic liquids.
8.	Solution thermodynamics
9.	Phase Equilibrium: Phase rule, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations, Equilibrium in systems with supercritical components, phase stability applications.
10.	Chemical Reaction Equilibria: Equilibrium constants for Homogeneous and heterogeneous reactions.
11.	Statistical Thermodynamics

Books Suggested:

1.Denbigh, K. G., The Principles of Chemical Equilibrium, Cambridge, 1971.

2.Tester, J. W. and Modell, M., Thermodynamics and its Applications, 3rd ed., Prentice-Hall, 1997.

3.Bejan, A., Advanced Engineering Thermodynamics, Wiley, 1988.

3. Transport Phenomena (CE3) (40 Hours)

S.No.	Course content
1.	Phenomenological description of continuum approach. Reynolds transport theorem. Basic laws of conservation of mass, momentum and Energy and Multicomponent systems.

2. Transport properties. Modeling of Engg systems and the specification of boundary conditions. Shell balances, Navier-Stokes equations; Momentum, Heat and Mass transfer in steady and unsteady viscous flows; turbulent flows; shell and differential thermal energy balances; steady and unsteady conduction; laminar, forced and natural convection; shell and energy balances of mass of species; diffusion under various driving forces, diffusion with chemical reaction; convective diffusion in dilute solutions; integral balances. Transport coefficient and the macroscopic treatment of momentum, Energy and mass transport in complex system.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Multi-phase flow systems (CE4) (30 Hours)

S.No.	Course content
1.	Multiphase flows and Classification of Multiphase, Flow Patterns (gas-liquid, liquid-liquid and gas-solid and gas-liquid-solid) - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum and energy transfer for different models: Multi-dimensional and flow regime specific models.
2.	Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. (Gas-liquid mixture transport in horizontal and vertical pipe.), vapour-liquid flow, flow boiling, sub-cooled boiling, critical heat flux.
3.	Applications of two-phase flow in the design of steam generators, thermo-syphon evaporators, condensers with non condensibles and air lift pumps. Hydrodynamic of liquid-liquid flow design variables such as holdup, characteristic velocity and pressure drop.
4.	Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. (Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile and pressure drop for turbulent slurry flow.)
5.	The phenomena of fluidization and its industrial application. Characteristics of particles. Principle of fluidization and mapping of various regimes. Two phase theory of fluidization. Bubbles in fluidized bed. Entrainment and Elutriation. Fast fluidized bed. Mixing, segregation and gas dispersion. Heat and mass transfer in fluidized bed. Solid-liquid fluidized bed and three phase fluidized bed. Design of fluidized bed reactors

Books suggested:

1. Wallis, G.B. - " One Dimensional Two phase flow", McGraw Hill Book Co., New York, 1969.
2. Govier, G.W. and K.Aziz., - " The flow of Complex Mixtures in Pipes ", Van Nostrand Reinhold Co., New York, 1972.
3. Brodkey, R.S. - " The Phenomena of Fluid Motions ", Addison - Wesley Publishing Co., New York, 1967.
4. Gad Hestsroni, (Ed.in Chief) - " Handbook of Multi Phase Systems ", Hemisphere Publishing Corporation, Washington and McGraw-Hill Book Company London, 1982.
5. Two-phase flow in pipe lines and heat exchangers – D.Chisholm, Longman Inc, NewYork.
6. Fluidization Engineering- Author: Daizo Kunni and Octave Levenspiel, Butterworth-Heinemann
7. Fluidized bed technology in Materials Processing**, -**Author: C. K. Gupta and D. Sathiyamoorthy, CRC Press.
8. Chemical Reaction Engineering, - Octave Levenspiel,Wiley Eastern Limited.
9. Handbook of separation techniques for Chemical Engineers, - Philip A. Schweitzer,: McGraw- Hill

5. Code Design for Pressure Vessels & Piping (CE5) (25 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.

6. Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B 31.3 Code.

7. Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.

8. Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, Buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.

9. Derivation of TEMA Design equation for tube sheets. Background of the ASME design rules for tube sheets.

10. Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Non-destructive examination of welds as per ASME Sec.VIII, Div.1 code. Difference between Sec. VIII Div.1 & Div.2.

Books suggested:

1. Harvey J F , 'Pressure vessel design' CBS publication
2. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
3. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
4. American standard code for pressure piping , B 31.1
5. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

6. Computational Fluid Dynamics & Heat Transfer (CE6 & CE610) (40 Hours)

Syllabus for CE6 : Computational Fluid Dynamics (30 hrs.)

S.No.	Course content
A.	**Basics of Fluid Flow, Heat Transfer and Numerical Analysis:**
1.	Kinematics of fluid flow. Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
2.	Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bemoulli equations.
3.	Classification of Partial Differential Equations (PDEs)
4.	Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA methods.
5.	Temporal integration: explicit, implicit scheme
6.	Discretization of convection, upwinding, Streamline-Upwind Petrev Galerkin method.
7.	Discretization of convection-diffusion problem: exponential scheme, power-law scheme

B. Numerical Solution of Complete Fluid Flow and Energy Equation:

1. Formulations of governing equations used in numerical simulation:
2. Streamfunction-temperature formulation
3. Stream function-vorticity-temperature formulation
4. Velocity-vorticity-temperature formulation: Poission, Cauchy-Riemaim and Biot-Savart form
5. Primitive-Variable (P-V-T) formulation
6. Pressure velocity coupling for incompressible flow.
7. Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
8. Discussion on MAC, PISO, SIMPLE and SIMPLEN family of Methods
9. Simple grid generation techniques for structured grid:
10. Elliptic. parabolic and hyperbolic equation method
11. Grid adaptation
12. Domain decompositions in CFD and heat transfer
13. SIP and preconditioned conjugate gradient methods for solution
14. Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method for laminar and forced convective boundary layer problems.
15. Numerical solution of approximate equations for natural convective heat transfer problems including porous medium.
16. Mathematical formulation and numerical solution of compressible flows and heat transfer.

Syllabus for CE610 : Heat Transfer (10 hrs.)

C. Laminar Boundary Layer and Forced Convective Heat:

1. Formulation of differential equation for hydrodynamic and thermal boundary layer
2. Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
3. Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
4. Convective heat transfer for internal and external flows
5. Low and high Prandtl number limits and different thermal boundary conditions
Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method

D. Turbulent Flow and Heat Transfer:

Reynolds decomposition for turbulence
Prandtl's mixing length theory, Mixing length models
Structure of turbulent boundary layer over flat plate and through circular cylinder
Calculation of friction factor and drag coefficient
Analytical and semi-analytical correlations for calculating heat transfer coefficients
Analogy between heat and momentum transfer
Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy

Turbulence Modeling:
Eddy diffusivity models: k-ε and k-ω) models, RNG based k- ε model
Reynolds stress models: algebraic and differential models
Low Reynolds number models
Large eddy simulation: Smagorinsky and Dynamic sub-grid scale models

E. Natural Convection:

Basic Equations of natural convection
Boussinesq approximation
Derivation of Dimensionless groups from basic equations
Analytical approximations
Numerical solution of approximate equations

F. Reactor Heat Transfer:

Pressure drop in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & methods; effect of orificing in BWR.

Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical methods of combining subfactors.

Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.

low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.

Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.

Radiation heat transfer: Introduction; Reflection, absorption, transmission and emission; concept of black and grey body; total emissive power and Stefan-Boltzmann constant. Kirchoff's law. Radiation heat transfer between two bodies: shape factor & law of reciprocity; radiation heat transfer between two grey bodies

G. Heat Transfer With Phase Change :

Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.

Basic equations of two phase flow; Homogenous & separated flow models for two hase flow; void fraction & phase velocity ratio (Zivi's model)

Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)

Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.

Critical heat flux: Various models of critical heat flux, CHFR, MCHFR. Critical power concept.
Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
Critical Flow: Models for single – phase and two-phase critical flow.

Books suggested:

1. Knudsen, J.G. and Katz, D.L. (1958): Fluid Dynamics and Heal Transfer, McGraw-Hill: NY.
2. Bird. R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schhchting, S. (1979): Boundary' Layer Theory, 7* ed., McGraw-Hill : NY.

4. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
5. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
6. Holman, J.P. (1997): Heat Transfer, 8"" ed., McGraw-Hill : NY.
7. Kays, W.M. and Crawford, M.E. (1993); Convective Heat Transfer, McGraw-Hill: NY.
8. Gebhart, B., et al. (1988): Buoyancy-Induced Flows and Transport, Hemisphere.
9. Barret, K. (1982): Numerical Modelling in Diffusion-Convection, Pentach Press : London, Polymouth.
10. Hussaini, M.Y. et al. (1997): Up-wind and High Resolution Schemes, Springer-Verlag : Berlin.
11. Warsi, Z.U.A. (1998): Fluid Dynamics: Theoretical and Computational Approaches, 2"" Ed., CRC Press.
12. Cebeci, T. and Bradshaw, P. (1984): Physical and Computational'Aspects of Heat Transfer, Springer-Verlag.
13. Quartepelle, L. (1993): Numerical Solution of the Incompressible Navier-Stokes Equations, Birkhauser Verlag.
14. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
15. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite
16. Volume Method, Addison-Weslev.
17. Gresho, P.M. et al.. (1999): Incompressible Flow and the Finite Element Method, John Wiley & Sons.
18. Comini, G., et al. (1994): Finite Element Analysis of Heat Transfer, Taylor & Francis : Washington DC.
19. Canuto, C., et al. (1988): Spectral Methods in Fluid dynamics, Springer-Verlag :NY, 557pp.
20. Thompson, J.F., Soni, B. and Weatherill, N.P. (1998): Handbook of Grid Generation, CRC Press.
21. Glowinski. R., et al. (Eds.) (1997): Domain Decomposition Methods in Science and Engineering, Wiley.
22. Turek, S. (1999): Efficient Solvers for Incompressible Flow Problems, Springer-Verlag.
23. Wesseling, P. (1992): An Introduction lo Multigrid Methods. Wiley : NY.
24. Wagner, S. (1995): CFD on Parallel Systems, Friedrich Wieweg & Sons.

7. Advanced Chemical Reaction Engineering (CE7) (30 Hours)

S.No.	Course content
1.	Stoichiometry rates and thermodynamics of chemical reactions. Influence of concentration and temperature. Reaction mechanism. Generalized balance equation for reactive systems.

2. Collection and analysis of rate data: differential method, Integral method, Graphical method, polynomial fit method, Methods of initial rates, Methods of excess, Methods of half life. Kinetics of homogeneous and heterogeneous reactions.

3. Conservation equations for chemically reacting mixtures; heterogeneous catalytic reactions.

4. Chemical reactions and processes of transport: external diffusion effects on heterogeneous reactions, diffusion and reaction in porous catalysts.

5. Design and analysis of chemical reactors: Isothermal and non-isothermal reacting systems, catalytic and non-catalytic reactions systems.

6. Uniqueness and multiplicity of steady states, stability analysis.
Non-ideal reactors: distributions of residence time for chemical reactors, models for non-ideal reactors.

7. Modeling of multiphase reactors: fixed, fluidized, trickle bed, slurry etc.

Books Suggested:

1. Aris R., Elementary Chemical Reactor Analysis, Prentice-Hall 1969.
2. Foggler, H. S., Elements of Chemical Reaction Engineering, Prentice Hall of India, 1994.
3. Froment G.F. and Bischoff K.B., Chemical Reactor Analysis and Design, John Wiley, 1994.
4. Smith J.M. - " Chemical Engineering Kinetics ", McGraw-Hill, 1981.

SPECIALISED COURSES

1. Process Analysis and Control (CE8) (25 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.
2.	Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3.	Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.

4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

2. Advanced Mass Transfer (CE9) (25 Hours)

S.No.	Course content
1.	Theories of mass transfer with and without chemical reaction-with examples from gas-liquid, liquid-liquid, and liquid-solid systems; Rate based approaches for design. Film, Penetration & Surface Renewal models, Solvent extraction theory
2.	Selection and design of contacting equipment in nuclear chemical industries-Spray, packed and tray columns trickle bed reactors. Extraction equipment: mixer settlers, centrifugal contactors, pulsed extractors, hollow fibre extractors. Adsorption and ion exchange equipment.
3.	Membrane separation and other advanced mass transfer processes. Process intensification approaches. (few hours for seminar by TSO’s).

Books suggested:

1. Transport phenomena in liquid extraction – G.S. Laddha and T.E. Degaleesan. McGraw Hill, 1978.
2. Separation process principles – J.d. Seader, Ernest J.Henley. John Wiley & Sons. 2nd Ed. 2005.
3. Mass transfer – Thomas K.Sher wood, Robert L.Pigford, Charles R. Wilkey. McGraw hill.
4. Mass transfer operations - Robert E. Treybal. Mcgraw-hill (1980)
5. Handbook of solvent extraction – The. C. Lo. Malcolm, H.I. Baird, Carl Hanson (editor), Krieger Pub. Co. Reprint edition (Feb 1991).

ELECTIVE COURSES

1. Preparedness & Response to Nuclear Emergencies (CE-EL) (30 Hours)

S.No.	Course content
1.	Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment
2.	Radiation Shielding & Study of Criticality parameters and control
3.	Nuclear Waste Management
4.	Nuclear Accidents/emergencies
5.	Transport of Radioactive material
6.	Radiological accidents/emergencies
7.	Effects of Hiroshima & Nagasaki bombing
8.	Detection of Nuclear detonation

9. Nuclear weapons: effect (Blast, heat, Radiation and EMP)

10. Medical decontamination with demonstration

11. Nuclear weapon tests (atmospheric)

12. Nuclear & Radiological terrorism (Method to contain and control)

13. Chemical warfare & Biological warfare (Method to contain and control it)

14. Emergency Response methodology/ Philosophy

15. Systems and methodology for Radiological impact assessment

16. Emergency Response Centres (Requirement in terms of instruments, manpower and communication facilities

17. Emergency Monitoring & Shelters

18. Nuclear Fuel Cycle, Reprocessing of Plutonium & Uranium enrichment

19. Civil defence WEB plan for Nuclear attack on major cities

20. Monitoring of High radiation field area

21. Lab Visits

Books suggested:

Material will be provided during the course.

2. Artificial Intelligence Methods & Applications (30 hours)

S.No.	Course content
1.	**Robotics** Forward and Inverse kinematics, Jacobians, Manipulator Dynamics, Trajectory generation, Sensors, Manipulator Control, Force control, Path planning, Mapping & Localisation of Mobile robots, Behavior based control, Robot learning.
2.	**Genetic Algorithm** Introduction to GA and its terminology, GA operators and working principle of GAs. Different selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling and elitism. Constraint handling. Multimodal function optimization. Application of GAs, real-coded GAs. Multiobjective optimization, difference with single objective optimization, concept of Dominance and Pareto-optimality. Multiobjective GAs.
3.	**Fuzzy Logic** Introduction;Need, Historical Development and Perspective of applications. Crisp and Fuzzy Sets, Operations on fuzzy Sets. Fuzzy Arithmetic, Fuzzy relations, Fuzzy logic. Possibility Theory and Uncertainty Based information. Construction of Fuzzy Sets (with examples), Approximate Reasoning.

Applications; Pattern Recognition and Process Control (with examples).

Books Suggested:
Material will be provided during the course.

3. Membrane/Separation Processes and Technology (30 hours)

S.No.	Course content
1.	Type of membranes and membrane processes
2.	Membrane transport theory – solution, diffusion model
3.	Membrane and modules
4.	Concentration polarization – boundary layer film model – concentration polarization in liquid separation processes
5.	Reverse osmosis – membranes and materials, RO membrane categories, membrane modules, fouling control and cleaning
6.	Ultra-filtration – characterization of UF, membrane fouling and cleaning – modules and system design
7.	Other membrane processes – microfiltration, nanofiltration, pervaporation and electrodialysis
8.	Application of membranes in water and wastewater treatment
9.	Application of membranes in radioactive waste management

Book suggested:

1. Membrane Technology and Applications (2nd edition) by Richards W. Baker
2. Membrane Filtration Handbook – Practical Tips and Hints (2nd edition) by Jorgen Wagner
3. Application of Membrane Technologies for Liquid Radioactive Waste Processing – IAEA Technical Report Series No. 431.

BARC Training School at IGCAR Campus
SYLLABUS SUMMARY
Materials Science

Course Code	Course Name	Hours	Credits
MS1	Engineering Mathematics	35	4
MS2	Computational Methods	30	4
MS3	Materials and Metallurgy	25	3
MS4	Reactor Physics and Fuel Design	30	4
MS5	Health Physics	25	2
MS6	Metallurgical Thermodynamics	30	4
MS7	Experimental Methods for Materials Research	45	6
MS8	Structural Materials for Nuclear Reactors	45	6
MS9	NDE Science and Technology	30	4
MS10	Physical Metallurgy	45	6
MS11	Fuel Cycle Physics and Introduction to Fuel Cycle	30	4
MS12	Introduction to Materials Science and Engineering	45	6
MS13	Corrosion Science and Engineering	30	4
MS14	Mechanical Behavior of Engineering Materials	30	4
MS15	Manufacturing Technology	30	4
Total		**505**	**65**

1. Computational Methods (MS2 -45 hours)

S.No	Course content
1.	**Programming:** Introduction to programming with C# as the reference language (C# software will be provided for practice), Getting familiarized with Matlab
2.	**Numerical Techniques:** Overview of standard numerical techniques with wpecial emphasis on statistics and solving ordinary and partial differential equations
3.	**Optimization:** Overview of techniques with special emphasis on non-linear optimi9zation using gradient descent, conjugate gradient and genetic algorithm
4.	**Neural network for predictive applications:** Overview of various neural network architectures, Multilayer perceptron model for prediction, need for neuro-fuzzy models
5.	**Atomistic modeling:** Introduction to Monte-Carlo Simulation, Basics of molecular dynamics, prediction of thermo-physical properties by molecular dynamics, computational challenges
6.	**Introduction to application of FEM:**Introduction to FEM and its application, demonstration of few simple application using Abaqus (FEM software)
7.	**Current status in modeling and simulation:** With respect to mechanical metallurgy

Books Suggested:

1. Sams Teach Yourself C# in 21 Days, B.L. Jones, SAMS publications
2. Numarical Recipes in C++: The art of scientific computing, *W.H. Press et al*, Cambridge University Press
3. Numerical Mathematical Analysis *J.B. Scarborough, MacMillan Publishers*
4. Genetic algorithms in search, optimization and machine learning, *D.E. Goldberg, Addison Wesley*
5. Guide to neural computing applications, *L. Tarassenko, Arnold publishers*
6. Monte Carlo Basics, *K.P.N. Murthy, ISRP publishers*
7. Molecular Dynamics Simulation by *J.M. Haile, John Wiley and sons*

2. Fast Reactor Physics and Fuel Design (MS4/CH8- 30 hours)

S.No.	Course content
1.	**Basic Nuclear Physics Concepts:** Properties of nuclei. Nuclear forces, Nuclear models. Nuclear decay, Liquid drop model and nuclear stability, Nuclear reactions including fission, Compound nucleus formation, Microscopic cross-section, Partial and total cross-sections.
2.	**Basics Neutron Physics Concepts:** Introduction to physics of fission process. Definition of flux current and sources, Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section and mean free path. Cross-sections of elements, compounds and mixtures.
3.	**Chain Reaction:** four factor formula; definitions of k-infinity, k-effective w.r.t. neutron balance equation (with diffusion approximation); boundary conditions; definition of reactivity; criticality.
4.	**Homogeneous Reactor:** Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector saving. Heterogeneous reactors; typical examples.

5. **Reactor Kinetics:**Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, Inhour formula, one group delayed neutrons, one dollar of reactivity, Prompt and delayed criticality. Feed back coefficients.

Books Suggested:

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C. Edlund. Van Nostrand, 1952.
2. Introducation to Nuclear Reactor Theory, Lamarsh J.R., ANS, 2002
3. Physics of Nuclear Reactors, Jakeman D., English Universities Press, 1966.
4. A.E. Walter and A.B. Reynolds, "Fast Breeder Reactors", Pergamon Press, 1981.

3. Metallurgical Thermodynamics(MS6- 30 hours)

S.No.	Course Content
1.	**Classical thermodynamics -** the scope of classical thermodynamics, basic concepts and definitions. First and second laws of thermodynamics and its applications.
2.	Thermodynamic Properties of pure substances and mixtures. The chemical potential, fugacity, activities, and activity coefficients, Phase rule
3.	Solubilities of gases in liquids, and solids
4.	**Solution thermodynamics**: Integral and Partial Molar Thermodynamic Properties, Solution Models, Ideal Solution, Regular Solution, Real Solutions
5.	**Phase Equilibrium and Stability**: Phase equilibria in multicomponent systems, phase diagrams, the differential approach for phase equilibrium relationships, pressure-temperature relations,
6.	**Chemical Reaction Equilibria**: Equilibrium constants for Homogeneous and heterogeneous reactions.
7.	Graphical Representation of Thermodynamic Information, Ellingham Diagrams, Predominance Area Diagrams, Pourbaix Ellingham Diagrams, Phase Diagrams,
8.	**Experimental Methods**: Methods for Determining Thermodynamic Properties, Presentation of Thermodynamic Data, Examples of Calculations.

Books Suggested:

1.D. Gaskell, Materials Thermodynamics, Talyor and Reid, 1981.
2. O. Kubaschewski, C.B. Alcock and P.J. Spencer, Materials Thermochemistry, Pergamon, 1985

4. Experimental Methods for Materials Research (MS7-45 hours)

S.No	Course Content
1	Vacuum Techniques (3): Fundamentals, Creation & Pressure Measurements, units, Pumps – fore Vacuum, high Vacuum and UHV
2	Thin Film synthesis methods- Physical, Chemical and MBE

3. X-RAY TECHNIQUES - techniques based on measuring the energy or angular distribution of scattered x-rays,

1.1 Wide angle elastic scattering (XRD): Atomistic – form factors; unit cell structure factors, Bragg equation, reciprocal lattice, Laue equations; Expwrimental methods- transmission, reflection, thin film, in-situ; Otjer information-particle size distributions.

1.2 Inelastic scattering- x-ray absorption spectroscopy: Basics- edges and extended fine structure; XANES and EXAFS quantitation; Surface sensitivity; Experimental methods
1.3 Small angle scattering-SAXS: Basics- what SAXS sees; Mathematical modeling;
1.4 X-ray fluorescence spectroscopy: Basics- core hole formation, fluorescence yield, transport ("ZAF"); Experimental realization – Bulk analysis; lab and synchrotron x-ray sources; Surface analysis – TXRF; Microscopy – x-ray beam manipulation.

4. **ELECTRON MICROSCOPIES:**

2.1 Transmission electron microscopy (TEM/STEM):
Electron interactions in solids-elastic and inelastic scatterin, phase change; Contrast generation-bright field, dark field, "high-resolution"; Images-information and resolution; Diffraction; Beam damage; Experimental methods hardware, specimen preparation; Inelastic scattering- electron energy loss; Emitted x-rays – elemental analysis, sensitivity, spatial resolution; STEM
2.2. Scanning electron microscopy:
Beam transport in bulk solids; Signals and images- backscattered and secondary electrons; Diffraction- channeling patterns – EBSD; X-ray generation and transport, detection and analysis; Other useful signals; Experimental methods;
EPMA Electron probe micro-analyzer
2.3. LEELS

5. ION BEAM TECHNIQUES

techniques using ions or neutrals made from them as the bombarding species
3.1. Ion beams – production-ion guns; manipulation- ion, filters
3.2. Rutherford (Nuclear) Backscattering Spectroscopy- (RBS):
High energy ions in solids- electronic and nuclear (Rutherford) stopping; Quantitative description; Experimental methods – energy spectroscopy
3.3. Nuclear reaction analysis – elemental specificity – depth profiling
3.4. PIXE (Proton Induced X-ray Emission) Signal to noise ratio – trace element analysis
3.5. Surface Mass Spectriscopy-SIMS:
Ejection of matter by bombardment: sputterin; Fate of ejected materials subsequent reaction, charge state; Mass dedtection – quad, magnetic sector, ToF; experimental issues

6. ELECTRON SPECTROSCOPIES -

techniques based on measuring the energy distribution of emitted electrons
4.1 Photoelectron spectroscopy:
Basics- energy balance, element identification; Not-so Basics- relaxation, chemical states, satellites; Surface sensitivity; Quantitation; UPS- the unfamiliar cousin
4.2 Auger Electron Sepctroscopy:
Electron excitation- why bother ? The Auger spectrum- energy balance; Chemical effects; Quantitation; Imaging- meaning of maps.
4.3 Experimental methods;
Surface of real-world things; Below the surface- profiling, variable energy; Hardware and software; samples and handling.

7. PROXIMAL PROBE MICROSCOPIES

Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM): Basics; Experimental methods; Spectroscopy in Scanning Probe Microscopy

8. NUCLEAR SPECTROSCOPY

Positron annihilation, Mossbauer – Application to defects, radiation damage defects in metals and alloys

9. VIBRATIONAL SPECTROSCOPIES

7.1 Vibrations in molecules and solids – normal coordinates, group frequencies

7.2 Infrared spectroscopy;

IR absorption – dipole scattering, selection rules; Optical arrangements-transmission, specular reflectance, diffuse reflectance, attenuated total reflectance, microscopy, in-situ; Signal collection and Fourier transform processing, data analysis

7.3 Raman: Energy transfer, selection rules; Normal, resonance, surface-enhances, Fourier transform, UV

10. 8.RESONANCE ABSORPTION SPECTROSCOPIES

8.1 Nuclear Magnetic Resonance (NMR):

Fundamentals; Experimental Techniques; Magnetic Resonance Imaging

8.2 Electron Paramagnetic Resonance (EPR): Fundamentals; Experimental Techniques

BOOKS FOR STUDY AND REFERENCE:

1. Cullity Addision, B.D., "Elements of X-ray Diffraction", Wesley Publishing Co., 1967.
2. Williams (D B), Carter (C B), Transmission Electron Microscopy: A Textbook For Materials Science, New York, Plenum, 1996
3. J.R. Tesmer et al 'Handbook of modern ion beam materials analysis' (MRS, Pittsburgh,1995)
4. L.C. Feldman, J.W. Mayer 'Fundamentals of surface and thin film analysis' (North-Holland, N.Y, 1986)
5. Prutton, M., "Surface Science and Technology, Volume27, "Analytical techniques for thin films", Academic Press, Inc.Newyork, 1991.
6. Bacon, G.E., "X-ray and Neutron Diffraction", Pergamon Press, 1966.
7. Concise Encyclopedia Of Materials Characterization Ed. Cahn (R W) and lifshin (E) Ed Oxfod, Pergamon, 1993
8. Advances in Materials Characterization Ed. G. Amarendra, Baldev Raj, M.H. Manghnani, University Press (India), 2007

8. Structural Materials for Nuclear Reactors (MS8)(Coordinator: –45hrs)

S.No.	Course Content
1.	Three stage Nuclear Power Program (Importance of Material Selection)
2.	**Thermal Reactors:** Concept, Selection of Materials – Core and out of core, Processing of Materials, Properties/Performance of Materials
3.	**Fast Breeder Reactors:** Concept, Selection of Materials for different systems, Brief description of different systems, Core materials, Design criteria for clad and wrapper, Radiation damage, Evolution of materials for clad and wrapper, Material performance, Material processing and fabrication, Structural materials, Design criteria, Materials processing and fabrication, Steam generator materials, Design criteria, Selection of materials, Materials processing and fabrication, Properties of materials and performance
4.	**Materials in Reprocessing Applications,** Closing of nuclear fuel cycle, Design concept of reprocessing plant component, Selection of materials, Processing and fabrication, Evaluation of properties and performance
5.	**Materials in Waste Storage Applications**

Books Suggested:

1. Materials research: Current scenario and future projections, Chidambaram R, Banerjee S Ed, Allied Publishers, New Delhi, 2003
2. High temperature reactor materials (workshop La Jolla,CA March18-21,2002), Allen T, Oak Ridge, U.S.Department of Energy, 2002.
3. Nuclear materials: Issues and concerns Vol 2., Bhaskara Rao D Discovery Publishing House, New Delhi, 2001.
4. Materials R & D for PFBR: Compilation of articles: (Eds) S.L. Mannan and M.D. Mathew, IGCAR, Kalpakkam, 2003.
5. An overview of R&D on fast reactor fuel cycle, Baldev Raj, Int. J. Nuclear Energy Science and Technology, Col.1, Nos.2/3, 2005, pp.164-177.
6. Selection of materials for PFBR, S.L. Mannan, S.C. Chetal, Baldev Raj, S.B. Bhoje, Trans IIM, Vol..56, No.2, April 2003, pp.155-178.
7. Development of fuels and structural materials for fast breeder reactors, Baldev Raj, S.L. Mannan, P.R. Vasudeva Rao and M.D. Mathew, Sadhana, Vol.27, Part 5, October 2002, pp. 527-558
8. Input of the atomic energy programme on special materials development in India, C. V. Sundaram, Trans IIM, vol. 41, No.5, Oct 1988, p.407.
9. Recent trends in fast breeder reactor materials, C.V. Sundaram, P. Rodriguez and S. L. Mannan, IE (I) Journal –MM, Vol.67, Sept. 1986, pp.1-11.
10. Radiation effects in nuclear reactor materials – correlation with structure, P. Rodriguez, R. Krishnan and C.V. Sundaram Bull. Mater. Sci. Vol. 6, No.5, May 1984, PP.339-367.

Nuclear Reactor Materials, C.O.Smith, Addison Wesley, 1967

<u>9. NDE Science and Technology (MS9 - 30 hours)</u>

S.No.	Course Content
1.	**Introduction to NDE:** Importance and need for NDE, classification of techniques, origin of defects; material processing related-casting, forging, rolling, welding etc., and service related-fatigue, creep, corrosion, irradiation etc. Detection, characterisation, sensitivity, reliability, accuracy,
2.	**Surface NDE:** Principle, instruments & sensors, capabilities, applications and limitations of visual, liquid penetrant, magnetic particle, eddy current and flux leakage techniques
3.	**Volumetric NDE:** Principle, instruments & sensors, capabilities, applications and limitations of radiography and ultrasonic techniques. Gamma, Micro-focal, LINAC and real-time radiography and tomography. IRIS, TOFD, SAFT, MEMS, Non-linear ultrasonics related to ultrasonics.
4.	**Dynamic NDE:** Acoustic emission, infrared radiography, intelligent processing of materials and continuous monitoring.
5.	**Digital NDE:** Forward and inverse problems, signal processing, numerical modeling, imaging, automation, probability of detection (POD), multiple NDE, data fusion and robotics.
6.	**Industrial NDE:** NDE for quality assurance, structural integrity, material characterization, condition monitoring and in-service inspection, reference standards for calibration, codes & standards, selection of NDE techniques
7.	**Practicals:** 1. Ultrasonic testing – detection of defects in weld/HAZ and measurement of thickness

2. X-radiography of welds and interpretation of radiographs
3. Eddy current testing of plates and heat exchanger tubes for defects
4. ***Seminar***: Preparation and submission of report on a topic in advanced NDE. Presentation and viva-voce

Books Suggested:

1. A practical NDT – Baldev Raj, T. Jayakumar and M. Thavasimuthu, Narosa, New Delhi, 1996.

2. ASNT Volumes on Visual, penetrant, magnetic particle, eddy current, ultrasonic, radiography, acoustic emission, thermography and other techniques, ANST, Ohio, Coloumbus.

3. Grandt, A. F. Jr., Fundamentals of Structural Integrity: Damage Tolerant Design and Non-destructive Evaluation, John Wiley & Sons, Inc. Hoboken, NJ, 2004.

4. Bray, D.E. and R.K. Stanley, 1997, Nondestructive Evaluation: A Tool for Design, Manufacturing and Service; CRC Press, 1996.

5. Peter J. Shull, Nondestructive Evaluation: Theory, Techniques, and Applications, Marcel Dekker Inc., 2002.

10. Physical Metallurgy (MS10- 45 Hrs)

S.No.	Course Content
1.	Structure and Properties of Materials
2.	**Crystalline solids:** Introduction: Engineering materials, materials cycle, application and selection criteria of materials. Significance of microstructure; crystalline defects:- dimensions, origin and their effect on properties; amorphous structure.
3.	**Phase diagrams**: Origin, construction, interpretation and application of binary phase diagrams with reference to a few important metallic and ceramic systems. introduction and classification of phase transformations, calculation of phase equilibria based on thermodynamic principles
4.	Correlation between Free energy, selection of a Phase and order parameter, different thermodynamic classification of phase transformations, order of a transformation
5.	**Diffusional transformations:** Diffusion in solids: phenomenological approach and atomistic approach. Nucleation and growth theories of vapour to liquid, liquid to solid, and solid to solid transformations; homogeneous and heterogeneous strain energy effect during nucleation; interface-controlled growth and diffusion controlled growth; overall transformation kinetics. Principles of solidification, evolution of microstructures in pure metals and alloys**.** Precipitation from solid solution: types of precipitation reactions, crystallographic description of precipitates, precipitation sequence and age hardening, spinoidal decomposition**.**
6.	**Iron-carbon alloy system:** iron-carbon diagram, nucleation and growth of pearlite, cooling of hypo-eutectoid, eutectoid, and hyper-eutectoid steels, development of microstructures in cast irons. Heat treatment of steels: TTT and CCT diagrams
7.	**Diffusionless transformations:** martensitic transformation, hardenability, role of alloying elements in steels. Bainitic transformation, Widmanstatten transformation, Massive transformation. Order-disorder transformation**.**

8. Diffusion, rate theory, mechanisms of, measurement techniques
9. Phase transformations in some nuclear non-ferrous metals and alloys
10. Characterization of microstructure – microscopy techniques, X-ray spectroscopy and diffraction.
11. **Metallographic techniques**: Optical metallography, image analysis, quantitative phase estimation.
12. Properties of X-rays: continuous and characteristics x-rays, absorption, filter, production and detection of X-ray Diffraction methods: X-ray diffraction, X-ray topography, residual stress measurement techniques, small angle X-ray and neutron scattering.
13. **Electron optical methods**: (a) Scanning electron microscopy and X-ray microanalysis including electron probe microanalysis, electron optics, electron beam specimen interaction, image formation in the SEM; (b) Transmission electron microscopy and analytical transmission electron microscopy: Electron diffraction, reciprocal lattice, analysis of SAD patterns; different electron diffraction techniques, atomic resolution microscopy, analytical devices with TEM, field ion microscopy, scanning tunneling microscopy, advanced techniques.
14. **Introduction to novel materials and processes**: composites, intermetallics, cermets, metallic foams, intelligent materials, Dependence of their properties on structure, Nanocrystalline Materials: Synthesis, Structure and Properties.: Amorphous Materials; Metallic glasses, Glass forming ability, Bulk Metallic Glasses, Properties; Quasi crystalline Materials; Structure, Synthesis, Properties;
15. **Advanced Processes**: Rapid solidification processing, Laser surface Modification, Mechanical Alloying, Rapid prototyping, Self propagating High temperature synthesis, inert gas condensation etc.
16. **LABORATORY** Microstructures of alloys of Fe, Al, Cu and Ti for each type of transformation at different levels of resolution; Crystal structure by diffraction techniques; Defects of different dimensions; Advanced processes – Laser Ablation, Magnetron Sputtering and Plasma and Chemical deposition methods.

11. Fuel Cycle Physics& Introduction to Fuel Cycle (MS11/PY11 - 30 Hrs)

S.No	Course content
1.	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India.
2.	Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Beneficiation, preconcentration, purification and recovery. Radio-activity of mill tailings.
3.	Methods of U enrichment:
4.	Oxide fuels: Preparation of UO_2, PuO_2, MOX and ThO_2. Physical and chemical properties. Phase diagrams of relevance.
5.	Advanced ceramic fuels : carbides and nitrides
6.	Metal and Alloy fuels: Preparation of U, Pu, Th. Historical over view of the alloy fuel development, alloys (U-Zr, U-Pu-Zr, U-Pu-Minor Actinide). Dispersions and composites. Salient physical and chemical properties. Relevant phase diagrams. Fabrication and quality control.
7.	Inert matrix fuels for partitioning and transmutation – A brief account of the current developments.

8. Fuel fabrication and criticality safety. Fresh and spent fuel transport and storage in SFSP and burnup credit. Transport of fresh and irradiated fuel.
9. U-Pu cycle: U, U-Pu (MOX), Th-U cycle. Examples in thermal and frast reactor systems. Enrichment versus discharge burnup; enrichment versus reactivity coefficients; fertile host versus inert matrix.
10. Fuel cycle indices - Conversion and breeding ratios; reactor doubling time. Fuel and system doubling times.
11. Fissile and fertile actinides and MA (inventory and isotopic vector) in discharged fuel in different fuel cycles; Long lived fission products (LLFP).
12. Issues related recycling – Effective fissile content of discharged fuel for next cycle; refabrication of fuel for the next cycle. Results of Pu composition change with once through, one recycle and multiple recycle in thermal and fast systems.
13. Activity and toxicity of discharged fuel – FPs and actinides; activation of structural materials. Fuel reprocessing – thermal and fast reactor fuel - U-Pu, U-Th and U-Pu-Th fuels.
14. Isotopic separation operation of bred uranium in thorium cycles to remove U-232.
MA and LLFP incineration. Waste management strategies; different levels of waste, LLW and HLW. Methods of dilution, discharge and fixation; long term storage in geological structures.

Books Suggested:

1. F.J.Rahn et al., A Guide to Nuclear Power Technology, John Wiley and Sons (1984).
2. R.G.Cochran and N.Tsoulfanidis, Nuclear Fuel Cycle Analysis and Management, ANS (1990).

12. Introduction to Materials Science & Engineering (MS12/CH4-40 hours)

S.No.	Course content
1.	**Structure, Bonding & Defects in Solids:** Single crystal & polycrystalline materials, Unit cell, Crystal symmetry, Bravais lattices, point groups & space groups, Miller indices, Cohesive forces in crystals, Madelung energy and its calculation for NaCl and CsCl, Crystal structures, Close packing, Ionic Radii and Radius ratios, Common crystal structures of elements & compounds, Factors influencing crystal structures, Structure-property relations, Defects in solids, Thermodynamics of defect formation, Non-stoichiometry, Ionic conduction, Solid electrolytes.
2.	**Diffraction Techniques:** Diffraction phenomenon, X-ray, neutron and electron diffraction, Bragg's Law, Size and shape of unit cell, Basics of crystal structure determination, Powder diffraction and single crystal methods, Phase identification by XRD, Powder diffraction data base, Indexing of diffraction patterns and lattice parameter calculation, Rietveld refinement, Particle size & residual stress determination by XRD.
3.	**Microstructure & Microscopy:** Microstructure - origin and significance, Optical & electron microscopy

4. **Physical Properties:** Mechanical properties, Fracture, Strengthening mechanisms, Thermal expansion, Thermal conduction, Thermoelectric effects, Electrical and magnetic properties - metals, semiconductors and insulators, Band picture of solids, Ferroelectric materials, Superconductors, Magnetic properties, Magnetic domains, Optical properties, Non-linear optical properties, Lasers, Fibre optics & applications.

5. **Chemical Reactivity of Solids:** Factors affecting chemical reactivity, Diffusion, Surfaces of solids, Surface analysis techniques – ESCA, Materials at very low and high temperatures, Materials under pressure, Radiation damage in solids, Corrosion.

6. **Synthesis of Materials:** Solid state reactions, Wet chemical reactions and precursor techniques, Combustion synthesis, Sol-gel process, Soft chemical reactions, Crystal growth techniques with examples, Thin films, Nanocrystalline materials, Sintering.

7. **Phase Diagrams &Phase Transformations:** Phase diagrams – significance, experimental & computational methods of phase diagram determination, Classification of phase transformations, Order-disorder transitions, Nucleation and growth theory, diffusion-controlled and diffusionless transformations, Thermal analysis techniques.

Books suggested:

1. Materials science and technology: a comprehensive treatment, (18 Vols.) Ed. R.W. Cahn, P. Haasen and E.J. Kramer, VCH, Weinheim, 1991.
2. Encyclopedia of materials: science and technology, (11 Vols.) K.H.J. Buschow et al., Elsevier, Amsterdam, 2001.
3. Introduction to solid state physics, C. Kittel, VII Ed, John Wiley & Sons, 1996.
4. Solid state chemistry and its applications, A.R. West, John Wiley & Sons, 1984.
5. The structure and properties of materials, (4 Vols.) Ed. J. Wulff, Wiley Eastern, 1974.
6. Materials science and engineering: an introduction, V Ed, W.D. Callister, John Wiley &Sons, N.Y., 2003.
7. Introduction to materials science and engineering, K.M. Ralls, T.H. Courtney and J. Wulff, Wiley Eastern, 1978.
8. Elements of x-ray diffraction, B.D. Cullity, Addison – Wesley, 1978.
9. Analytical chemistry by open learning: X-ray methods, C. Whiston, John Wiley & Sons, 1987.
10. X-ray diffraction: a practical approach, C. Suryanarayana and M. Grant Norton, Plenum, 1998.
11. The science and engineering of materials, IV Ed D.R. Askeland and P.P. Phule, Brooks/Cole, 2003.
12. The physics and chemistry of materials, J.I. Gersten and F.W. Smith, John Wiley & Sons, 2001.
13. Metallic materials: physical, mechanical and corrosion properties, P.A. Schweitzer, Marcel Dekker, 2003.
14. Introduction to Solids, L.V. Azaroff, Tata McGraw-Hill, Bombay, 1960.
15. Materials science and engineering: a first course, III Ed V. Raghavan, Prentice Hall of India, 1996.
16. Understanding materials science: history, properties, applications, R.E. Hummel, Springer Verlag, N.Y., 2004.
17. Crystal growth: processes and methods, P. Santhana Raghavan and P. Ramasamy, KRU Publications, Chennai.
18. Preparative methods in solid state chemistry, P. Hagenmuller, Academic, 1972.
19. Thin film deposition: principles and practice, D.L. Smith, McGraw-Hill, 1995.
20. Properties of materials, M.A. White, Oxford Univ. Press, 1999.

13. Corrosion Science and Engineering (MS13/CH13 - 30 hours)

S.No.	Course content
1.	Thermodynamics of Aqueous Corrosion: Electrode processes – electrode potential, free energy, EMF series, potential measurements with reference electrodes, three electrode systems, computation and construction of Pourbaix diagrams of Fe, Al, Ni and Zn, practical use of E-pH diagrams. Chemical Vs electrochemical mechanisms of corrosion reactions, corrosion rate expressions.
2.	Kinetics of Aqueous Corrosion: Corrosion current density and corrosion rate, exchange current density. Polarization – activation control, Tafel equation, mass transport control, mixed potential theory and behavior of galvanic couples in acidic environments, effect of oxidizer, combined polarization, factors affecting polarizations and rate of corrosion. Passivity, potentiostatic polarization curves, factors affecting passivity, mechanism of action of passivators.
3.	Forms of Corrosion: General corrosion – atmospheric corrosion, galvanic corrosion, general biological corrosion. Localized corrosion – filiform corrosion, crevice corrosion, pitting corrosion, localized biological corrosion. Metallurgically influenced corrosion-inter granular corrosion, de-alloying. Mechanically assisted corrosion – erosion corrosion, fretting corrosion, corrosion fatigue. Environmentally induced cracking – mechanisms of stress corrosion cracking and hydrogen embittlement.
4.	Corrosion in Reactor and Reprocessing Plants: Corrosion in liquid sodium, cooling water, sea water; Corrosion in nitric acid – effect of flow, environment and metallurgical variables of materials.
5.	Prevention and Control of Corrosion: Corrosion control by design. Selection of corrosion resistant materials – alloying, stainless steel and brass. Oxidation resistant materials, control of high temperature oxidation. Cathodic and anodic protection methods. Use of inhibitors-types. Corrosion in cold water pipes – Langalier saturation index.
6.	**Corrosion Monitoring:** Introduction – On-stream monitoring – Electrical resistance, linear polarization, hydrogen test probe, ultrasonic testing, radiography and corrosion coupons. Off-stream monitoring equipments – Acoustic emission testing, eddy current inspection, liquid penetration inspection.
7.	**Corrosion Testing:** Purpose and classification. Dimensional charge – Ultrasonic thickness measurements, eddy current, microscopic examination. Weight charge – Specimen preparation, test conditions and evaluation of results for overall corrosion, SCC, IGC. Electrochemical techniques – Polarization curves, Tafel extrapolation, linear polarization, AC impedance methods (EIS).

Books Suggested:

1. Herbert H. Uhlig and R.Winston Revie, “Corrosion and corrosion control – An introduction to corrosion science and engineering”, Third Edition, John Wiley & Sons, 1985.
2. Mars G. Fontana, “Corrosion Engineering”, Third Edition, Mc Graw Hill Inc., 1987.
3. D.A.Jones, Principles and prevention of corrosion, Second Edition, Prentice Hall Inc, 1996.

4. ASM hand book – Vol 13: Corrosion, ASM International, 2001.
5. Philip A. Schweitzer, “Corrosion and corrosion protection handbook”, USA, 1983.

14. Mechanical Behaviour of Engineering Materials (MS14- 30 hours)

S.No.	Course Content
1.	**Engineering Materials:** Alloys, intermetallics, ceramics, composites, polymers.
2.	**Basic Crystal Structure of Materials**: Unit cell, packing fractions, planes and directions, slip systems
3.	**Defects in Materials:** Point defect, line defect (dislocation), surface defects (grain boundary, twins, stacking faults), volume defects
4.	**Dislocation:** Types, Burger's vector, stress field and energy, stacking faults, dislocation glide and slip systems in crystal, interaction between dislocations, interaction between dislocations and point defects, dislocation pile up, dislocation climb, dislocation sources, multiplication of dislocations.
5.	**Elastic Behaviour of Materials:** Stress and strain at a point and their relationship
6.	**Plastic Behaviour of Materials:**
7.	**Tensile Deformation:** single crystal, yield point, CRSS, polycrystalline materials (Schmidt's factor), grain size effect-Hall-Petch relation, thermally activated deformation, constitutive equation for plastic deformation, strain hardening and dynamic strain ageing (DSA).
8.	**Strengthening Mechanism:**Strain hardening, strengthening from grain boundary, solid-solution strengthening, order-disorder strengthening, precipitation strengthening, dispersion strengthening, strengthening by point defects, martenisitic strengthening, and composite materials.
9.	**Creep:** Creep curve, mechanisms of creep deformation, activation energy for creep deformation, structural changes during creep, deformation mechanism map, super plasticity, presentation of creep data, prediction of long-term creep properties, irradiation creep, grain boundary sliding, nucleation, growth and coalescence on inter granular cavities, effect of impurity segregation on cavitation, creep fracture of weld joint, design of creep deformation and fracture resistance materials.
10.	**Fatigue:** Types of loading, high cycle fatigue, low cycle fatigue, thermo-mechanical fatigue, creep-fatigue interaction, fretting fatigue and corrosion-fatigue of various engineering materials, effect of surface treatment and coating, fatigue behaviour of welds, characterization of fatigue deformation and damage, fatigue under combined stresses, notch sensitivity, design criterion, life prediction techniques, alloy design against fatigue.
11.	**Fracture Mechanics:** Ductile to brittle transition, Griffith's law, strain energy release rate, introduction to linear and non-linear fracture mechanics, fracture toughness, fatigue and creep crack growth, material design against fracture.

Books Suggested

1. Physical Metallurgy Principle – R. E. Reed-Hill
2. Modern Physical Metallurgy – R. E. Smallman
3. Mechanical Metallurgy – G. E. Dieter
4. Plastic Deformation of Metals – R. K. W. Honeycomb
5. Introduction to Creep – W. W. Evans
6. Fatigue of Materials - S. Suresh, CambridgeUniversity Press.
7. Deformation and Fracture Mechanics of Engineering Materials – R. W. Hertzberg

15. Manufacturing Technology (MS15 - 30 hours)

S.No.	Course content
1.	**Nuclear materials and their melting practices**: Selection criteria for in-core, structural and steam generator materials, Radiation damage, Properties of nuclear materials. Principles of Vacuum melting & casting processes, including general descriptions of vacuum induction melting, vacuum arc re-melting and electro-slag refining.
2.	**Hot and cold working processes and tube making processes**: Fundamentals of mechanical processing, defects during manufacturing, Various techniques for producing seamless pipes, design of tooling for hot extrusion and principles of pilgering and Various presses and their characteristics.
3.	**Special metal forming processes**: High velocity forming processes like explosive forming, pertroforge forming, electro magnetic and hydraulic forming, comparison of HVF methods, Super-plastic forming.
4.	**Powder metallurgy** : Introduction, characterization of metal powders. Manufacturing of metal and composite powders. Compaction and sintering of metal powders. Secondary operations. Applications of typical P/M components.
5.	**Computer aided design:** Role of computers in design and manufacture, Solid modeling – techniques and algorithms for modelling – data structures for solid models; Surface modeling – curves and surface representation – composite surfaces – application to computer aided manufacture; Current developments in CAD – feature based modeling – Design by feature – function, feature linkages – Application of feature based models. Parametric modeling.
6.	**Metal joining principles and processes**: Fusion and non- fusion welding processes, modern welding processes, design of welded joints, Introduction to residual stresses and distortion in welds.
7.	**Weldability of materials**: Welding of austenitic stainless steels, ferritic steels, weldability tests, dissimilar welding and selection of weld consumables and welding defects, principles of post weld heat treatment and stress relieving.
8.	**Welded Fabrication**: Codes and Standards, Procedure and performance Qualification, Evaluation of the welded joints, NDT of welds.
9.	**Hard facing Technology**: Introduction, Need for hard facing, Hard facing processes, Hard facing in nuclear power plants.
10.	**Heat Treatment**: Annealing, normalizing, quenching and tempering, Precipitation hardening, Recrystallisation annealing, Importance of heating and cooling rate and hold time in heat treatment, Heat Treatment furnaces.

Books Suggested:

1.Metal Forming Handbook, Schuler, Springer Verlag, Berlin, 1998.
2.Welding Technology for Engineers, Baldev Raj, Shankar (V) And Bhaduri (A K), Narosa Publishing House, New Delhi, 2006.
3.Fundamentals of Metal Forming, Wagoner (R H), John Wiley & Sons, New York, 1997.
4.CAD/CAM from Principles To Practice, Chris Mcmahon And Jimmie Browne, Addison – Wesley, 1993.
5.Manufacturing Technology: Foundry, Forming And Welding, Rao (P N), Tata Mcgraw-Hill, New Delhi, 1987

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING I

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (MECHANICAL/CHEMICAL)

S. No	*Code*	*SUBJECT TITLE*	***HOURS***	***CREDITS***
1.	FRE1	Code Design for pressure vessel and piping	30	4
2.	FRE2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	30	4
3.	FRE3	Transport Phenomena	30	4
4.	FRE4	Reliability Engineering	20	2
5.	FRE5	Process Design and Control	30	4
6.	FRE6	Vibration Engineering and Condition Monitoring	20	2
7.	FRE7	Seismic Design of Nuclear Reactors and Facilities	30	4
8.	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**210**	**26**

MODULE III- OPERATIONS

S. No	*Code*	*SUBJECT TITLE*	***HOURS***	***CREDITS***
1.	FRE9	Plant Dynamics and Control	25	3
2.	FRE10	Turbine Generator Fundamentals	25	3
3.	FRE11	Mechanical and Electrical Equipments	25	3
4.	FRE12	Maintenance Engineering	25	3
5.	FRE13	Regulatory Framework for NPPs	25	3
6.	FRE14	Practical's	**6 Weeks**	**12**
		Total	**125**	**27**
		Total	**510**	**74**
1.	Viva Voce	**Grand Total**		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths.A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals **Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc.
2	**Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

31. Nuclear Power Engineering, M. El-Wakil, Mcgraw Hill Book Co., New York.
32. Steam Power Station, G.A. Gassort.
33. Power Plant Engineering & Economics, Strosal & Vapet.
34. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
35. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
36. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
37. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
38. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
39. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
40. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**
1	**Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.

2. **Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3. **Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4. **Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5. **Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6. **Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7. **Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8. **Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities
8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II - CORE ENGINEERING (MECHANICAL/CHEMICAL)

1. Code Design for Pressure Vessel and Piping (FRE1) (30 Hours)

S.No.	Course content
1.	Membrane theory for thin shells, stresses in cylindrical, spherical and conical shells, dilation of above shells, general theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
2.	Thick cylinder and sphere and derivation of Lame's equations. ASME Sec. VIII Div. 1 & Div -2 equations for cylindrical, spherical and conical shells, ellipsoidal and torispherical end closures.
3.	Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures. Thermal stresses in plates and shells.
4.	Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits.
5.	Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement rules for ASME, Sec. VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc (WRC-297)
6.	Bolted Flanged joints. Types of flange joints. Types of gasket and their selection. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel Code.
7.	Supports for vertical and horizontal vessels. Design of base plate and support lugs. Types of anchor bolt, its material and allowable stresses. Design of saddle supports.
8.	Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling (collapse) coefficients. ASME procedure for design of vessels under external pressure. Design for stiffening rings. Design of shells for axial compression.
9.	Design of tube sheets as per TEMA and ASME Sec VIII Div. 1.
10.	Piping thickness as per ANSI ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3

11. Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec. VIII Div.1 code. Difference between Sec. VIII Div.1 & Sec III-NB.

12. Introduction to design codes (structure of RCC-MRx) both insignificant and significant creep. Service levels and design class. Introduction to shell and piping design. Thin Shell Design Against Buckling as per RCC-MR Appendix A-7, Elastoplastic instability under monotonic loading – linear elastic analysis, Elastoplastic instability under cyclic loading - elastic linear analysis -negligible creep, Elastoplastic instability in significant creep - simplified method.

Books suggested:

11. Harvey J F , 'Pressure vessel design' CBS publication
12. Brownell. L. E & Young. E. D , 'Process equipment design', Wiley Eastern Ltd., India
13. ASME Pressure Vessel and Boiler code, Section VIII Div 1 & 2, 2003
14. American standard code for pressure piping , B 31.1
15. Standards of Tubular Exchanger Manufacturers Association, Eighth Edition ,1998

2. Heat Transfer and Computational Fluid Dynamics (FRE2) (30 Hours)

S.No **Course content**

1. **Basic equations:** Kinematics of fluid flow. Streamline, streakline and pathline; stream function, vorticity & deformation of a fluid element. Basic equations governing heat conduction, fluid flow & mass transfer (viz. the continuity, momentum and energy equations) with special reference to Navier-Stokes & Bernoulli equations.
2. **Laminar Boundary Layer and Forced Convection:** Formulation of differential equations for hydrodynamic and thermal boundary layers. Different analytical methods for reduction of boundary layer equations and theoretical formulation for boundary layer thickness. Study of jets and flow separation in the light of Boundary Layer Theory. Convective heat transfer in internal and external flows. Low and high Prandtl number limits and different thermal boundary conditions.
3. **Turbulent Flow and Heat Transfer**: Reynolds decomposition for turbulence. Prandtl's mixing length theory, Mixing length models. Structure of turbulent boundary layer over flat plate and through circular cylinder. Calculation of friction factor and drag coefficient. Analytical and semi-analytical correlations for heat transfer coefficients. Analogy between heat and momentum transfer. Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy.
4. **Natural Convection**: Basic Equations of natural convection. Boussinesq approximation. Derivation of dimensionless groups from basic equations. Analytical approximations.
5. **Principles of heat transfer in porous media**: Single phase flow in porous medium Darcy Law, porosity & permeability, homogenization method, continuity equation & energy equation.
6. **Heat Transfer with Phase Change**: Introduction of two phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows. Basic equations of two phase flow; Homogenous & separated flow models for two phase flow, void fraction & phase velocity ratio (Zivi's model). Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling & (b) flow boiling: Heat transfer correlations for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation). Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling. Critical heat flux: Various models of critical heat flux, CHFR, MCHFR Critical power concept. Post-dryout heat transfer. Various

models available for calculation of heat transfer coefficient. Critical Flow. Models for single -phase and two-phase critical flows.

7. **Radiation heat transfer**: Radiation heat transfer. Reflection, absorption, transmission and emission; concept of black and grey bodies; total emissive power and Stefan-Boltzmann constant. Kirchoffs law. Shape factor & law of reciprocity; Radiation heat transfer between two grey bodies
8. **Numerical Methods in Heat Transfer**: Discretization of conduction equation with Dirichlet & Neumann boundary conditions; Temporal integration: Explicit & Implicit schemes. Discretization of convection-diffusion equations (Upwind & Exponential schemes). Estimation of flow field: stream function-vorticity formulation and primitive variable formulation. SIMPLE family of algorithms. Turbulence Modeling: Eddy diffusivity models: k-ε and k-ω models. Reynolds stress models: algebraic & differential versions. Large eddy simulation and Director numerical simulation.

Books suggested:

AHMT

1. Fox. J. A, Introduction to Engineering Fluid Mechanics, New York, Mc Graw Hill, 1974.
2. Frank M White, Fluid Mechanics, 5th Edition, Boca Raton, CRC Press, 2000.
3. Cengel Y.A, Introduction to Thermodynamics and Heat Transfer, New York, Mc Graw Hill, 1997.
4. Frank P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th Edition, New York, John Wiley & Sons, 1996
5. Adrian Bejan, Convection Heat Transfer, New York, John Wiley & Sons, 2004.
6. Wilcox. D.C, Turbulence Modeling for CFD, California, Dcw Industries, 1993.
7. Pope S.B, Turbulent Flows, Cambridge, Cambridge University Press, 2000.
8. Stephan K, Heat Transfer In Condensation Boiling, Berlin, Springer Verlag, 1992.
9. Tong. L.S, Boiling Heat Transfer And Two Phase Flow, New York, John Wiley & Sons, 1966.
10. P.B. Whalley, Two-Phase Flow and Heat Transfer, Oxford Press, 2005.
11. Hetsroni G, Handbook of Multiphase Systems, Washington, Hemisphere, 1982.
12. Hewitt. G.F, Process Heat Transfer, Boca Raton, CRC Press, 1994.
13. Collier. J.G, Convective Boiling and Condensation, London, Mc Graw Hill, 1972.

CFD

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method - H.K. Versteeg and W. Malalasekera, Addison-Wesley Longman, Limited, 1995, Reprinted in 1996.
2. Numerical Heat Transfer and Fluid Flow - S.V. Patankar, McGraw-Hill, 1981.
3. Computational Fluid Flow and Heat Transfer – K.Muralidhar, T.Sundararajan, Narosa Publishing - New Delhi, 2003 (IIT Kanpur series of advanced texts).
4. Heat Transfer- J.P.Holman, 9th Ed., McGraw Hill, NY.
5. Convective boiling and condensation- J.G.Collier, McGraw Hill, London,1972.

3. Advanced Mass Transfer (FRE3) (30 Hours)

S.No.	Course content
1.	**Momentum Transport:** **1.1 Viscosity and Mechanisms of Momentum Transport**: Generalized Newton's Law of Viscosity, Pressure and Temperature Dependence of Viscosity, Molecular Theory of the Viscosity of Gases and Liquids, Viscosity of Suspensions and Emulsions, Convective Momentum Transport.

1.2 Velocity distributions with two independent variables: Time-Dependent Flow of Newtonian Fluids, Flow near Solid Surfaces by Boundary-Layer Theory.

1.3 Macroscopic Balances for Isothermal Flows: Macroscopic mass, momentum, mechanical energy balances; Estimation of viscous loss, Performance of Liquid-Liquid Ejector, Thrust on pipe bends.

2. **Energy Transport:**

Fourier's Law of Heat Conduction; Thermal Conductivity, its measurement & its dependence on temperature / pressure. Theory of thermal conductivity of gases, gas mixtures and liquids, Effective thermal conductivity of composite solids, Convective transport of energy.

3. **Mass Transport:**

3.1 Diffusivity and the Mechanisms of Mass Transport: Fick's Law of Binary Diffusion, Diffusivity, its measurement & its dependence on temperature / pressure, Theory of diffusion in gases, binary liquids, colloids etc. Molar transport by convection.

3.2 Concentration Distributions in Solids and Laminar Flows: Diffusion through Gas Films, homogenous / heterogeneous chemical reactions, Diffusion into a Falling Liquid Films.

3.3 Equations of Change for Multi-component Systems: Equations of Continuity for a Multi-component Mixture, Multi-component Equations of Change, Multi-component Fluxes and their applications.

3.4 Concentration Distributions with More than One Independent Variable: Time-Dependent Diffusion, Steady-State Transport in Binary Boundary Layers, Boundary Layer Mass Transfer with complex interfacial motion. Concentration Distributions in Turbulent Flows.

3.5 Interphase Transport in Nonisothermal Mixtures: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions, Combined Heat and Mass Transfer by Free Convection, Effects of Interfacial Forces on Heat and Mass Transfer, Transfer Coefficients at High Net Mass Transfer Rates.

3.6 Other Mechanisms for Mass Transport: Equation of Change for Entropy, The Flux Expressions for Heat and Mass, Concentration Diffusion and Driving Forces, Applications of the Generalized Maxwell-Stefan Equations, Mass Transport across Selectively Permeable Membranes, Mass Transport in Porous Media.

Books Suggested:

1.Bird, R.B, Stewart, W.E. and Lightfoot, E.N., Transport Phenomena, Wiley, 1994.
2.Denn, M.M, Process Fluid Mechanics, Prentice Hall, 1980.
3.Whitaker, S., Fundamental Principles of Heat Transfer, NewYork, Pergamon, 1997.
4.Cussler, E, L., Diffusion: Mass Transfer in Fluid Systems, Cambridge, 1985
5.Welty, J.R., C.E. Wicks and R.E. Wilson - " Fundamental of momentum, heat and mass transfer ", John Wiley and Sons, 1976.
6.Sissom, L.E. and D.R.Pitts - " Elements of Transport Phenomena ", McGraw Hill, New York, 1972.
7.Brodkey, R.S. and H.C.Hershey - " Transport Phenomena ", A United Approach McGraw Hill, 1988.

4. Reliability Engineering (FRE4) (20 hours)

S.No	Course content
1.	Reliability Mathematics- Fundamentals of probability, Random Variables and their probability distributions, common distribution functions, Uniform, Normal, Lognormal, Exponential and Extreme value distribution, correlations, Regression analysis, Bayesian Methods, Functions of Random Variables, Central Limit theorem
2.	Elements of Component Reliability – Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.
3.	Reliability in Engineering Design – Limit state, Probability of failure, Monte Carlo simulation method, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Accuracy of probability estimates, Reliability Index, First Order Second Moment Reliability estimates, Reliability Index, First Order Second Moment Reliability Index, Hasofer Lind Reliability Index, Rackwitz Fiessler procedure, Correlated random variables.
4.	Probabilistic Fracture Mechanics – Brief overview of failure modes for flawed structures, linear elastic fracture mechanics, net section collapse, R6 method, fatigue analysis, crack growth analysis, Application of PFM to nuclear structural components.
5.	System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems.
6.	Application of Reliability – PSA of Nuclear Plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of Core Damage. Frequency and its significance. Internal and External events, Reliability centered maintenance, Risk based in-service inspection strategies, Important measures, Risk based ranking matrix.

Books Suggested:

1. Reliability and Maintainability Engineering, Charles.E.Ebeling, Tata- McGraw Hill, 2000.

2. Fracture Mechanics- Fundamentals and Applications, T.L.Anderson , CRC Press, 2005.

3. Lecture Notes-Topics in Solid Mechanics-Reliability Analysis and Design, Sharit Rehman, 1999.

4. Structural reliability analysis and prediction-R.E.Melchers, Ellis Horwood Limited, 1987.

5. Probablistic Safety Assessment in Chemical and Nuclear Industry-R.R.Fullwood, BH, Oxford, 2000.

6. Probability, reliability and statistical methods in engineering design – Halder. A and Mahadevan.S., 2000, John Wiley & Sons, Newyork.

7. Introduction to reliability engineering - E.E. Lewi, John Wiley, NY, 1987

8. An introduction to reliability and maintainability engineering, Tata-Mcgraw hill, New Delhi 2000.

9. Probabilistic structural mechanics handbook – C(Raj) Sundararajn, 1995, Chapman and Hall, NY

5. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	Distinctive characteristics of dynamics of chemical process systems; process control objectives and strategies; material balance and product quality control Review of dynamic behavior of linear systems and their control system design. Linear processes with difficult dynamics.

2. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behavior; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design.
3. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems

Books Suggested:

1. Buckley P.S., Techniques of Process Control, John Wiley, 1964.
2. Douglas, J.M., Process Dynamics and Control, Vols, I & II, Prentice Hall, 1972.
3. Stephanopoulos G., Chemical Process Control, Prentice Hall, 1988 Current Literature.
4. Emanule, S.Savas - " Computer Control of Industrial Processes ", McGraw-Hill London, 1965.
5. Peter Harrior - " Process Control ", Tata McGraw Hill publishing Co., Ltd., New Delhi., 1977

6. Vibration Engineering and Condition Monitoring (FRE6) (20 Hours)

S.No. Course content

1. Single-degree-of Freedom (SDOF) Systems: Free vibration equation of motion; Concept of natural frequency; Solution of equation of motions for undamped and damped free vibrations – underdamped, overdamped and critically damped systems; Material and structural damping – evaluation of damping in SIDOF systems' Response to harmonic loading – complementary solution and particular solution; Response to periodic loadings using Fourier Series, Response to general dynamic loading – Duhaml's Integral.
2. Multi-Degree-of Freedom (MDOF) Systems: Equations of motion – lumped mass and distributed parameter systems; Eigen value problem, concepts of Eigen values and eigenvectors; Normal mode vibrations – Free and forced; Orthogonality conditions; Mode superposition method & Direct integration methods; Vibration of continuous systems; Vibration absorption, vibration isolation and dampers, transmissibility and isolation efficiency.
3. Response of Systems to Ground Motion: Earthquake motion – Safe shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake; Design basis earthquake – Design Time History and Design Response Spectra; Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules; A seismic design of equipments and piping systems as per ASME Sec.III Appendix-N
4. Rotor Dynamics: Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeff Cott rotor; Phase-amplitude relationship, effect of damping; Amplitude build up at critical speed; Effect of support flexibility; Performance verification of rotating machinery.
5. Dynamic Balancing: Static and Dynamic unbalance; Single plane and two plane balancing; Sources of unbalance; Method of mass correction and balancing practice; Balancing quality standards and specification for rotors; Classification of rotors and type of balancing required.
6. Flow Induced Vibration: Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass; Models and analysis for vortex-induced Vibration; Sources of Vibration in pipes containing fluid; Codes and standards applicable for flow induced vibrations.

7. Vibration Measurement and Signal Analysis: Types of transducer, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration); Characterization of periodic, periodic and random signals; Fourier Spectrum, Power spectrum, Cross-power spectrum, coherence, auto and cross – Correlation and significance of these parameters; Application of vibration of condition monitoring and diagnostics; Vibration standards for acceptance.

Book suggested:

1. Theory of Vibration with Applications, William T. Thomson, CBS Publishers & Distributors, 1988.
2. Mechanical Vibration Practice with basic theory – V. Ramamurti, Narosa publishing house, Chennai.
3. Vibration measurement and analysis - B.C. Nakra, G.S.Yadava, L.Thuestad, National Productivity council.
4. Flow-induced vibration – Robert D. Blevins, Krieger publishing, Latest edition.
5. Machinery vibration - Victor Wowk, Tata Mcgraw hill publishers, Latest edition
6. Machinery malfunction diagnosis and correction – Robert C. Eisenmann, Pearson education publications, Latest edition.
7. Practical machinery management for process plant – H.P. Bloch, vol 2, Gulf publishing company, London, Latest edition.
8. Engineering applications of correlation and spectral analysis – Bendat J.S. and Piersom A.G., John wiley publications, Latest edition.

7. Seismic Design of Nuclear Reactors and Facilities (FRE7) (30 Hours)

S.No.	Course content
1.	**Introduction to Earthquakes:** Tectonic features, faults e.g., plate boundaries, intra faults, horizon of earthquakes, Definition of various terms e.g., focus, epicenter distances, energy release, relations of magnitude v/s energy, magnitude v/s peak ground accelerations, definition of various waves generated e.g., p-waves, recording of earthquake motions, strong motions, attenuation relations.
2.	**Design Basis Ground Motion and IS 1893 Spectra:** Selection of design magnitudes of earthquakes, Evaluation of peak ground accelerations, return/recurrence periods, spectral shapes, synthetic time histories, peak ground accelerations for various zones of India.
3.	**Introduction to Earthquake Engineering:** Equations of motion for simple systems, importance of inertia forces, elastic forces, energy dissipation and damping, natural frequencies, mode shapes, modal participation factors, evaluation of seismic forces for single and two degree freedom systems.
4.	**Analysis Procedures for multi degree freedom systems:** Formation of matrices for stiffness, mass and damping. Frequency evaluation methods-subspace iteration, lanczos. Response spectrum analysis-modal combinations. Time history analysis- Wilson-q, Newmark-b
5.	**Soil-Structure Iteration:** General requirements, types of foundations, evaluation of subsurface material properties such as shear modulus, material damping ration, Poisson's ration etc. Analyses- direct method, impedance method, foundation uplift analysis.
6.	**Analysis and design of Structures:** Modeling of structures considering soil-structure interaction, structure-equipment interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.

7. **Analysis and design of Equipment:** Modeling of equipment, structure-equipment interaction, equipment-piping interaction, damping of the structures, analysis of structures, evaluation of seismic forces, design of structures for seismic loads.
8. **Analysis and design of Piping:** Modeling of piping, equipment-piping interaction, damping of the piping, analysis of piping, evaluation of seismic forces, and design of piping for seismic loads.
9. **IS 1893, 2002, Indian Standard Criteria for earthquake resistant design:** Seismic Coefficient method, Importance factors for industrial systems, response reduction factors, ductility design provisions, seismic design of chimneys, towers as per IS 1893.
10. **Testing:** Pseudo-dynamic testing, shake table testing, in situ testing, ambient testing, testing for functional requirements, determination of natural frequencies and damping.
11. **Response Control and Retrofitting:** Merits of response control design, passive (EPD, LED, base isolation etc) and active control, various devices of active and passive control, various retrofitting techniques, FRP wrapping, steel plate wrapping.
12. **Seismic Design of Nuclear Facilities:** Earthquake resistant design of nuclear facilities with limited radioactivity inventory such as Research Reactors, `Waste Management Plants suing IAEA-TECDOC-348, Design of nuclear fuel cycle facilities using IAEA-TECDOC-1250.
13. **Seismic re-qualification of old plants:** Inelastic response spectra, push over analysis, retrofitting techniques.
14. **Tutorials:** Simplified models for structures like towers, chimneys, simple frames, equipment like heat exchangers, pressure vessels and piping considering various support conditions like fixed-fixed, fixed-free, pin-pin, evaluation of seismic responses using first fundamental modes or peak values of design response spectrum.
15. **High Temperature and Creep Fatigue Interaction:** Damage mechanisms and failure modes, Time-dependent and frequency-dependent damage, Cumulative damage rules, Different approaches for life prediction under creep-fatigue conditions: Frequency-modified approach, strain range partitioning (SRP), Ductility exhaustion method, Creep-fatigue interaction Diagram, Thermomechanical fatigue, Codes and Standards

Books Suggested:

1. Chopra, A.K., “Dynamics of Structures, Theory and applications to Earthquake Engineering”, Pearson Education Inc., 2003.
2. Ray W.Clough and Joseph Penzien, Dynamics of Structures”, New York, McGraw-Hill Book Company.
3. Mariopaz, “Structural Dynamic (Theory and Computation)”, CBS Publishers and Distributors, Delhi.
4. Bathe, K.J., and Wilson, E.L., “Numerical Methods in Finite Element Analysis”, Englewood, N.J., Prentice-Hall.
5. ASCE 4-98, “Seismic Analysis of Safety Related Nuclear Structures and Commentary”, ASCE, New York.
6. United States Nuclear Regulatory Commission (USNRC), 1990, Standard Review Plan
7. P.N. Agarwal, “Engineering Seismology”, IBH Publishers, New Delhi.
8. Safety Guide, AERB/SG/D-23, “Seismic Qualification of structures, Systems and Components of PHWRS.
9. AERB/SG/S-11, 1990, “Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites”. AERB, Mumbai, India.
10. IS: 1893 (Part 1,2 & 4) 2002, criteria for Earthquake Resistant Design”, BIS, New Delhi.

8. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.

- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.
- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.
- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings, Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,

Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.

- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.
- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evolution of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extension of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Independence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.

- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974

11. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

1. **Class room Training**
    a. Reactor System

        Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

    b. Sodium system

        Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

    c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*
    d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

2. **Field training**
    a. Reactor Operation
    b. Maintenance Activities
    c. Technical Service Activities
    d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

SYLLABUS SUMMARY: FAST REACTOR ENGINEERING II

MODULE I: FUNDAMENTALS

S.No	Code	Subject Title	HOURS	CREDITS
1	NR	Nuclear Reactors & Sodium Technology	50	6
2	RE	Reactor Engineering	40	5
3	RP	Fast Reactor Physics and Shielding	35	4
4	MM	Materials and Metallurgy	25	3
5	HP	Health Physics and Radiological Safety	25	3
		Total	**175**	**21**

MODULE II-CORE ENGINEERING (ELECTRICAL/ELECTRONICS)

S. No.	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE15	Reactor Control Engineering	30	4
2	FRE16	Nuclear Instrumentation	25	2
3	FRE4	Reliability Engineering	20	2
4	FRE5	Process Design and Control	30	4
5	FRE17	Embedded System Design & Human Machine Interface	45	6
6	FRE18	Process Instrumentation	45	6
7	FRE8	Emergency Preparedness and Disaster Management	20	2
		Total	**215**	**26**

MODULE III- OPERATIONS

S. No	Code	SUBJECT TITLE	HOURS	CREDITS
1	FRE9	Plant Control	25	3
2	FRE10	Turbine Generator Fundamentals	25	3
3	FRE11	Mechanical and Electrical Equipments	25	3
4	FRE12	Maintenance Engineering	25	3
5	FRE13	Regulatory Framework for NPPs	25	3
6	FRE14	Practical's	6 Weeks	12
		Total	125	27
		Total	515	74
1	**Viva-Voce**			**2**
		Grand Total		**76**

Fast Reactor Engineering - 2018
MODULE - I : FUNDAMENTALS

1. Nuclear Reactors and Sodium Technology (NR) (50 Hours)

S.No.	Course content
A.	**Mechanical Aspects of Power Plant Engineering:** Basic thermal Cycle used in NPS, means of Improving cycle efficiency, Major components in thermal and Nuclear stations, Heat Balance typical calculations, Details of equipment – Steam Generators, Turbines, Condensers, Feed Water heaters, De-aerator feed pumps, condensate and other pumps: condenser cooling water system: C&I; steam pressure control, steam discharge and steam dumping features.
B.	**Thermal Power Reactors :** Layout of Nuclear Power Plant; Zoning requirements: layout of typical PHWR; description of layout in the reactor building; Special requirements for'; nuclear components regarding material selection, reliable operation with examples of pumps, valves, heat exchangers etc. operating environment (including capabilities to withstand seismic loads). Description of calandria, end shield and coolant channel (including fitting). Description of reactivity control scheme and related hardware e.g. zone control, regulating rods, absorbers, shutdown systems etc. Fuel and Fuel transfer system; Primary Heat Transport System; emergency core cooling system; Moderator system; Auxiliary System; Description of process Water, Fire Water and Ventilation system (emphasis on role played as safety support systems); Containment and associated safety systems to mitigate consequences of accidents and contain reactivity release; ultimate heat sink and heat removal paths. A brief overview of PWR, BWR and AHWR
C.	**Fast Power Reactors :**
1	Fast Reactor Physics and Safety: Role of FBR's, breeding ratio, doubling time, core design features - Static and Dynamic, control rod design, shielding principles, Fuel management, safety.
2	Overview of FBR: FBTR and PFBR. Comparison of FBRs: Core & important design parameters, comparison of core components, major primary and secondary system components.
3	Core Engineering: Description, choice of core materials, Engineering design of core, High temperature design methods.
4	Heat Transport Systems: Introduction, Design of IHX, SG, sodium pump, sodium piping, Decay heat removal system.
5	Instrumentation & Control: FBR instrumentation requirements, Neutronic Instrumentation and failed fuel detection methods, Reactor protection instrumentation and process instrumentation.
D	**Sodium Technology**
1	**Properties of Sodium:** Physical and chemical properties, (Hazardous nature and sodium-air, sodium-water reactions), heat transfer properties, Manufacture of sodium, Heat transfer in liquid metals, Hartman effect in liquid metals
2	**Sodium Systems – General Description:** Components of a sodium system, process, cover gas system etc. **Impurities in Sodium, Purification Methods:** Impurities in sodium, purification methods, impurity monitors, (plugging indicator, on-line hydrogen, oxygen and carbon monitors) **Sodium System:** Components, piping and Quality Control Materials, design aspects, tanks, valves, vapor traps and other mechanical engineering aspects, sodium centrifugal pumps, high temperature piping for sodium, fabrication aspects, quality control **Sodium Pumps and flowmeter:** Electromagnetic pumps and flowmeter for sodium systems **Electrical Systems for Sodium Loops:** Electrical supply, heating systems, heater control, types of power supply

3 **Instrumentation and Control:** Level, leak, flow and temperature monitoring, pressure measurement, control of process parameter in sodium systems, under sodium viewing.

System Operation Aspects: Sodium system pre-commissioning checks, methods of checking all components, limiting conditions of operation, surveillance checks etc.

Sodium component cleaning, fire and safety

Sodium removal and sodium disposal methods, sodium fire and extinguishment methods, system and industrial safety aspects.

Books suggested:

1. Nuclear Power Engineering, M. EI-Wakil, Mcgraw Hill Book Co., New York.
2. Steam Power Station, G.A. Gassort.
3. Power Plant Engineering & Economics, Strosal & Vapet.
4. Central Electricity Generating Board (London), Modern Power Station Practice, Nuclear Power Generation Ed 2, Oxford, Pergamon, 1971.
5. Weisman. J. Modern Power Plant Engineering, Englewood Cliffs, Prentice Hall, 1985.
6. IAEA Directory of Nuclear Reactors, Vol. IV, Power Reactors, Vienna.
7. Fast Reactor Technology: Plant Design, J. G. Yevick, M.I.T. Press.
8. Fast Breeder Reactors, A.E. Waltor & A.B. Reynolds, Permagon Press.
9. Status of liquid metal cooled fast reactor technology, IAEA-TECDOC—1083
10. Material for Sodium Technology portion will be provided during the course.

2. Reactor Engineering (RE) (40 Hours)

S.No.	Course content
A.	**Core design**
1.	Introduction - Role of FBR, Main Characteristics of LMFBR, Sodium as coolant, Core Configuration, Definition of NSSS & BOP, Pool & Loop Type Design.
2.	Fixing Size & Parameters of LMFBR - Test Reactor, Commercial & Prototype Reactor, Unit energy cost, Hot Spot temperature of Clad, Optimisation on Pin Diameter.
3.	Definition of Smear Density, DPA & Burn up.
4.	Fast Reactor Core – Fuel, Basic Requirements, Choice of fuel material, Candidates for Fuel, Swelling, Fabrication cost, Reprocessing, Negative Doppler coefficient, Thermal expansion, Burnup.
5.	Absorber – required features, candidate materials.
6.	Structural Material in Core - Requirements of Core Structural Material, Effect of Neutron Irradiation on SS, Radiation Hardening, Embrittlement, Void Swelling, Irradiation Creep, Effect of Swelling & irradiation induced creep, Efforts to reduce swelling
7.	Sub-Assembly (SA) Design - Basis for Number of pins in a fuel SA, Pin spacers, Gas Plenum, Duct considerations, Volume Fraction, Assembly Length.
8.	Other Subassembly design - Blanket, CSR, DSR, Reflector, Inner B_4C, Outer B_4C and Steel Shielding subassemblies.
9.	Thermal Design of Fuel Pin - Thermal Analysis, Causes for fuel restructuring, Developing Analytical Model, Necessary physical parameters, Na Heat Transfer coefficient, Hot spot Analysis, Calculation of temperature distribution across fuel pin.
10.	Mechanical Design of Fuel Pin - Failure Criteria for Pin, Strain Limit Approach, Cumulative Damage Fraction, Stress analysis, Cladding wastage.
11.	Hydraulic Design of Core - Factors to be reviewed for Core Hydraulic Design - Hydraulic lifting force, Mixing studies, Power flattening & flow zoning, Vibration.
12.	Handling of core subassemblies - Inherent problems associated with on-line fuel handling, Fresh SA Handling, Spent SA Handling.

B. Coolant circuits

1. Selection of coolant for FBRs, thermal, transport, nuclear, chemical and other considerations. comparison between various coolants. Special characteristics of sodium. Its impact on heat transfer and structural mechanics considerations. Selection of structural materials, basis and important alloying elements
2. Main heat transport system: primary and secondary sodium system, necessity of intermediate loop. Safety Grade decay Heat removal system, Decay heat, necessity for independent system.
3. Features of major components such as intermediate heat exchangers, steam generators, sodium to air exchangers, sodium pumps, electro magnetic pumps, sodium tanks, support design for sodium components from thermo mechanical and seismic considerations, sodium valves and types
4. Design criteria, Loadings to be considered, Analysis method and validation methodology
5. Special characteristic of sodium piping, sodium leak, sodium fire, various types of leak detectors, continuous and discontinuous level detectors etc.
6. Sodium purification loop, oxygen control, plugging indicator, cold trap, characteristics and features
7. Operating experiences of fast reactors, failures and sodium leaks reported for Phenix, Monju, PFR and other fast reactors, reasons for leak and remedy.

Books suggested:

1. Fast Breeder Reactors - Walter, A.E. & Reynolds, A.B., PERGAMON Press.
2. Fast Reactor Technology - Plant Design - Yevick, J.G., M.I.T. Press.
3. Fundamental Aspects of Nuclear Reactor Fuel Elements - Donald R. Olander, U.S.Department of Energy, 1985.

3. Fast Reactor Physics and Shielding (RP) (35 Hours)

S.No.	Course content
A	**NUCLEAR THEORY BASICS :**
1	**Properties of Nuclei:** Size, shape and density of the nucleus, nuclear forces, nuclear structure, binding energy, stability of nucleus, radioactivity
2	**Fission Process :** Spontaneous and induced fission, liquid drop model, fission neutrons, delayed neutrons, fission gammas, fission products, fission product yield, FP mass asymmetry, formation and removal of FPs in a reactor
3	**Concept of Nuclear Reactor** Fission energy, fission rate and reactor power, energy balance, fissile, fertile and fissionable materials, reactor materials: fuel, coolant, structure, control and shield, fission product activity after shutdown – decay heat, types of reactors
4	**Interaction of Neutrons with Matter** Production of neutrons, elastic and inelastic scattering, radiative capture and their significance in reactors, production of photo neutrons, transmutation
5	**Concept Cross-section** Microscopic and macroscopic cross-section, mean free path, Maxwell-Boltzmann distribution and its departure, structural changes caused by neutron reactions
6	**Variation of Cross-section with Energy** Fast, resonance and thermal ranges, 1/v law of neutron cross-section, resonance absorption, Breit-Wigner formula, Doppler effect Capture to fission ratio, Eta vs E curve, conversion and breeding concepts, Thorium utilization
B	**BASIC REACTOR PHYSICS-STATIC**

1 **Diffusion of Neutrons:** Fick's law and its validity, steady state neutron diffusion equation, concepts of neutron flux and current, interface conditions, diffusion coefficient, diffusion length and extrapolation distance

2 **Chain Reaction :**Four factor formula, conceptual treatment of diffusion of one group of neutrons in non multiplying and multiplying media, infinite and effective multiplication factors, bare homogeneous reactor concepts, material and geometrical buckling, sub criticality and super criticality, critical mass, non leakage probabilities in bare homogeneous cores, neutron cycle and life time in finite reactor

3 **Slowing Down Process:** Neutron Slowing down, slowing down power and moderating ratio of moderators, slowing down with spatial migration, Fermi age concepts, migration length, multi zone reactors, ideas of reflectors/blankets, reflector savings, form factor

C TIME DEPENDENCE

1 **Reactor Kinetics:** Time dependent neutron diffusion equation, one group kinetic equation, role of delayed neutrons, prompt neutron life time, point kinetic model to illustrate importance of delayed neutrons, reactor period, reactivity and its units

2 **Core Burnup and Neutron Poisons**: Burnup equations including fission products, Xenon and Samarium poisons, Xenon loads (operating and post shut down), variation of Xenon load with power and enrichment, Xenon oscillations and their control

3 **Reactivity Coefficients and Reactor Experiments**: Temperature and void coefficients of reactivity, their relevance to reactor safety

Techniques to control reactors, typical reactivity balance, long term burnup, fuel management, reactor control system – requirements of physics aspects, reactor shutdown mechanisms and neutron monitoring during operation and shut down

Approach to criticality, physics measurements and calibrations/validations

D FAST BREEDER REACTORS

1 **Introduction:** Fast reactors as breeders, comparison of fast and thermal reactors, types of fast reactor, role of fast reactors in Indian nuclear power program

2 **FBR Neutronics:** Neutron spectrum, reaction cross-section, core characteristics, blanket characteristics, breeding potential, breeding ratio and breeding gain, doubling time, Multigroup diffusion theory methods and summary of steady state computational methods for FBR

Effective delayed neutron fraction and prompt neutron life time, fuel expansion and bowing, sodium void reactivity effect, Doppler reactivity effect, long term reactivity effect - in FBR

3 **FBR Core Design:** General features of FBR core, specific power, linear rating, burnup, fluence, requirement and choice of core materials (fuel, coolant and structural materials), test reactors, commercial fast reactors, pin diameter, core height/diameter ratio, blanket thickness.

4 **Salient physics aspects of FBTR and PFBR**

5 **Reactor Shielding:** Source of various neutron & Gamma radiation within the reactor system; Attenuation of neutrons & gamma rays; Dose rates for gamma rays for various source geometries; Buildup factors for homogeneous & multiple layer shields; Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Streaming of radiation through gaps & void in the shield; description of various shielding arrangements of Indian reactors

Books suggested:

1. S. Glasstone and S. Sesonske, Nuclear Reactor Engineering, Van Nostrand, 1963.
2. S. Glasstone and M.C. Edlund, Elements of Nuclear Reactor Theory, Van Nostrand, 1952.
3. J. R. Lamarsh, Introduction to Nuclear Engineering, Addision Wesley, NY, 1960.
4. M. El-Wakil, Nuclear Power Engineering, McGraw-Hill
5. P.P. Zweifel, Reactor Physics, McGraw-Hill, 1973.
6. Weston M. Stacy, Nuclear Reactor Physics, John Wiley & Sons, Inc. A.E. Walter & A.B. Reynolds, Fast Breeder Reactors, Pergamon Press

4. Materials and Metallurgy (MM) (25 Hours)

S.No.	Course content
1.	**Classification of Materials**: Structure, Ferrous and non-Ferrous metals, Polymers, Ceramics, Composites, Electronic materials, Nano-structured materials.
2.	**Selection of Materials**: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martenistic stainless steel. Selection and application of advanced alloys, stainless steels, Cr-Mo steels, Ti-alloys
3.	**Heat Treatment and Mechanical Testing of materials including standards and specifications**: Mechanical properties of materials & their evaluations as per ASTM or equivalent standards, tension, hardness, creep, fatigue (low & high cycle) & impact toughness tests.
4.	**Metal Forming, Welding Science & Technology**: Metal fabrication technologies, rolling, forging, extrusion, deep drawing and introduction to material modelling. Welding metallurgy for stainless steels, ferritic steels, dissimilar metal welds and Ti-alloys, hard-facing and repair welding.
5.	**Metallographic Examination**: Experimental techniques for characterization of microstructure (Optical, TEM/SEM and microscopic techniques) specimen preparation and evaluation of microstructure of different materials.
6.	**Corrosion**: Galvanic, Uniform, Crevice, Stress corrosion cracking, Corrosion fatigue, Corrosion fast reactors and re-processing plants, Corrosion test methods and standards.
7.	**Non-destructive evaluation techniques for materials and components:** Visual, LPT, MPT, UT, Eddy current, X-ray Radiography, Neutron, Gamma ray etc. for quality assurance and in-service inspection.
8.	**Nuclear Fuels**: Production, fabrication, properties and application of nuclear fuels (metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide)) and heavy water. Radiation damage and post irradiation examination of core materials.

Books Suggested:

1. Introduction to Materials Science for Engineers - James Shackelford
2. Physical Metallurgy Principles & Practice - V.Raghavan
3. Introduction to Solids - L.V.Azaroff
4. Structure and Properties of Materials - Wulff Series, Wiley Eastern, New Delhi
5. Materials in Nuclear Application - C.K.Gupta
6. Nuclear Chemical Engineering - Benedict and Pigford
7. Physical Metallurgy, Reed - Hill
8. Heat treatment of steel - Avener
9. Introduction to Solid State Physics - Charles Kittel (Wiley Eastern)
10. Physical Metallurgy: Principles and Practice - V. Raghavan (Prentice Hall)
11. The Physics and Chemistry of Materials - Joel Gersten and Fiedenick Smith (Wiley, Canada)
12. Fundamentals of Materials Science and Engineering - D. Callister (Wiley, Europe)

5. Health Physics and Radiological Safety (HP) (25 Hours)

S.No.	Course content
1.	**Introduction:** Radiation sources: Natural and Induced radioactive sources, units of radioactivity, half-life and decay constant, specific activity. Basic interaction mechanism of a) alpha b) Beta c) Gamma/X-rays d) Neutrons with matter. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (SI units & new units). Concepts of Exposure measurement: Free air and Air wall chambers, Exposure-dose relationship, Bragg-Gray principle.
2.	**Biological effects of Radiation:** Human body: Cells, tissues and organs, structure of cell, cellular effects. Factors, which influence the damage of cell. Interaction of radiation with biological matter. Radiation effects: stochastic and deterministic. Acute and delayed effects. Types of exposure (natural, occupational, medical and public).
3.	**Radiation Protection and Regulations:** Importance of radiation protection program in DAE, Atomic Energy act, National and International regulatory bodies, their role and responsibilities., Radiation Protection Rules, Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy, Principles of radiation protection, concept of ALI & DAC (with suitable problems). Fundamentals of ICRP respiratory model, entry through ingestion, GI track model. Principles of radiation detection and monitoring: Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors Type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection
4.	**Radiation protection and measurement (External and Internal):** Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, Radiotoxicity and classification of laboratories, design of laboratory for radioactive work, Radioactive waste classification and management. Personal monitoring, area-monitoring, air monitoring. Bioassay, whole body counting techniques. Use of personal dosimeters (TLDs, pocket dosimeters)
5.	**Radiation Protection procedures:** Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (gloves + absorbing paper), Decontamination techniques. Precautions during radioactive source storage and handling, safety during transportation. Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
6.	**Nuclear Accidents, Emergency Preparedness and Management:** Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
7.	**Radiological aspects and Environmental Impact of FBRs** Radiological aspects of Fuel Cycle Facilities

8.	**Industrial Safety Aspects**: Introduction to Industrial Safety (accident prevention technique, Job safety analysis, control measures), Factories Act, 1948 & Atomic Energy Factories Rules, 1996, industrial safety aspects (Physical and Chemical Hazards),Industrial safety aspects (safety in Machineries, hand tools & Material handling equipments, personal protective equipments, etc)Construction safety (includes Electrical Safety & Work Permit System)

Books suggested:

1. Introduction to Health Physics – Herman Cember
2. Introduction to Radiation Protection – Alan Martin
3. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-Dember 18, 1998
4. Nuclear Radiation Detection - W.J. Price
5. Radiation Detection and Measurement - G.F. Knoll
6. Biological Effects of Radiation – J.E. Coggle
7. Nuclear Radiation Detectors by S.S. Kapoor and V.S. Ramamurthy (Publication: New Delhi, Wiley Eastern Ltd, 1986)
8. Atoms, Radiation and Radiation Protection by James E. Turner 1986
9. Problems and solutions in Radiation Protection by James E. Turner, 1988
10. Guide Lines for Hazard Evaluation Procedures – American Institute of Chemical Engineers
11. Risk Analysis in the Process Industries: The Institute of Chemical Engineers, England.
12. Loss Prevention in The Process Industries: Hazard Identification, Assessment and Control; Vol-1, 1996 2 Edition, Frank P Lees.

MODULE II A- CORE ENGINEERING (ELECTRICAL AND ELECTRONICS)

1. Reactor Control Engineering (FRE15) (30 Hours)

S.No.	Course content
1.	Physics of Reactor Control
2.	Reactor Kinetics – Point kinetic model, reactor response to step and ramp reactivity inputs, stable reactor period.
3.	Reactor as a control element: basic zero energy state space model and transfer function, feedback loop transfer functions, effect of temperature and voidage, poisoning due to xenon and samarium, fuel burn-up, reactor system stability analysis from transfer function and state space model. Manual and computer control.
4.	Large reactor control: Neutronically decoupled cores. Modeling techniques for large reactors-modal, nodal and quasi-static methods (introduction only) flux tilt and spatial instability.
5.	Typical reactor control system: BWR, PWR, PHWR, Fast Reactor, research reactor and 235MWe PHWR, FBTR and PFBR.
6.	Reactor operation: Approach to criticality, re-start up, operation in power range, shut down.
7.	Power plant control: Power plant programming. Constant T_{av} program, constant pressure program, boiler level and pressure control. PHT pressure control. Pressuriser pressure and level control. Secondary circuit and feed water control.

Books Suggested:

1. Nuclear reactor physics – W.M. Stacey. John Wiley and sons. 2001.
2. Nuclear reactor kinetics – Ash. M. Mcgraw Hill, Newyork, 1979.
3. Nuclear reactor kinetics and control, Weaver. L.E. American Elsevier, 1968.
4. Optimal control of nuclear reactors, Mohler.R.B. and Shen.C.N., Academic Press. 1970.

2. Nuclear Instrumentation (FRE16) (25 Hours)

S.No. **Course content**

1. Fundamental considerations/philosophies, requirements and scope-Reactor and Health Physics Instrumentation
2. Principles of detection and types of radiation detectors: in-core and out – of –core. Consideration in reactor start-up (cold & hot) and normal operation, GM counters, Scintillators, Gamma Ion chambers
3. Detector signal conditioning (Pulse, Campbell and DC modes) and generation of logarithm & period signals
4. Block Schematics of Pre-amplifier, Count rate meters, Nuclear ADCs, MCA, Low-voltage and High voltage Power supplies, Scalar timers.
5. Introduction to various reactor instrumentation and radiation monitors:
6. Start-up, Intermediate and Power Range Instrumentation, Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Stack Monitoring System, Area Gamma and Neutron Monitors, Contamination Monitors, GM Survey meters, Gun monitors, Neutron REM monitors, RADAS

Books Suggested:

1. Radiation Detection and measurement -G.F. Knoll
2. Nuclear Electronics - P.W. Nicholson
3. Selected topics in Nuclear Electronics, IAEA-TECDOC-363 (CC library Acc no: 123583)
4. Nuclear Power Reactor Instrumentation Systems Handbook, Vol: 1 J.M. Harrer, J.G. Beckerly
5. The Technology of Nuclear Reactor Safety Vol1, T.J. Thompson, J.G. Beckerly

3. Reliability Engineering (FRE4) (20 Hours)

S.No **Course content**

1. **Introduction: Reliability Engineering Applied to C&I Systems**
   Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
   Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer based systems.
   Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.
2. **Reliability Maths/Statistics:**
   - Mathematical and statistical expressions required for reliability study
   - Types of failures in electrical, electronic and computer components
   - Failure probability concept, statistical distribution models
   - Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
   - Chi-square distribution and its use in confidence and risk factors
   - Baye's theorem
   - Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
   - Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions
   - Derivation of exponential reliability expression

- R(t)=[exp-(lt)] for electronic components and systems.
- Examples to solve

3. **Fault Tolerance and Systems Reliability:**
    - Fault tolerance concept for electronic and Computer based C&I systems.
    - Circuit hardware redundancy concept to enhance system reliability, types of redundancy
    - Series, parallel, active, passive, and voting redundancy
    - Redundancy and other fault tolerance methods for software
    - FMEA, FMECA concepts for C&I and Examples to solve
    - Concepts for the analysis of System Reliability, availability, and maintainability.
    - System reliability and availability analysis methods
    - Boolean logic
    - Digraph, cutest-tie set method
    - Fault tree model, and consideration of CCF, CMF, software errors
    - Markov Model

    Example from C&I system in the NPPs
4. **QA/QC Concepts in Brief:**
    - QA/QC Concepts in the components, systems procurement, manufacture and Site installation for C&I systems in the NPPs.
5. **Environmental Qualification and Reliability Testing:**
    - Environmental qualification, testing of the C&I systems
    - Effects of various environments on the electrical/ electronic components
    - Climatic Qualification tests: Temperature, Humidity
    - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
    - Reliability Testing of the electronic components, equipment and C&I systems
    - Reliability screening tests for electronic components
    - Accelerated environmental tests
    - Failure terminated and time terminated tests
    - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
    - Few examples to solve
6. **PSA/PRA Concepts in NPPs:**
    - Probabilistic Safety (Risk) Assessment: PSA/PRA methods or safety/ risk assessment in the NPPs
    - Explain Event Tree
    - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency
    - Level-1, Level-2, Level-3 PSA studies (Brief introduction only)

7. **Additional safety concepts:**

- Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
- Single failure criteria, engineered safety systems in the NPPs
- Safety Classification and Seismic categorization of C&I Systems
- Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
- Reliability and safety aspects for the integrated C&I systems
- (hardware, software, human errors considerations)
- IEC, IAEA, AERB, IEEE standards relevant to C&I in the NPPs
- Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs

Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Methods, etc

Books Suggested:

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier
Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)
6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ.
(1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill
Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants
(2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment
(1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier
Publ.(1987)
14. Software Reliability Methods, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher
(2001),
('Formal Methods' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

4. Process Design and Control (FRE5) (30 Hours)

S.No.	Course content
1.	State Variable Descriptions Introduction, The concept of state, Elementary definitions, state space representations of continuous-time and discrete-time systems, State diagrams, illustrative examples, solutions of state equation, state transition matrix, computation methods of state transition matrix, relationship between state equations and transfer functions, characteristic equations.
2.	Controllability and Observability: Introduction, definitions of Controllability and Observability, Controllability and Observability tests, Kalman Controllability Criteria, Principle of Duality, Controllability and Observability of discrete – time systems
3.	Control System Design: Introduction to state feedback, Controller design using pole placement technique, Stabilizability, LQR technique.

Books Suggested:

1.John J.D'Azzo and C.H.Houpis, "Linear Control System Analysis and Design- Conventional and Modern", 2nd Ed. McGraw Hill Book Co.1986.
2.Chi-Tsong Chen, "Linear System Theory and Design", CBS College Publishing, Holt, Rinehart and Winston, 1984.
3.M.Gopal, "Modern Control System Theory", 2nd., Wiley EasternLtd.,1993.
4.Gene F. Franklin et al, "Feedback Control of Dynamic Systems", 3rdEd., Addison-Wesley Publishing Co. 1994.
5.B.Friedland, "Introduction to State-space methods"
6.K.Ogata, "Modern Control Engineering", Prentice- Hall.
7.H.Kwakarnaak, R.Sivan-"Linear Optimal Control Systems"-Wiley interscience
8.D.G.Schultz,James.L.Melsa- "State Function and linear control systems"- McGraw Hill.

5. Embedded System Design and Human Machine Interface(FRE17) (45 Hours)

S.No. **Course content**

Embedded System Design

A. Microprocessor Based Hardware Design:

1. Overview of Microprocessors: Comparative study of Intel and Motorola family microprocessors (80186, 80486, Pentium series, 68XXX), Overview of 16-bit Micro-controllers (e.g. 80196), Overview of 8-bit Atmel Micro-controller (AT89C51), Real Time Clock, DSPs (e.g. TMS320, SHARC family) and ARM processor.
2. Personal Computers: Architectures, Memory organization, Industrial PC, Embedded PC
3. Industry Standard Bus Systems: ISA, PCI, VME: Mechanical, electrical, functional & procedural specifications, multi-processing, bus arbitration, plug & play
4. Design Case Study: Single board computer architectures, Remote Terminal Unit, Circuit design, and logic design, application of FPGA and CPLDs, ac/ dc analysis, timing analysis, thermal, EMC and signal integrity analysis. Design accommodations for testability, reliability and maintainability. Physical design and design tools.

B. Computer Communication and Networks

Asynchronous & synchronous communication standards, RS232C, RS485, USB, encoding (NRZI, Manchester), Modems, SDLC, Local area networks, Ethernet, Token passing principles, TCP/ IP, Fibre optic communications for LANs, wireless LANs (WAP, Blue tooth), Industrial networks, Real-time issues in networking, Networking hardware (cables, hub, switch, routers etc.);Concept of Fieldbus, fieldbus standards, Industrial networks and Protocols.

C. Fault Tolerant and Distributed Architectures

1. Principles of fault tolerance, Hot- standby and Triple Modular Redundant (TMR) configurations, software implemented fault tolerance, reliability, and availability and safety issues.
2. Principles of distributed systems, architectures, Distributed control systems, Impact of Internet technology, Web enabled devices.

D. Programmable Logic Controller Design

Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, Relevant communication protocol and standards, PLCs for package systems.

Human Machine Interface

E. Human Machine Interface (HMI)

1. Overview of plant automation, Control Room, Control Panels and Cabinets : Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMI & EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciation (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
2. Design of HMI, Soft Console versus Conventional control panels, Virtual Control Panel.
3. PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software, SCADA for substation. Concept of Fieldbus, fieldbus standardization, Industrial networks and Protocols.
4. Guidelines for design of HMI displays.
5. Case study of a commercially available Professional HMI package.
6. Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, Methods of passing data to HMI package

Books Suggested:

1. Microprocessor and interfacing: D. V. Hall – McGraw Hill
2. The Advanced Intel Microprocessors: 80286, 80386, 80486: Barry. B. Brey, - McGraw Hill
3. Microprocessor, Micro-controller and DSP Handbooks: Motorola, Intel, Texas Instruments, Analog Devices
4. Hardware Bible: W.L Rosch- Tech Media
5. VME Bus specifications: IEEE 1014- 1987
6. Embedded System design – A Unified hardware/ software introduction: Frank Vahid / Tony Givargis – John Wiley and sons

7. Computer networks: A.S. Tanenbaum, Prentice Hall
8. Internetworking with TCP/ IP: Vol I to III: D.E.Comer, Prentice Hall
9. Complete guide to networking: P. Norton & Kearns – Tech Media
10. Wireless communication & networks: W. Stallings – Pearson education
11. Fault-tolerant computing – Theory & Techniques: D.K. Pradhan (Ed), Vol I & II – Prentice Hall
12. The theory and practice of reliable system design: D.P. Siewiorek& R.S. Swarz, Digital press
13. Modern Operating Systems: Andrew S Tanenbaum, Prentice Hall
14. Distributed Operating systems: A .S. Tanenbaum – Pearson education
15. Windows NT device driver development: P.G. Viscarola & W. Mason – Tech Media
16. Real-time systems: Jane W.S. Liu – Pearson education Hill.
17. IntellutionIfix documentation
18. NPC Guidelines for development of soft consoles

6. Process Instrumentation (FRE18) (45 Hours)

S.No.	Course content
1.	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of following process variables: Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, elbow flowmeter. Different standard pressure taps for orifices, sizing calculations, straight length requirements. Applicable codes for design of Orifices , venturies and flow nozzles. Orifice flanges, Jackscrews, carrier rings, flow straighteners, square root extractors, flow totalisers. Variable Area Flowmeters- Glass tube rotameters; Armoured rotameters; Bypass rotameters; Density correction factors. Magnetic, Turbine, vortex flowmeter; Ultrasonic flowmeters- transit time, Doppler type, Clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters, air velocity meters. Applications and limitations of various flowmeters. Two phase flow measurements.
2.	Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, high temperature thermocouples, cold junction compensation techniques. Applicable standards. RTDs- Wire wound and thin film RTDs, limits of error, self heating error, matched pair of RTDs. Applicable standards for RTD. Thermistors - performance and applications. Thermowell - Design considerations, Applicable design code for thermowell, thermowell installation aspects. Surface temperature measurement techniques. Temperature transmitters- Head mounted temperature transmitters, isolated temperature transmitters, Smart temperature transmitters. Radiation thermometry- Optical pyrometer, total radiation pyrometer, two colour pyrometer, factors affecting the performance of radiation pyrometers.
3.	Pressure: Manometers-U tube, well and inclined manometers, pressure gauges, hydraulic and pneumatic dead weight testers- ranges and factors affecting the performance of dead weight testers. Pressure Transducers and transmitters- strain gauge, capacitance, LVDT, piezo-resistance type and piezoelectric type pressure transducers, transmitters with remote diaphragm seal, high temperature pressure transducers, Smart pressure and

differential pressure transmitters. Vacuum measurement- Pirani and thermocouple gauges, cold cathode and hot cathode ionization gauge, Mcleod gauge.

4. Level: Hydrostatic pressure and differential pressure methods, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer, ultrasonic, nucleonic, hydra step level gauge and radar level gauge. Level switches- conductivity, capacitance, ultrasonic, displacer, float type.

5. Analytical Instrumentation: Conductivity, pH, ORP , Turbidity dissolved oxygen, silica and sodium Measurement. Other Measurements: Moisture, Relative humidity; viscosity and density measurement Turbovisory Instrumentation: Measurement of speed, vibration, differential expansion, overall expansion, eccentricity, Governor valve position, CIES valve position, Speeder-gear & load limiting gear position

6. Sodium Instrumentation: Properties of sodium-special requirement of sodium Instrumentation-sodium flow measurement- Magnetic flowmeter, Eddy current flowmeter sodium level measurement-continuous- discrete-resistance type-mutual inductance type- Sodium Leak Detection-spark plug type & wire type leak detection-Sodium aerosol detection - Mutual Induction type leak detectors - Steam Generator Leak Detection systems-Hydrogen in sodium detection- Nickel diffuser based detection-Electrochemical meter based detection-Hydrogen in cover gas (argon) detection- Failed fuel detection system-Gammatography etc.,

   Signal Conditioning Circuits: Operational amplifiers-instrumentation amplifiers-signal linearization techniques, isolation amplifiers-two port-three port isolation.

7. Control valves: Valve types, construction and applications, Valve sizing calculations, Applicable standard for sizing calculations, Control valve rangeability, Valve characteristics-inherent and installed, selection of valve characteristics, Cavitation and flashing in control valves, Valve capacity testing, Valve actuators- pneumatic, hydraulic and electric, selection of actuator, Typical specifications for control valve, Smart valves, valve positioner, I/P converter, P/I converter, volume boosters, air lock relays, Solenoid valves, Pressure regulating valves, Installation aspects of control valves, Quality of air for pneumatic valves.

   Instrument Impulse lines and instrument fittings: Tubes- materials and sizes, tube fittings-materials, types of fittings, instrument isolation valves, guidelines for routing of impulse lines, considerations for impulse line response time. Applicable standards for tubes and fittings.

8. P & I Diagrams, loop and hook up diagrams: P &ID symbols, Applicable ISA standard for P &ID symbols, typical loop diagrams, typical instrument hook up diagrams.

   Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, Linear and switching mode power supplies, Fault Tolerant Dual redundancy power supplies, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.

9. Reliability principles, Fail safe design principles, Diversity, active and passive redundancy, availability, maintainability, MTBF, MTTR, preventive-predictive-proactive-corrective maintenance-spares inventory control principles, Condition Monitoring etc.

   Note:Course Work -35 Hours and Practicals -10 Hours

Books Suggested:

1. Principles & practice of flow meter Engineering by L. K. Spink. The Foxboro Company.
2. Fluid Meters. ASME publication

3. Manual on the use of thermocouples in Temperature Measurements (ASME Publication by subcommittee 4)
4. Measurement Systems: Application and Design, Ernest O Doeblin
5. Process Control Systems: Application, Design and Tuning, F. G. Shinskey, Mcgraw Hill.
6. Applied Instrumentation in the Process Industries, Volume I & II, Edited by W.G. Andrew.
7. Process Control Engineering, M. Polke
8. ISA Handbook of Control Valves, Editor-in-Chief J. W. Hutchison
9. British Standard Code of practice for Instrumentation in Process Control Systems: installation design and practice (BS 6739)
10. Handbook on Applied Instrumentation: Edited by D.M. Considine and S.D. Ross, Mcgraw Hill
11. Process Instruments and Control Handbook: Edited by D. M. Considine, Mcgraw Hill
12. Instrument Engineer's Handbook, Part I & II: Edited by Bela G Liptak, Chilton Book Company
13. Instrumentation in the Processing Industries Edited by Bela G Liptak, Chilton Book Company
14. IEC standard 61131.3 - PLC Programming Languages
15. Human Factors in Control Room Design - EPRI NP 1118 / EPRI NP 3659
16. NUREG-700 Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission
17. Eight Open Net works and Industrial Ethernet, (www.industrialethernet.com)
18. Basics of Field bus, Rosemount Inc. (www.rosemount.com)
19. MIL-STD-1553B Standard

7. Emergency Preparedness and Disaster Management (FRE8) (20 Hours)

Emergency Preparedness

Bases and contents of emergency response plan by operating organization, Classification of emergencies - Emergency Standby - Personnel Emergency - Plant Emergency Site Emergency - Off-Site Emergency, Organisation for emergency response – Plant Emergency organization - Site Emergency Organisation – Off-Site Emergency Organisation., Emergency measures – Notification - assessment action during emergency - Corrective Actions - Protective Measures - Contamination Control Measures - Termination of Emergency, Assistance to affected personnel - First-aid - Decontamination - Transportation- Medical Treatment, EMERGENCY PREPAREDNESS – Training - Exercises - Review and Updating of Plans and Procedures - Emergency Equipment and Supplies

Disaster Management

Nuclear and Radiological Emergency/Disaster Scenarios

Nuclear and Radiological Emergency/Disaster Scenarios, Accidents in Nuclear Power Plants and Other Facilities in the Nuclear Fuel Cycle, 'Criticality' Accidents, Accidents during Transportation of Radioactive Materials, Accidents at Facilities using Radioactive Sources , Nuclear/Radiological Terrorism and Sabotage at Nuclear Facilities, Need for a Comprehensive National Radiation Emergency Management System , Disaster Management in India

Approach to Nuclear and Radiological Emergency Management

Strategies for Nuclear Emergency Management, Nuclear Emergency Management, Framework, Prevention of Nuclear Emergencies, Emphasis on Prevention (Risk Reduction) and Mitigation Measures, Prevention (Risk Reduction), Mitigation Measures , Compliance with Regulatory Requirements, Nuclear Emergency Preparedness, Capacity Development , Nuclear Emergency Response, Strengthening the Framework of Nuclear Emergency, Monitoring the Implementation of Nuclear/Radiological Emergency Action Plans

Mitigation of Nuclear/Radiological Emergencies

Mitigation Measures, Defence-in-Depth: Salient Features, Mitigation of Nuclear and Radiological Emergencies, Engineered Safety Features, Accident Management, General Mitigation Features, Engineered Safety Features (to Mitigate the Consequences of an Accident) in Nuclear Power Plants

MODULE III - OPERATIONS

1. Plant Control (FRE9) (25 Hours)

- Control Physics: Review of Reactor Kinetics - neutron power - prompt and delayed neutrons - Criticality – Reactivity Feedbacks - reactivity coefficients Sodium void coefficients;
- Reactor Control Concepts: Start-up - Operation at steady power - shutdown criteria - design considerations - reactivity disturbances and transients.
- Reactivity control devices - reactivity insertion rates – principles. Calibration of control rods.
- Plant Dynamics and Overall Control: Reactor Physics and engineering experiments
  Transient analysis concept - Routine Operating transients - Accidents such as LOCA, LOFA, reactivity excursions etc
- Thermal balance & reactivity balance calculations.

2. Turbine Generator Fundamentals (FRE10) (25 Hours)

- Principles of steam turbine cycle, steam turbines, impulse and reaction turbines, Rankine cycle, velocity diagram for impulse / reaction turbine, state point locus or condition line for multistage turbine, reheat factor, Willan's line variation of stage pressure with load, heat rate, thermal efficiency, peak load, base load, spinning reserve and capacity factor.
- Turbine parts, construction of nozzle, turbine blades, turbine rotor, turbine casing, cylinder supports.
- General design aspects, output of a steam turbine, effect of higher steam inlet pressure, effect of high inlet steam temperature, effect of the size of the turbine, effect of back pressure on the economy of a turbine, effect of reheat, effect of feed water regenerating cycle, double cylinder construction speed of a turbine.
- Nuclear turbine, erosion of blades, methods of reducing moisture content, moisture removal within the turbine, external moisture separator, re-heater, protection of blades against erosions, over speeding of turbine.
- Lubrication of bearings, turbine oil system, theory of lubrication of turbine bearings, viscosity, oiliness, boundary lubrication, film lubrication, the journal bearing, hydro dynamic lubrication, hydrostatic lubrication, properties of oil, additives, treatment of oil.
- Governor theory, basic methods of governing, throttle governing, nozzle governing, difference between governor and fly wheel, types of governors, centrifugal governor, effect of friction, speed droop, speed regulation for machines operating, inertia governor, electric governor, new governing systems used in the latest NPPs.
- Turbovisory instruments, purpose of turbovisory instruments, location of Turbovisory instruments, differential expansion indicator, eccentricity recorder, turbine pedestal movement indicator, speed indicator and recorder, vibration indicator.
- Turbine commissioning, pre-start commissioning, lubricating oil system, checking tightness of vacuum system, flushing the condensate, feed water and other piping of the various sub-systems, turbine supervisory instruments, governor systems, main steam line blow out, Vacuum pulling, starting a new turbine for the first time.

- Pre-heating of turbine, cold start and hot start, heating process, heating rates, differential expansion of cylinder and rotor, effect of flanged horizontal joint, flange bolts, conditions in a standing hot turbine, turbine shaft turning gear, thermal expansion during warming up.
- Operation of turbine, start-up procedure, on-load operation, routine tests, turbine shutdown procedure.
- Turbine troubles, shaft vibration, disc vibration, blade vibration, internal defects of material, expansion of steam piping, corrosion of blades and diaphragms, turbine blade deposits.
- Protection and safety devices, turbine regulating system, turbine protective system, protections on boiler feed pumps, H.P. heaters and L.P. heaters
- Inspection and overhauling, lifting the cover, inspection of diaphragms, checking the clearances, inspection of rotor, Inspection of shafts, inspection of steam valves.
- Condensers, design of condenser, effect of changes in cooling water temp. in condenser operation, effect of varying cooling water flow on condenser back pressure, air leakage, water leakage, maintenance of condensers, condenser as a deaerator, back washing of condenser, Hoggers and methods of vacuum creation, replacement of Hoggers with vacuum pumps, reasons for this replacement and their advantages.
- Regenerative feed heating, selection of feed heating system, components of feed water system, effectiveness of feed water heater, deaerating contact heaters, deaerators, closed heaters, cascading of feed water heater drains, venting of feed water heaters, performance of feed heaters.
- Boiler feed pumps, condensate extraction pumps and controls, Boiler feed pump and controls, Boiler feed pump recirculation and up warm-up lines, Net Positive Suction Head (NPSH) for a pump, boiler feed pump NPSH.
- Chemical control, design intent of a system chemical control, review of basis and material of construction, co-ordinated phosphate pH control, all volatile or zero solid treatment, mixed treatment, Oxygen scavenging, ferrous sulphate injection for prevention of condenser tube corrosion.
- Generator and auxiliaries, stator cooling water system, hydrogen cooling system, seal oil system.

3. Mechanical and Electrical Equipment (FRE11) (25 Hours)

- Bearings and Lubrication, Types and identification of bearings - Illustration of different types of bearings - Selection of bearings - Lubrication methods - Types of lubricants - Lubricant properties - Bearings and lubrication methods used in: - Turbine – Primary & Secondary sodium Pumps - Boiler feed pump Bearing mounting in motors (Horizontal and vertical) - Operating care for bearings - Causes of bearing failure.
- Seals, Types of static and dynamic seal. Gland packing - Mechanical seal - O ring – etc. Inspection of mechanical seal - Causes of failure of mechanical seals - Operating care for all the seals - Importance of seals in nuclear power plant operation.
- Power Transmission, Types of couplings and belts - Application of various couplings like tyre coupling, love joy coupling, steel flux coupling, bush and pin sliding disc, sliding block, flange muff and coupling. - Types of misalignment - Effects of misalignment on equipments.
- Pumps, Types of pumps - Centrifugal, rotary and reciprocating pumps – Pumps used in Sodium system-Construction details of pumps - Types of casing - Types of impeller - Effects of radial thrust and axial thrust - Methods of balancing of radial thrust and axial thrust - Operation of centrifugal pump, external gear pump, internal gear pump, screw pump, radial piston pump - Head - Flow characteristics of centrifugal pump - System head characteristics - Power characteristics of centrifugal pump - Effect of drooping head characteristic - Cavitations, aeration and Net Positive Suction Head (NPSH) - Series and parallel operation of centrifugal

pump - Practical operation of centrifugal pump and rotary pump - Effect of direction of rotation - Primary heat transport pump - disassembly and assembly - alignment procedure - lift adjustment - Canned rotor pump details, operation and testing – Trouble shooting procedures. Vacuum pumps - Types of vacuum pumps.

- Electromagnetic Pumps – types of EM pumps – construction- characteristics- protections for EM pump-Operation of EM pumps.
- Valves and Actuators, Types of valves - gate valve - globe valve - check valve - relief valve and safety valve - butterfly valve - diaphragm valve -bellow seal valve Application of the above valves - Construction detail of valves Gland packing - Live loading - Testing of valves - Types of valve actuator - Features of actuators - Hopkinson actuator -Limitorque actuator -Rotork actuator -piston type actuator - diaphragm type actuator. Operation of the above actuators - Test procedures for valves actuators.
- Sodium system valves – bellow seal valves – frozen seal valves
- Hydraulics, Circuits and control - Hardware in hydraulic circuits -tube -pipe -fittings and connectors :-flared fitting, swagelok fitting, quick disconnect coupling.-hoses - Specifications of hardware parts - Operation and maintenance problems - Hydraulic controls, types and application of - hydraulic cylinder – pressure regulating valves - directional valves - sequence valve -decelerating valves - flow control valves - Effect of pressure and flow of hydraulic oil on actuators.
- Compressors, Types of compressors - Constructional details of - reciprocating compressor - sliding vane compressor. Blowers- Types of Blowers.
- Chillers. Types of Chillers , refrigerants, refrigeration cycles, Air handling units
- Filters, Types of filters & specifications, HEFA filters, testing of HEFA filters
- Heat Exchangers, Types of Heat Exchangers - Types of tube and tube sheet connections - General details of heat exchangers. Types of maintenance
- Piping and Tubing, and pipe fitting.
- Vibration and measurements, Causes of vibration, characteristics of vibration, significance of displacement, velocity, acceleration, phase and frequency. Single plane balancing. Vibration measurement devices.

Power Systems and Electrical Equipment

Part – I: Power Systems

Grid characteristics, Interaction of NPP with grid, Power system analysis and representation, Voltage and frequency control, Synchronous machines, synchronizing and load shedding, Main output and station service systems, Line, transformer and generator protections, Short circuit calculations, Power systems components

single line diagrams, concept of real and reactive power flows, voltage and frequency relations to real and reactive power, AC and DC transmission systems, Automatic voltage and frequency control, Definitions of related plant factors, synchronous machine theory, isolated and parallel operation, Automatic voltage regulator, Stability of alternators, steady state & transient stability, abnormal operating conditions, Excitation systems, loss of excitation, loss of synchronism, current unbalance, switchyard concepts, Station service and unit transformer arrangements, Classes of power supplies, standby systems, Automatic and emergency transfer schemes, Transformer, switchgear and protective relaying concepts, specific relaying for generators, motors, transformers, buses and transmission lines.

Part – II Electrical Equipment

Electrical control components and circuit checks. (415V / 3.3kV / 6.6KV), Principles of electrical control, control circuit components like relays, contactors, switches, fuses, control transformers, indicating lights, terminal blocks, control cables, Reading of electrical drawings,

Local and remote controls, interlocks, push buttons, types of hand switches, forward / reverse controls, resetting meaning of logic, auto and standby modes, motor control centres (MCCs), MCC types, parts, construction, Pump, valve, crane, diesel generator controls, synchronizing controls, circuit breaker controls,
Various types of starters and controls (D-O-L), Star- Delta (manual and automatic)

- Electrical test equipment in commissioning checks.
- Use of test equipment in commissioning including - Meggers, Motor Rotation Testers - Phase Sequence Indicators - Transformer Turns Ratio Testers - Tachometers - Tong testers – Multimeters, Resistance bridges - Stroboscopes - Oscilloscopes – Harmonic Analyzers
- Commissioning tests on motors, generators, transformers, valve actuators, switchgear, protective relays, batteries and chargers
- Motors, Identification of motor leads - Measurement of insulation and winding resistance - Measurement of no load current, speed, bearing checks -Magnetic balance tests - Measurement of power factor
- Transformers, Polarity checks - Measurement of turns ratio, vector group - Insulation checks - No load and short circuit tests - Measurement of magnetizing current - Measurement of %impedance - Measurement of dielectric strength of insulating oil - New types of transformers – dry type transformers - On line tap changers
- Generators, Measurement of insulation and winding resistance - Starting, stopping, synchronizing, loading and unloading - Phase sequence tests, Excitation control.
- Switchgear, Measurement of contact resistance - Measurement of closing and tripping time - Measurement of contact pressures - Study of link mechanisms - Study of stored energy features.
- Valve actuators, Limit and torque switches - Valve position indicators – Types of actuators.
- Protective relays, Calibration of relays - Use of primary and secondary injection tests - Testing of time over current, thermal overload and directional relays - Study of relay test sets - Multiamp, Gyro, English Electric Makes - Solid state protective relays and their use in NPPs – Latest methods in relay testing using micro-processors.
- Batteries, Parts of lead acid cells - Measurement of specific gravity, voltage - Charging and discharging of cells - Study of charging circuits, Nickel cadmium batteries.
- High Voltage Equipment, High voltage equipment and electrical layout study of high voltage equipment like - Current transformers - Potential transformers - Disconnect switches - Capacitor voltage transformers - Line traps - Air blast circuit breakers, SF_6 ,Circuit breakers.
- Lightning arresters.
- Switchyard layout, indoor and outdoor switchyards, problems associated with costal sites - corrosion, salt deposition, line washing.
- Uninterrupted Power Supplies (UPS), Control UPS and Power UPS, SCADA.

4. Maintenance Engineering (FRE12) (25 Hours)

- Overview of maintenance in NPPs, Challenges in NPP maintenance, Maintenance economics.
- Reliability engineering and maintenability, Definition of reliability, bathtub curve, reliability prediction for complex plant, reliability for series and parallel arrangement, Maintainability, Availability, mean time to failure, (MTTF) mean time to repair (MTTR), means adopted to improve reliability in NPP.
- Maintenance policies, Different types of maintenance policies, fixed time maintenance, condition based maintenance, opportunity based maintenance, operation to failure maintenance, design out maintenance. Application and relative advantages and disadvantages of the policies.
- Maintenance planning, maintenance decision making, maintenance planning, manrem budgeting, determination of maintenance plan, classification and identification of equipment, equipment histories, selection of maintenance policy, preventive maintenance program.

- Spare parts management and inventory control, Requirement of the spare parts management. Economic order quality. Safety stock and when to order. Special condition for storage of sensitive spares, shelf life management.
- Condition based maintenance, Requirement, relative advantages and disadvantages, condition monitoring categories -on load and off load monitoring. Types of monitoring techniques i.e. lubricant monitoring techniques, wear debris analysis and malfunctions that can be detected by lubricant monitoring. Thermal monitoring, types of thermal monitoring, and parameters that can be detected by thermal monitoring.
- Vibration monitoring, basic characteristics, analysis, vibration meter construction, factors contributing to vibration monitoring.

5. Regulatory Framework for NPPs (FRE13) (25 Hours)

- The Atomic Energy Act 1962 and the Factories Act 1948, Salient features of the Act covering the major provisions and including brief title, scope of application, appropriate government, ownership, processing and usage of radioactive materials, authorisation for power generation and storage of certain chemicals, regulating and enforcing bodies under the Act. Salient features of the Factories Act 1948 with particular emphasis on safety and welfare provisions, inspection of factories and returns needed to be filed. Salient features of the Atomic Energy (Factories) Rules 1996 and authorisation for safe disposal of radioactive waste.
- The Atomic Energy Regulatory Board (AERB), Evoluation of AERB. Statutory status, role, powers and activities of AERB. Approach to safety as defence in depth. Authorisation process - site approval, construction authorisation, commissioning authorisation, operating authorisation, life extention of NPPs, decommissioning authorisation. Regulatory inspection. Safety assessment. Role and powers of SORC and SARCOP. Staffing, training, qualification and licensing. Simulator training and human error reduction. Design review for plant modifications. Major guidelines for NPP O&M. Technical specifications. Licensing practices. Indepence of the regulatory body. Periodic review of NPPs. Advisory committees of AERB. Instances requiring notification and clearances.
- Electricity Act 2003 and the Boiler Act, Salient features of the act covering the major provisions and including brief title, scope of application, appropriate government, regulation and inspection of electricity generating utilities. Training and authorisation of certain personnel.
- Environmental Protection Legislation, Introductory features of covering highlights and permissions needed by NPPs under the following acts:
- The Environmental Protection Act 1986
- The Air (Prevention and Control of Pollution) Act 1981
- The Water (Prevention and Control of Pollution) Act 1974
-

6. Practicals (FRE 14) (6 Weeks)

12. Practicals (FRE 14) (6 Weeks)

Turbine and Generator

- *Class room training on Generation Plant,* Steam water system, Turbo- generator

Simulator and Fuel Handling

- *Class room and Field Training on Fuel Handling*
- *Field Training on PFBR Simulator*

Operations

3. Class room Training

a. Reactor System

Reactor Assembly, Reactor Core, Control Rod Drive Mechanisms, Emergency Core Cooling Systems

b. Sodium system

Primary Sodium System, Secondary Sodium System, Sodium Purification System, Cover Gas System, Steam Generator Leak Detection System, Sodium Instrumentation

c. Control and Electrical system, *Neutronic Instrumentation, Reactor Protection System, CDPS, Power Supply Systems*

d. Radiation protection

At the end of classroom training written exam will be conducted for evaluation. After classroom training field training will be provided as follows

4. Field training

a. Reactor Operation

b. Maintenance Activities

c. Technical Service Activities

d. Quality assurance & Industrial safety

TSOs will be asked present a project report and walk-through test on the above modules.

BACK TO MAIN

PGD in CHEMICAL SCIENCES (Program Code: CHEM00)

Course Structure:

I. Courses at BARC

Program Code : CHEM00	Programme Specific Outcome	Firm foundation in the fundamentals and application of current chemical and scientific theories including those in Analytical, Inorganic, Nuclear and Physical Chemistry.
		Ability to design and carry out scientific experiments as well as accurately record and analyze the results of such experiments.
		Skill development in problem solving, critical thinking and analytical reasoning as applied to scientific problems.
		Ability to clearly communicate the results of scientific work in oral, written and electronic formats to both scientists and the public at large.
		Appreciate the central role of chemistry in DAE programmes and use this as a basis for ethical behavior in issues facing chemists including an understanding of safe handling of chemicals, environmental issues and key issues facing our society in energy, health and medicine.

(A) FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Mathematics, Quantum Chemistry & Computational Methods	CY501
2	Analytical Chemistry	CY502
3	Material Science	CY503
4	Radiation Detection and Measurements	CY504
5	Nuclear and Radiochemistry	CY505
6	Thermodynamics	CY506

(B) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Lasers	CY601
2	Electronics & Chemical Instrumentation	CY602
3	Production and Applications of Radioisotopes	CY603
4	Reactor Physics and Reactor Chemistry	CY604
5	Molecular Structure & Spectroscopy	CY605
6	Radiation and Photochemistry	CY606
7	Chemistry in Nuclear Fuel Cycles	CY607
8	Advanced Chemical Kinetics & Dynamics	CY608
9	Health Physics and Radiation Biology	CY609
10	Research Methodology	CY610
11	Safety in Chemical and Radiochemical labs	CY 611

(C) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Nanomaterials, Chemical Sensors	CY701
2	Soft Condensed Matters	CY702
3	Nuclear Probes for Material Characterization	CY703
4	Molecular Bioorganics	CY704
5	Laser Spectroscopy	CY705
6	Actinide Chemistry	CY706
7	Computational Chemistry	CY707
8	Advanced NMR Spectroscopy	CY708
9	Atmospheric Chemistry	CY709
10	Statistical Analysis	CY710

(D) NON-SUBJECT ASSIGNMENTS

Sr. No.	Name of the Course	Course code
1	Viva Voce	CY591
2	Mini Project	CY592
3	Seminar	CY593

Course Outcomes:

(A) FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Mathematics, Quantum Chemistry & Computational Methods	CY501	Learn foundations of quantum mechanics to understand the difference between classical and quantum phenomena.
		Understanding the role of rotational and spin angular momenta in chemistry.
		Develop expertise in molecular orbital theory that helps in understanding structure of polyatomic molecules.
		Understanding molecular symmetry to predict the chemical reactions of atoms and molecules.
		Calculation and interpretation of errors in numerical computation.
Analytical Chemistry	CY502	Acquaintance with various analytical techniques
		Idea on how to tackle an analytical problem, pertaining to DAE and other industries.
		Acquaintance with theories of various matrix separation techniques
		Acquaintance with statistical treatment of analytical data
		The course gives sufficient expertise leading to enhanced employability
Material Science	CY503	Ability to analyse the Powder X-ray diffraction pattern for solving crystallographic structures
		Description of specific crystal structures by applying basic crystallographic concepts
		Establishing correlation between electrical behavior and crystal structure
		Understanding different types of defects and their effect on the functional properties
		Understanding the concept of solid solution formation for fine tuning the properties
Radiation Detection and Measurements	CY504	Expertise to choose a particular detector for a specific application
		Expertise to carry out identification and quantification of radionuclides
		Knowledge base to understand safety aspects while working with radioactivity
		Basic knowledgebase for orientation towards working in areas involving applications of nuclear techniques
		Basic knowledge to develop need-based measurement systems

Nuclear and Radiochemistry	CY505	Identifying the factors that affect nuclear stability
		Explain the different kinds of radioactive decay and interpret a radioactive decay series, apply radiotracer principles
		Calculate the specific activity of the produced radionuclides, estimate the conditions required for producing important isotopes
		Understand the basic concepts in fission and the production yields of different radioactive isotopes during fission
		Identify the nuclear analytical techniques useful for analysing the samples (neutron activation, Ion beam analysis techniques)
Thermodynamics	CY506	Analyze thermal effects on a chemical process
		Understanding that change in environmental conditions can change the process itself.
		Important concepts on Carnot engine and energy conversion efficiencies
		Thermodynamics of nuclear materials
		Idea about experimental thermodynamics

(B) CORE COURSES

Name of the Course	Course code	Course Outcome
Lasers	CY601	Understanding of the operation of laser
		Understanding the principle behind the selection of specific laser for a specific application in the field of laser spectroscopy
		Knowledge of different classes of laser and their applications in different fields.
Electronics & Chemical Instrumentation	CY602	Understanding the principle of operation of common laboratory instruments
		Setting up / wiring of components for furnace, thermocouple, temperature controller etc.
		Ability to do simple trouble-shooting related to instruments (checking fuse, voltage, resistance etc.)
		Application of noise reduction techniques during measurements
Production and Applications of Radioisotopes	CY603	Knowledge of different processes employed for the production and radiochemical processing of important artificially produced radionuclides
		Understanding how the radiation and radioisotopes can be employed to divulge the useful information regarding different human ailments as well as how to treat various diseases specifically cancer

		Appreciate how the radiation and radioisotopes have emerged as an essential tool in various industries
		Expected to comprehend the important roles radiation technologies are playing in various processes
		Appreciate that radiation and radioisotopes are boon for the development of nation and mankind
Reactor Physics and Reactor Chemistry	CY604	Understand various designs of nuclear reactors and its components.
		Gain insight about the details of reactor physics calculations which are required for designing a nuclear reactor.
		Become conversant with the purification techniques used for the preparation of demineralized water at large scale and also about the variation in its thermo-physical properties with temperature and pressure.
		Develop the understanding of the behaviour of various materials of construction in their operational environment of nuclear power plants.
		Understanding the guiding principles for evolving the chemistry control process and the actual practice been adopted for the various heat transport systems of the nuclear power plants.
Molecular Structure & Spectroscopy	CY605	Understand the general characteristics of the d and f block elements
		Thorough knowledge of the different theories to explain the bonding in coordination compounds
		Improve the level of understanding of the chemistry of lanthanides and actinides
		Develop understanding of various advanced spectroscopic techniques for analyzing complex compounds.
		Thorough knowledge of the fundamentals of microwave, infrared, Raman, electronic and magnetic resonance spectroscopy, X-ray photoelectron spectroscopy.
Radiation and Photochemistry	CY606	Awareness of radiation induced reactions and its applications
		Expertise to analyse and quantify radiation/photochemical induced chemical reactions
		Trained man power for using various radiation and photochemical sources and state-of art experimental facilities
		Hands-on experience and research training during project work

		Knowledge development in the DAE relevant activities and planning for future R&D programs
Chemistry in Nuclear Fuel Cycles	CY607	Knowledge of processes involved in recovery of nuclear material from ores
		Understanding the chemistry involved in different stages of nuclear fuel cycle
		Understanding of fabrication and quality control of nuclear fuel
		Knowledge in physico-chemical characterization of nuclear fuel, irradiation behaviour
		Understanding of reprocessing of spent fuel and waste management
Advanced Chemical Kinetics & Dynamics	CY608	Learn difference between chemical kinetics and dynamics, and their applications in real systems
		Predict the energy state of a reaction product, and required reactant states to obtain a desired product for a simple reaction.
		Learn the importance of energy transfer affecting the population inversion in a gas laser.
		Expertise developed in carrying out research in relevant area of chemical physics with acquired knowledge.
		The course gives sufficient expertise leading to enhanced employability
Health Physics and Radiation Biology	CY609	Basic knowledge of handling hazards of various radioactive materials
		Knowledge of radiation protection aspects in nuclear and radiation facilities
		Radiation Protection Aspects in Designing of Nuclear and Radiation Facilities
		Design of advanced radiation monitoring equipments
		Management of Nuclear/Radiological Emergencies in facilities
Research Methodology	CY610	Demonstrate knowledge of research processes (reading, evaluating, and developing)
		Perform literature reviews using print and online databases
		Identify, explain, compare, and prepare the key elements of a research proposal/report
		Knowledge of writing reports and thesis
		Idea about following ethical practices in research
Safety in Chemical and Radiochemical labs	CY 611	Develop an understanding of the principle of chemical/radiochemical safety.
		Acquire the ability to apply the safety concepts in to practice when they work in chemical /radiological laboratories.

		Inculcate a culture of safety which shall benefit the organization.
		Knowledge about various safety aspects including good laboratory practices.
		Awareness about various emergencies and the need of emergency preparedness plans.

(C) ELECTIVES

Name of the Course	Course code	Course Outcome
Nanomaterials, Chemical Sensors	CY701	Idea about different synthesis methods for nanomaterials,
		Knowledge about modern techniques like pulsed laser deposition, spray pyrolysis etc.
		The concepts of Chemical sensors are taught which comprise of various per-requisites of a sensor material.
		Idea about several characterization techniques which are very useful for research work in this area.
		Theory behind the unique properties exhibited by nano-materials help the students to rationally design these materials.
Soft Condensed Matters	CY702	Students get to know about the physical basis of soft condensed matter systems
		Learn interpretation of rheological properties of soft matter with specific examples relevant to pharmaceutical formulations
		Learn about how to choose appropriate amphiphiles for emulsification
		Learn about tools for kinetic stabilization of colloidal systems
		Get an overview of application of soft matter systems in industry
Nuclear Probes for Material Characterization	CY703	Idea about defects using positron annihilation spectroscopy (PAS)
		Free volume structure characterization of amorphous material using PAS
		Compositional characterization using Ion beam techniques
		Phase structure, pore structure, Dynamics, magnetic structure using neutron scattering techniques
		Analysis of local structure of amorphous and crystalline materials using X-ray absorption methods

Molecular Bioorganics	CY704	Knowledge about synthetic design, and to enable a student to devise a synthetic route for a target molecule
		Knowledge about the various strategies in organic synthesis
		Knowledge about the green strategies, and the know-how of applying the same in organic synthesis
		Knowledge about the most recent advancements in organic synthesis
		Knowledge about the use of functional materials used in nuclear fuel cycle in DAE
Laser Spectroscopy	CY705	Skill development in handling high power ultra-short pulsed laser
		Application of time-resolved and nonlinear laser spectroscopy techniques in chemistry, biology and material science
		Expertise in indigenous development of novel spectroscopy techniques using Lasers
Actinide Chemistry	CY706	Understanding of the fuel cycle operations including reprocessing and waste management.
		Idea about environmental aspects of actinide migration in case of accident
		Pursue further areas of study such as transactinides and ‘atom at a time chemistry’
Computational Chemistry	CY707	Calculation of transition state structure and understand reaction mechanism
		Interpretation of IR and UV-Vis spectra of a system
		Band structure calculations of solids and analyze results
		Planning theoretical calculation to explain experimental results and predict molecular properties
		MD simulation and analysis of simulation results
Advanced NMR Spectroscopy	CY708	Student can learn how to validate the experimental results of synthesis and purity in a fast and efficient way.
		Determination of solution structure with the help of 1H and multi-nuclear NMR spectra
		Student can analyze the inter-molecular interactions and dynamics in solution state
		Familiarise the student to use solid state NMR technique for solving problems in Materials science
Atmospheric Chemistry	CY709	Idea about structure of atmosphere and atmospheric radiation
		Knowledge about various photochemical cycles

		Knowledge about various atmospheric pollutants and their harmful effects
		Idea about experimental methods to study reactions of importance in the atmosphere
Statistical Analysis	CY710	Knowledge of various terminologies used in Statistics
		Understanding of various statistical tools which can help in decision making
		Ways to improve quality in analytical data
		Proper way of representing analytical data

(D) NON-SUBJECT ASSIGNMENTS

Name of the Course	Course code	Course Outcome
Viva Voce	CY591	To evaluate the understanding of subject
		To judge the thinking process
Mini Project	CY592	Idea about how to do literature survey on a given topic
		Idea about planning and execution of an experiment
		Data analysis
		Writing project report
		Presentation of data and results
Seminar	CY593	Idea about how to do literature survey on a given topic
		Dissemination of information available in literature
		Practical experience of preparing presentation slides
		Practical experience of discussing scientific results in front of a knowledgeable audience

Course Structure:

II. Courses at IGCAR

Program Code : CHEM00	Programme Specific Outcome	Theoretical work for understanding solvent – metal ion interactions.
		Matrix isolation spectroscopy to understand conformers and weak molecular attractions
		Solvent development for reprocessing of nuclear fuels.
		Novel sensor materials development and characterization for sensor applications
		Materials development for matrices for nuclear waste immobilization

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Mathematical and Computational Methods, Numerical Analysis and Computer Programming	CH1
2	Chemical Thermodynamics	CH2
3	Electrochemistry	CH3
4	Introduction to Materials Science and Engineering	CH4
5	Analytical Chemistry for Nuclear Fuel Cycle	CH5
6	Chemical Instrumentation and Laboratory Techniques	CH6
7	Health Physics and Radiation Sciences	CH7
8	Introductory Reactor Physics and Fuel Design	CH8
9	Chemistry of Fuel Cycle - I	CH9
10	Chemistry of Fuel Cycle - II	CH10
11	Materials for Nuclear Reactors and Fuel Cycle Processing Systems	CH11
12	Nuclear and Radiochemistry	CH12

13	Corrosion Science and Engineering	CH13

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Mathematics and Computational methods	CH-1	Practical applications of mathematical and computational methods are taught; besides these, computational software packages are introduced. The course basically prepares students to apply these aspects in their research areas for solving problems.
Chemical Thermodynamics	CH-2	This course helps students to understand various processes employed in chemical industries. Experimental methods to determine thermodynamic properties and phase diagram investigations are unique to this course. Estimation of thermodynamic properties and thermodynamic modelling study helps for a career in research and industry.
Electrochemistry and Corrosion Science	CH-3	Fundamentals and practical applications of electrochemistry are discussed. Advanced electrochemical techniques, pyrochemical process are taught. Aqueous corrosion and engineering help students to take up career in research and industry.
Introduction to Materials Science and Engineering	CH-4	Various characterisation techniques are taught. Material synthesis methods e.g. sol-gel are discussed extensively. Students handle various characterisation tools e.g. XRD, and Thin-film deposition followed by characterisation.
Analytical Chemistry for Nuclear Fuel Cycle	CH-5	Handling and learning about various sophisticated analytical techniques and instrumentation. Students are exposed to latest analytical techniques. Methodology for development of analytical technqiues for various materials is discussed. This Course prepare students for both research and industry.

Chemical Instrumentation and Laboratory Techniques	CH-6	This course helps students to have flair for setting-up of facility and analytical instruments.
Health Physics and Radiation Sciences	CH-7	Specialised course for students to work on radiation and associated safety aspects. Basics of interaction of radiation with matter. Introduces theory of various nuclear radiation detectors and their practical applications Introduces Biological Effects, Radiation Protection and Regulation procedure, Emergency Preparedness and Management
Chemistry of Fuel Cycle-I	CH-9	This course gives basic introduction to nuclear materials and thermodynamic properties of fuel at higher temperature. Many theories and concepts taught will be directly applied to nuclear plants.
Chemistry of Fuel Cycle-II: Actinide chemistry and separation science	CH-10	This course gives basic introduction to nuclear reactors and fuels. Many theories and concepts of re-use of nuclear fuel, need for nuclear energy are dealt extensively.
Materials for Nuclear Reactors and Fuel Cycle Processing Systems	CH-11	Brief overview of nuclear reactors in India and across the world. Details of nuclear materials are dealt extensively.
Nuclear and Radiochemistry	CH-12	Advanced course in nuclear chemistry. Helps students to understand and appreciate various fundamental aspects of radioactivity. Practicals help students to develop expertise in handling radioactive materials. Students measure half-life of radioactive nuclides. The fundamentals and applications taught helps in preparing students for various out-reach programs.
Corrosion Science and Engineering	CH-13	Fundamentals and practical applications of corrosion science and engineering help students to take up career in research. Also prepares students for a career in industry.

Quantum Chemistry & Group Theory	CH-14	Train students to gain expertise in theoretical chemistry. Students are trained to handle modelling software packages. Students apply these for metal-complexation, weak intermolecular interactions, thermodynamic calculations.
Molecular Spectroscopy	CH-15	Train students to gain expertise in theoretical chemistry. Besides applied experimental spectroscopy is taught which helps candidate in research career and subsequent job prospects. Special techniques such as matrix isolation spectroscopy, laser-Raman techniques are taught with experimental demonstration.
Lasers and Application	CH-16	(a) Both fundamentals and general applications of Lasers are taught. (b) Students handle lasers in the practical for technological applications. (c) Students handle lasers for various analytical chemistry applications.
Nanomaterials and Advanced Chemical Sensors	CH-17	The fundamental knowledge gained in this course had helped to (a) understanding and development of materials (b) tailor made materials for preparation of chemical sensors (c) indigenous sensors (d) special sensors (for e.g. in-sodium) which have to be developed - which will not be supplied by commercial sources.
Course on Research Methodology	CH-RM	Ethics in research, plagiarism, manuscript writing, Data analysis, presentation of results are dealt extensively. Ensure students are ready for taking up research work.

BACK TO MAIN

PGD in ENGINEERING SCIENCES (Program Code: ENGG00)

Course Structure:

I. Courses at BARC

Program Code : ENGG00	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Accelerator Physics and Technology	EN501
2	Engineering Mathematics	EN502-505
3	Health Physics and Rad & Indl Safety	EN506
4	Nuclear Fuel Cycle Technology	EN508
5	NPP & Advanced Reactor Concepts	EN509
6	Reactor Physics and Engineering	EN510

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Accelerator Physics and Technology	EN501	The course introduces basic concepts of accelerator physics, Vacuum and cryogenic systems
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Engineering Mathematics	EN502-505	Advanced knowledge in computational data analysis, data fitting and error analysis

		Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
Health Physics and Rad & Indl Safety	EN506	Learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Nuclear Fuel Cycle Technology	EN508	Familiarisation with font and back end of nuclear fuel cycle technology
		Knowledge of radioactive waste generation on nuclear fuel burning and its processing
NPP & Advanced Reactor Concepts	EN509	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts
		Familiarization with reactor physics design challenges
Reactor Physics and Engineering	EN510	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with nuclear reactors.

(A) MECHANICAL COURSES

(A1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Code design for PVP	EN610
2	Computational fluid Dynamics and Heat Transfer	EN611
3	Finite Element Method	EN621
4	Fracture Mechanics	EN622
5	Mechanics of Solids	EN624

(A2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Machine Design	EN711
4	Material Science in Nuclear Engineering	EN712
5	Multi-scale material modelling	EN715
6	Nuclear Emergencies	EN716
7	Reliability Engineering	EN718
8	Vibration	EN721

(A3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(A1) Core Engineering

Name of the Course	Course code	Course Outcome
Code design for PVP	EN610	Basis of ASME Sec.VIII and Sec.III eqns. for Pressure Vessel and Piping Design
		Nozzle openings, Vessel design under ext. pressure
		ANSI / ASME B31.1 and B31.3 piping code
		NDE Examination of welds, Acceptance standard
Computational fluid Dynamics and Heat Transfer	EN611	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer

Finite Element Method	EN621	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Fracture Mechanics	EN622	LEFM and EPFM, Material fracture props. determination
		PTS event of RPV and Master Curve Concept
		Computational Fracture Mechanics
		Fracture Mechanisms
Mechanics of Solids	EN624	Principles and Fundamental Equations of Elasticity
		Analysis of Stress and Strain, Thermal Stresses
		Introduction to Plasticity
		Theory of Plates and Shells

(A2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Programming Language C++
		Parallel Programming
		Scientific Visualization
		Artificial Neural Network
Fluid Power Technology	EN709	Basic principles of hydraulics and pneumatics, pressure control
		Fluid power pumps and compressors, Fluid experiments
		Directional and flow control valves, Fluid Logic & Control
		Advanced Hydraulic Control Circuits, Electronics and Instrumentation for Hydraulics
Machine Design	EN711	Basic Principles of Machine Design, Design and Drawing Practices
		Sealing Methods
		Special Dimensional Inspection Techniques
		Advanced Manufacturing Techniques
Material Science in Nuclear Engineering		Metallurgy of steels
		Nuclear Materials

	EN712	Advanced Polymeric materials and Composites
		Corrosion
Multi-scale material modelling	EN715	Atomistic models: Molecular dynamics, Monte Carlo methods
		Inter-atomic potentials, Mesoscopic methods
		Modeling at microscale
		Bridging the scale gaps between different simulation levels
Nuclear Emergencies	EN716	Radiation Shielding, Nuclear Waste Management
		Nuclear Accidents/emergencies, Effects of Hiroshima & Nagasaki bombing
		Medical decontamination with demonstration
		Monitoring of High radiation field area
Reliability Engineering	EN718	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Vibration	EN721	Single and Multi-degree-of-freedom Systems, Free vibration
		Response of Systems To Ground Motion: Earthquake motion
		Flow Induced Vibration
		Vibration Measurement and Signal Analysis

(A3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
MiniProject		To provide a hands-on experience of working in an

	EN593	ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee

(B) CHEMICAL ENGINEERING COURSES

(B1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Chemical Reaction Engineering	EN601
2	Advanced Mass Transfer	EN604
3	Code design for PVP	EN610
4	Computational Fluid Dynamics and Heat Transfer	EN611
5	Nuclear Chemical Engineering	EN628
6	Process Dynamics and Control	EN634
7	Process Modeling, Simulation and Optimization	EN635

(B2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Material Science in Nuclear Engineering	EN712
4	Membrane Technology	EN714

(B3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591

2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(B1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Chemical Reaction Engineering	EN601	Fundamentals of Non-ideal reactors & RTD studies
		Understanding Non-isothermal effects & dynamical behaviour
		Overview of Heterogeneous reactions
		Approaches in Advanced reaction engineering & reactor design
Advanced Mass Transfer	EN604	Understanding Mass transfer with and without chemical reactions
		Rate based approaches for design
		Selection and design of various contacting equipment
		Process intensification approaches
Code design for PVP	EN610	Overview of Theories for pressure vessel design
		ASME Sec. VIII Div. 1 and Div - II equations
		Pressure vessel design as per ASME
		Design of piping as per B31.1 piping code.
Computational Fluid Dynamics and Heat Transfer	EN611	Understanding Kinematics of fluid flow and governing equations
		Classification of Partial Differential Equations & their discretization
		Convective heat transfer for internal and external flows
		Numerical Solution of fluid flow and heat transfer equations
Nuclear Chemical Engineering	EN628	Overview of Recovery and processing of nuclear materials
		Uranium conversion and reconversion

		Isotope Separation
		Nuclear Waste Management
Process Dynamics and Control	EN634	Introduction to process control & control loop dynamics
		Fundamentals of state-space controls, state, measurement equations
		General solution of the state equation
		Multi-variable controls, de-coupling, relative gain array
Process Modeling, Simulation and Optimization	EN635	Formulation of Dynamic and steady state models
		Flow sheet Analysis & Plant Simulation
		General Approaches for Non-Linear Systems
		Plant optimisation by Genetic Algorithms and Neural Nets

(B2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Understanding Programming Language C++
		Finite difference, finite volume, finite element discretization, grid generation, artificial neural network
		Parallel Programming, Message Passing Interface and MPI communications
		Scientific Visualization methods
Fluid Power Technology	EN709	Basic principles of Hydraulics and pneumatics
		Properties of hydraulic fluids and pneumatic air
		Roto-dynamic pumps, pressure and flow control
		Approaches in Hydraulic Circuit Design
Material Science in Nuclear Engineering	EN712	Overview of Nuclear Materials & their classifications
		Structure and properties of nuclear materials
		Processing of Nuclear Materials

		Material characterization techniques
Membrane Technology	EN714	Overview of Novel Membranes
		Preparation and Characterization
		Membrane Technologies
		Applications of Membrane Technology

(B3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering

(C) METALLURGY

(C1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Corrosion	EN615

2	Extractive Metallurgy	EN620
3	Mechanical Metallurgy	EN623
4	Nuclear Materials	EN628
5	Nuclear Metallurgy	EN629
6	Physical Metallurgy	EN630
7	Process Control & Instrumentation	EN631

(C2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Digital Signal Processing & Image Processing	EN706
3	Image processing and Machine Vision	EN710
4	Materials Characterization	EN713
5	Multi scale Material Modeling	EN715
6	Nuclear Chemical Engineering	EN628
7	Nuclear Emergencies	EN716
8	Welding Science & Technology	EN723

(C3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(C1) Core Engineering

Name of the Course	Course code	Course Outcome
Corrosion	EN615	Understanding electrochemical theory of corrosion & corrosion basics
		General principles of corrosion control
		Forms of corrosion and its mitigation
		Corrosion problems in nuclear industry and its mitigation
Extractive Metallurgy	EN620	Thermodynamics and kinetics of metal extraction
		Advanced material processing techniques
		Process metallurgy of rare metals, special materials and alloys
		Process metallurgy of U, Th, Pu, Be, Zr, Hf, Nb, Ta & rare earths
Mechanical Metallurgy	EN623	Exposure to stress tensor, state of stress, principal stress, hydrostatic, deviatoric stress
		Dislocations and deformation behaviour
		Creep & creep law, deformation mechanism map
		Fracture mechanics and fatigue of metals
Nuclear Materials	EN628	Vacuum melting & solidification, controlling casting defects of U, Zr and Ti alloys
		Cold & hot working, dynamic recovery, recrystallization of fuel tube, texture microstructure control
		Powder metallurgy of oxide, mixed oxide, carbide, intermetallic nuclear fuel material
		Applications of powder metallurgy in applications relevant to DAE
Nuclear Metallurgy	EN629	Fabrication of different types of fuel for research and power reactors

		Health physics, radioactivity and safety aspects of Pu handling
		Effects of irradiation on nuclear fuel and structural materials, hydriding related problems in Zr alloys
		Post irradiation examination (PIE) of nuclear fuel and structural material
Physical Metallurgy	EN630	Understanding basics of crystallography, crystal defects during irradiation
		Thermodynamics, phase equilibria & phase transformation
		Diffusion mechanism, equations & solutions
		Recovery, Recrystalization and Grain Growth
Process Control & Instrumentation	EN631	Understanding basic principles of measurement
		Sensors, transducers & transmission methods for pressure, vacuum, flow, level
		Principles of Automatic Control Systems
		Fail safe principles, simple logic circuits, ladder circuits for control action

(C2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Exposure to programming languages: C and C++
		Application of finite difference, finite volume, finite element techniques, ANN etc. in DAE
		Introduction to parallel programming concepts
		Data storage & visualisation techniques and case studies
Digital Signal Processing & Image Processing	EN706	Introduction to digital signal processing system & applications
		Discrete Fourier transform, fast Fourier transform

		Image processing, image enhancement, image segmentation & analysis, morphological operations
Image processing and Machine Vision	EN710	Introduction to digital image model representation, image sensor, digitizer, computer, standard file format
		Image enhancement segmentation and analysis, restoration
		Morphological operations and image compression
		Machine vision & introduction to image understanding
Materials Characterization	EN713	Introduction to microscopy techniques: optical, SEM, TEM, AFM, STEM, EBSD, FIM
		XRD and applications, basics of SIMS, RBS
		Analytical TEM, chemical analysis in materials science
		Thermal expansion and conductivity, TGA/DTA/DSC, mechanical properties
Multi scale Material Modeling	EN715	Introduction to types of models and multiscale approaches
		Atomistic models – molecular dynamics
		Basics of Monte Carlo methods
		Analysis of simulation results, bridging scale gap between different simulation levels
Nuclear Chemical Engineering	EN628	Recovery & processing of U, Th, Zr, rare earths from from ores / intermediates
		Uranium Conversion/reconversion
		Isotope Separation
		Nuclear Waste Management
Nuclear Emergencies	EN716	Introduction to nuclear fuel cycle, transportation of radioactive material
		Radiological accidents / emergencies
		Effects of nuclear detonation, testing nuclear weapons
		Emergency Response methodology/ Philosophy

Welding Science & Technology	EN723	Overview of various welding processes - arc welding, beam welding, hybrid welding
		Cold Bonding/Solid State Bonding
		Welding metallurgy under high cooling rates
		Types of welding defects and its prevention

(C3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I & VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
Mini Project	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee

(D) CIVIL ENGINEERING

(D1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1

2	Civil Engg Design of Concrete & Steel Strct II	EN608.2
3	Design Basis Hazards & Geotechnical Engg	EN621
4	Earthquake Engineeing & Structural Dyanmics	EN609
5	Finite Element Method	EN626
6	Mechanics of Solids	EN624

(D2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Struct Dynamics & Earthquake Engg	EN724
2	Construction Materials, Management & Quality	EN614
3	Safety & Reliability of Civil Engineering	EN722
4	Project Management	EN717

(D3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(D1) Core Engineering

Name of the Course	Course code	Course Outcome
Civil Engg Design of Concrete & Steel Strct I	EN608.1	Various structures of nuclear facilities; safety, seismic, design and quality classifications of structures
		Design loads on structures and load combinations as per BIS, ACI and AERB standards
		Design of RC structures; fracture mechanics concept in RC design

		Shallow and deep foundation design; machine foundation design
Civil Engg Design of Concrete & Steel Strct II	EN608.2	Design of prestressed concrete structures
		Design of lined and unlined reactor containment structures using RCC-G/BPEL/BAEL and ASME codes
		Design of steel structures using BIS, AERB and AISC standards
		Design of underground and overhead water retaining structures; design of natural draft cooling tower
Design Basis Hazards & Geotechnical Engg	EN621	Siting of nuclear facilities; hazards due to internal and external events; design basis natural hazards, such as, seismic, flood, wind, snow and solar radiations
		Human-induced design basis hazards, such as, aircraft/missile impact, explosions/blast, and toxic gas release
		Soils and its classifications; laboratory and field tests on soils and rock; compaction of soils; bearing capacity of soils and rocks
		Stages of geotechnical investigations; soil and rock sampling; geophysical investigations; seismic refraction survey, cross-hole seismic test; ERT; liquefaction potential of sites
Earthquake Engineeing & Structural Dyanmics	EN609	Seismic waves and wave propagation; time history; response spectra; seismic instrumentation
		Dynamic loadings; dynamic response of SDOF and MDOF systems; dynamics of continuum system
		Response spectra and time history approaches for determining seismic structural

		response; SSI and FSI; structural response in frequency domain
		Seismic requalification of existing installations; retrofitting techniques
Finite Element Method	EN626	Basis of FEM; energy principles; shape function requirements; C0 and C1 continuity
		Derivation of stiffness matrix and load vector for bar, beam, 2D plane and 2D iso-parametric elements; evaluation of strain and stress
		Incompatible quadrilateral elements; Tetrahedron, and hexahedron elements; plate bending elements; shell elements; patch test; adoptive meshing; error analysis
		Non-linear problems; material and geometric non-linearity
Mechanics of Solids	EN624	Concepts of elasticity; Equilibrium equations; Solution of 1-D boundary value problem; tensors algebra
		Analysis of stress and strain; transformation using direction cosines; principal planes; octahedral plane; state of pure shear; strain deviator tensor
		Strain displacement relationship; Isotropy and Anisotropy; Strain energy; Plane stress and plane strain problems; solution for beam bending problem; solution in polar co-ordinates; thermal stresses
		Analysis of thin and thick plates; shear deformation theories; membrane theory of shells of revolution and translation; bending analysis of shells; application to cylindrical, spherical and conical shells; introduction to plasticity

(D2) Electives

Name of the Course	Course code	Course Outcome
Advanced Struct Dynamics & Earthquake Engg	EN724	Concept of performance based seismic design; seismic demand; capacity of structures; performance levels
		Concept of seismic and vibration control; passive control; semi-active control; active control; base isolation techniques
		Methods of testing; qualification of system by testing; seismic instrumentation; measurement of displacement, velocity, acceleration
		Fluid-structure interaction techniques; multibody dynamics
Construction Materials, Management & Quality	EN614	Construction materials, such as, concrete, reinforcement, structural steel, paints, water-proofing materials
		Design of formworks; slip forms; prestressing systems
		QA in civil design, materials, construction, O&M, and regulatory inspection
		Dewatering; rock excavation, construction safety and JHA; mode of tendering; contract clauses; dispute adjudication
Safety & Reliability of Civil Engineering	EN722	Statistics and probability; discrete and continuous random variables; probability distributions
		Concept of structural safety; limit states; MVFOSM; Hasofer Lind reliability index; Cornell reliability index; Monte Carlo simulation
		Probabilistic safety assessment; seismic fragility analysis; seismic risk; health assessment of existing concrete and steel structures; rehabilitation and retrofitting

		techniques; service life prediction
		Concept of industrial safety; fire hazard analysis; safety in handling machinery, equipment and tools; fitness and protection of personnel
Project Management	EN717	Type, cost and schedule of nuclear power projects; resources of project; project organization chart; delegation of power
		Scheduling in a project by PERT, CPM, precedence diagram method; project management software for planning, scheduling and monitoring
		Preparation of target plan, updating of progress, monitoring variance and reporting; physical and financial monitoring; capital budgeting and expenditure control
		Contingency plan; construction management; project management; SWOT analysis; problem solving techniques

(D3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
Mini Project	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg.

(E) ELECTRICAL ENGINEERING

(E1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design I	EN602
2	Computer Based System Design I	EN612
3	Electrical Systems for Nuclear Power Plants	EN618
4	Modern Control Systems Design and Simulation	EN625
5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(E2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design II	EN702
2	Artificial Intelligence and its Applications	EN703
3	Computer Based System Design II	EN704
4	Digital Signal Processing & Image Processing	EN706
5	Image Processing & Machine Vision	EN710
6	Signal Conditioning, Recovery and EMI Aspects	EN719
7	Software Engineering	EN720

(E3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(E1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design I	EN602	Materials and Electrical Properties, NDT, MFL
		Superconducting Properties
		Understanding Control Techniques of Electrical Motors and Electronics
		FEM and Applications
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Electrical Systems for Nuclear Power Plants	EN618	Recapitulation of Power System Design Analysis
		Basics of Switchyard Design Principles
		Understanding Protection Systems
		Exposure to Electrical Systems in NPP
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity

		Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(E2) Electives

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design II	EN702	Understanding Vector Control of PM Synchronous Motors
		Exposure to Design and Applications of Variable Reluctance Stepper Motors and Switched Reluctance
		Understanding Pulse Power Techniques
		High Voltage Systems
Artificial Intelligence and its Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies

		Understanding Reinforcement Learning and Dynamic Programming
Computer Based System Design II	EN704	Exposure to Data Communication Interfaces for Control Applications, Fieldbuses
		Understanding Real Time System Design Principles
		Understanding IPC mechanisms in RTOS
		Exposure to Safety System Design Regulations
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics

		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(E3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering

(F) ELECTRONICS ENGINEERING

(F1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electronic Circuit Design Techniques	EN603
2	Advanced Nuclear Instrumentation	EN605
3	Embedded & Computer Based Sys. Design	EN619
4	Modern Control Systems Design and Simulation	EN625

5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(F2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Digital Signal Processing & Image Processing	EN706
3	Embedded Electronics Software	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720
7	Artificial Intelligence & Applications	EN703

(F3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(F1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electronic Circuit Design Techniques	EN603	Introduction to VLSI Design Flow, HDL, Design and Simulation of HPD
		Understanding Semiconductor Detectors , MEMS Desin
		Introduction to RF Electronics

		Understanding Transmission Lines, Waveguides, RF Amplifiers,
Advanced Nuclear Instrumentation	EN605	Understanding Electronics in Spectroscope Design
		Nuclear Instruments, Alpha, Beta and Gamma Detectors, Scintillation Counters
		Introduction to Accelerator Instrumentation
		Understanding Reactor Neutronic Instruments and Signal Processing
Embedded & Computer Based Sys. Design	EN619	Overview of Microprocessors and Interfacing
		Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements
		Exposure to Computer Communication, Encoding and Technologies
		Understanding Software Developments for NPP/Accelerator C&I
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters

		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(F2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models

		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

(F3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(G)INSTRUMENTATION ENGINEERING

(G1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Applied Process Instrumentation	EN607
2	Computer Based System Design I	EN612
3	Modern Control Systems Design and Simulation	EN625
4	Reactor C&I and Human Machine Interface	EN636
5	Reactor Control Engineering and Instrumentation	EN637-8
6	Reliability Engineering	EN639

(G2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Computer Based System Design II	EN706
3	Digital Signal Processing & Image Processing	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720

(G3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(G1) Core Engineering

Name of the Course	Course code	Course Outcome
Applied Process Instrumentation	EN607	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation
		Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and

		Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Reactor C&I and Human Machine Interface	EN636	Overview of Reactor C&I & Power Supply Requirements for Instrumentation
		Understanding Control Room Design and Exposure to Codes & Guides
		Exposure to Relay & Control Logic Design, Critera for Relay, PLC & DCS Technologies
		C&I Cable Requirements
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(G2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

Computer Based System Design II	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Digital Signal Processing & Image Processing	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(G3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(H)COMPUTER SCIENCE AND ENGINEERING

(H1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Operating Systems	EN606
2	Computer Graphics & Visualisation	EN613
3	Distributed Computing	EN616
4	Networking & Information Security	EN627
5	Reactor Control Engineering	EN637
6	Software Engineering and Formal Methods	EN640

(H2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Data Base Management System & Web Technology	EN705
3	Digital Signal Processing & Image Processing	EN706
4	Embedded Electronics Software	EN707
5	Feedback Control System	EN708
6	Image Processing & Machine Vision	EN710

(H3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(H1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Operating Systems	EN606	Understanding IPC Calls
		Shell Programming
		Understanding Distributed File Systems
		Applications of System Calls
Computer Graphics & Visualisation	EN613	Understanding Geometric Transformations
		Applications of Geometric Projections
		Techniques for Hidden Surface Removals
		Applications of Scientific Visualisation
Distributed Computing	EN616	Understanding modern CPU Architectures
		Understanding Interconnect Techniques
		Understanding and Applications of HPC

		Understanding Grid Computing and Workflows
Networking & Information Security	EN627	Understanding Issues in the transport of data and Techniques
		Satellite Communications
		Understanding Network Security Concepts
		Advances in Cryptography and Cryptanalysis
Reactor Control Engineering	EN637	Understanding Physics behind Rector Control
		Understanding Point Kinetics Model and Reactor Periods
		Understanding Issues with Large Reactor Control and Modelling
		Understanding Control Requirements for PWR, PHWR, BWR and FBR
Software Engineering and Formal Methods	EN640	Understanding Techniques for modelling software
		Application of Model Checking and Theorem Proving
		Understanding Agile Programming
		Understanding Software Testing

(H2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Data Base Management System & Web Technology	EN705	Understanding SQL and Complex queries
		Understanding Clusters and Distributed Databases
		Understanding and Working with Web Technologies
		Modelling data and design of real data bases

Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Feedback Control System	EN708	State Space Representation and Applications
		Time Domain Analysis
		Appreciating need for Stability Analysis & Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications

(H3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life

Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

BACK TO MAIN

PGD in GEOLOGY & GEOPHYSICS

(Program Code: ENGG00)

CORE COURSE:

II. Courses at BARC - AMD:

Program Code: ENGG00	Program Specific Outcome	
		Thorough knowledge on geological aspects of exploration for uranium and other atomic minerals.
		Inter-disciplinary approach and application of geophysical, geochemical and radiometric methods in exploration.
		Field and laboratory data generation techniques, geological modeling and resource estimation
		Giving research orientation to the young minds, training in formulation and implementation of research projects.

COMMON COURSES:

Sr. No.	Name of the Course	Course Code
1	Nuclear Physics	102
2	Remote Sensing and GIS	110
3	Airborne Geophysics	209
4	Nuclear Reactor and Fuel Cycle	212

Course Outcome:

Name of the Course	Course Code	Course Outcome
Nuclear Physics	102	The course introduces nucleus, it's properties, natural radioactivity, decay, equilibrium, natural decay series, fission and fusion
		Learning principles and types of radiation detectors, and their characteristics
		Familiarization of gamma ray spectrometry, gamma ray logging and sample analysis techniques used in exploration, Instrumental Neutron Activation Analysis.

		The course also introduces radon emanometry, methods for measurement of Radon
Remote Sensing and GIS	110	The course introduces concepts of Remote Sensing, mineral and rock spectra and use in geological studies, available sensors, and types of resolutions
		Learning fundamentals of image interpretation, digital image processing, enhancement techniques, image classification for geological interpretation.
		Introduction to GIS, spatial and attribute data, coordinates and map projections.
		The course also teaches GIS analysis, data integration and modeling techniques in mineral exploration using various software.
Airborne Geophysics	209	The course introduces airborne survey design and survey parameters, type of geophysical surveys carried out.
		Students are acquainted with airborne survey instruments, navigation aids and procedures in data acquisition.
		Learning processing and presentation of airborne data, identification of anomalous zones and conductors.
		The course also teaches QA & QC and validation of data sets, geological interpretation, depth estimates, delineation of alteration zones, forward and inverse modeling, and procedures for obtaining licenses for flying,
Nuclear Reactor and Fuel Cycle	212	Understanding nuclear energy, Indian scenario, fission and fusion
		Reactor systems, types of nuclear reactors, moderator and coolant, control systems, behaviour and safety systems.
		Nuclear fuel cycle options for various types of reactors, mining, processing, manufacturing, usage and burning of fuel, quality control, storage and transportation, enrichment, reprocessing and management of waste.
		Environment, legislation and controls, EIA requirements.

SUBJECTS FOR GEOLOGY:

Sr. No.	Name of the Course	Course Code
1	Mathematics for Geologists	101
2	Geophysics for Geologists	103
3	Uranium Geology	105
4	Drilling and Mining Techniques	106
5	Geochemical Exploration	108
6	Exploration for Beach Sand and RM&RE	202
7	Petrographic Techniques	206
8	Mineral Process Engineering	208
9	Analytical Techniques	210
10	Ore Reserve Estimation (Covered as part of 9 weeks field training in the months of December, January and February)	204

Course Outcome:

Name of the Course	Course Code	Course Outcome
Mathematics for Geologists	101	To introduce the students on concepts of Geostatistics and basic Mathematical techniques.
		Apply principles of Geostatistics and mathematical methods for analysis and predictions in Geoscience research and Geomodelling.
		Development of skill set necessary for solving complex problems in the field of Geoscience.
		Expose the young students to state-of-the art modelling techniques applicable to the Uranium exploration programme and build a strong foundation.
Geophysics for Geologists	103	The course introduces geophysical methods, their role in mineral exploration and geophysical signatures of uranium deposits.
		Learning gravity and magnetic fields, it's variation across the earth, instruments, data collection, processing and application.
		Understanding various electrical and electro-magnetic methods, electrical properties of rocks, instrumentation, data collection, processing and interpretation.
		The course also introduces seismic methods and borehole logging methods in exploration.
Uranium Geology	105	The course imparts knowledge on distribution of uranium in crust, rocks and minerals, time bound character and classification of uranium deposits.
		The course also deals with geological aspects of various types of uranium deposits, world and Indian deposits, controls of mineralization, exploratory guides.
		Students also learn stages of uranium exploration,

		survey methodologies, sampling techniques, drilling, borehole logging techniques
		Training on interpretation of exploratory data, correlation of mineralized intercepts, estimation of resources, recent trends in exploration, status of uranium supply and demand
Drilling and Mining Techniques	106	Understanding types and techniques of drilling used in atomic mineral exploration
		Learning about rock drilling, diamond drilling, controlled directional drilling, types of drilling used in the department.
		The course also introduces mining, mining terminologies, types of mining.
		Students learn techniques in open cast and underground mining, blasting, economic feasibility, milling and waste disposal.
Geochemical Exploration	108	The course introduces geochemistry as branch of geology, elements - primary geochemical differentiation, classification and associations, major, minor, trace, REE and uranium geochemistry.
		Students learn geochemical thermodynamics, standard states, non-ideal solutions and phase diagrams.
		Hydro-geochemical concepts, pH and Eh, physico-chemical environment of ore genesis under various geological environments.
		Types of geochemical surveys for mineral exploration, primary and secondary dispersions, geochemical maps, processing and interpretation of geochemical data.
Exploration for Beach Sand and RM&RE	202	Introduces placer minerals and environments, processes controlling formation of placer minerals, transportation and deposition.
		Learning exploration of beach sands, sampling, analysis, methods of estimation and classification of resources, mining methods and processing, world resource scenario.
		The course also introduces Rare Metal and Rare Earth minerals, their geochemistry, mineralogy. Geology of Rare Metal bearing granites, pegmatites, carbonatites.
		Study of exploration techniques, geochemical methods, sampling, resource estimation and recovery.
Petrographic Techniques	206	Study of minerals and rocks under transmitted and reflected light, polarising microscope, thin sections and polished sections.
		Learn petromineralogical techniques, optical properties of minerals, microindentation hardness, radioactive, rare earth element and rare metal bearing minerals, mineralogical expression of radioactivity, EPMA analysis.
		Study of petrography, paragenesis, learning modal analysis and norm calculation.

		Presentation and preservation of data and assessment
Mineral Process Engineering	208	The course introduces basic principles of mineral processing unit operations and hydrometallurgy with special emphasis on atomic minerals
		The curriculum familiarizes with flowsheet development for low grade uranium ores of Indian origin and beneficiation of beach sand minerals.
Analytical Techniques	210	The course introduces principles and instruments of analytical methods used in atomic mineral exploration.
		X-ray diffraction technique for identification of minerals and cell parameters, WD & EDXRF, ICP, AAS, flourimetry and other chemical methods for analysis of geological materials
		Concepts and use of radiometric dating methods, stable isotope studies for understanding geological processes.
Ore Reserve Estimation (Covered as part of field training)	204	Resource database generation, geological model, density factor, sampling issues, validation of data.
		Ore body configuration, traditional and geostatistical methods of resource estimation
		Resource categories, feasibility studies, environmental issues

SUBJECTS FOR GEOPHYSICS:

Sr. No.	Name of the Course	Course Code
1	Geology for Geophysicists	104
2	Theory of Fields	107
3	Seismic Methods	109
4	Computational Geophysics	201
5	Signal Processing & Inversion Techniques	203
6	Gravity and Magnetic Methods	205
7	Electrical & Electromagnetic Methods	207
8	Well logging Techniques	211

Course Outcome:

Name of the Course	Course Code	Course Outcome
Geology for Geophysicists	104	The course introduces structure and composition of the earth, surface and internal processes, rock structures, stratigraphy principles and elements of Indian stratigraphy.
		Gives brief introduction to rock forming and ore minerals, common igneous, sedimentary and metamorphic rocks, structures and textures.
		Learn dynamic earth, continental drift, plate tectonics and associated mineral deposits.
		The course also introduces ore forming processes and

		mode of occurrence of common ore deposits.
Theory of Fields	107	The Course introduces the basic concepts of the mathematics and physics of Potential Field theory.
		The topics covered in this course are gravitational, magnetic, electrical & electromagnetic fields of the earth and their derivations from potential functions with applications.
		The course also discusses about theorems of Laplace, Poisson's, Gauss and Green and their applications to geophysics. Computations of numerical problems
Seismic Methods	109	Familiarization of the basic concepts and principles of seismic prospecting. Reflection, refraction and diffraction from multilayered media, Seismic wave propagation, Factors affecting seismic wave velocities discussed.
		Energy sources, geophone, hydrophone, noise profile analysis and Source -detector arrays. Seismic reflection & refraction methods, geometry of waves and interaction with two layer and multilayer media. Field layouts, Static corrections, NMO, Migration, Common Depth Point techniques. Vertical seismic profiling; 3D and 4D seismic exploration, Seismic tomography
		Processing and interpretation of seismic refraction and reflection data. Determination of velocities and depths to the layers.
Computational Geophysics	201	The course provides an introduction to different numerical methods applied to geophysical problems. Partial differential equations in geophysics .The course offer hands-on experience in numerically solving partial differential equations, statistical data and variance Analysis in geophysics.
		The finite-difference (FDM) & finite-element methods (FEM) applied to basic geophysical problems. Explicit and Implicit finite difference methods, Error and stability analysis. Fundamentals of FEM, interpolation functions, method of weighted residuals, Laplace and Poisson equation, Numerical integration
Signal Processing & Inversion Techniques	203	Application of advance signal processing techniques in geophysics. Various integral transforms – Fourier, Hilberet, Hankel, Walsh, Laplace and Z transforms. Digital filtering, sampling and designing filters.
		Application of inversion techniques in geophysical data processing. Fundamental concepts of Inversion with discrete and continuous models. Optimization techniques and algorithms, generalized and constrained inversion. Singular value decomposition, Backus-Gilbert Inverse problem
Gravity and Magnetic Methods	205	The course discusses in detail the theoretical concepts of Earth's gravitational field and geomagnetic field. Theory and principles of Gravimeter and magnetometers.
		Data acquisition and corrections applied to gravity and magnetic data are explained in detail with data. Processing of data and application of time domain and frequency domain filters and various data enhancement techniques.

		Computation of gravity and magnetic anomalies due to regular shaped bodies. Spectral analysis of potential field data. Modeling and inversion of gravity and magnetic data.
Electrical & Electromagnetic Methods	207	Electrical properties of rocks and minerals. Electrical conduction in rocks and earth materials. Familiarization of the concepts of electrical and electromagnetic prospecting. Classification of Electrical and Electromagnetic methods
		Resistivity and Induced Polarization techniques – Theory, Practice and applications with case studies. Electromagnetic methods – Frequency domain, Time Domain and Natural Source EM methods – Equipment, field procedures
		Interpretation techniques of Electrical and Electromagnetic data – Vertical Electrical Sounding, Pseudo-sections, VLF, HLEM, TURAM and TEM sounding data.
Well logging Techniques	211	Learning the basic concepts, characteristics of borehole conditions, reservoir properties, principles and instrumentation of well logging techniques.
		The course introduces the different types of electrical, nuclear, sonic, EM and other logging techniques and their application in mineral exploration. Operational survey procedures and interpretation of various logs.
		Identification of sub‑surface formations based on interpretation. Computation of various parameters from the log data.

BACK TO MAIN

PGD in ENGINEERING SCIENCES
(Program Code: ENGG00)

III. Courses at NFC:

BARC TS NFC Hyderabad Course Outcome

Chemical Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Computational Fluid Dynamics and Heat Transfer	CEM1 E21 CM40	Understanding Kinematics of fluid flow and governing equations Classification of Partial Differential Equations & their discretization Convective heat transfer for internal and external flows. Numerical Solution of fluid flow and heat transfer equations.
2	Basic Process Instrumentation and Control	CEM2 CC03 M20	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides.
3	Process Dynamics, Analysis and Control	CEM3 E31 E29:50	Introduction to process control & control loop dynamics Fundamentals of state-space controls, state, measurement equations General solution of the state equation Multi-variable controls, de-coupling, relative gain array.
4	Advanced Mass Transfer, Equipment Design and Solvent Extraction and Equipment design	CEM4 E32 AC03:C45	Understanding Mass transfer with and without chemical reactions Rate based approaches for design Selection and design of various contacting equipment Process intensification approaches.
5	Process Modeling, Simulation and Optimization	CEM5 E 33 C20	Formulation of Dynamic and steady state models Flow sheet Analysis & Plant Simulation General Approaches for Non-Linear Systems. Plant optimization by Genetic Algorithms and Neural Nets.
6	Advanced Chemical Reaction Engineering	CEM6 E30 C25	Fundamentals of Non-ideal reactors & RTD studies Understanding Non-isothermal effects & dynamical behavior. Overview of Heterogeneous reactions Approaches in Advanced reaction engineering & reactor design.

Core Electives Module:

Sl. No.	Name of the Course	Course Code	Course Outcome
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Electrical Engineering Practices in Process Industries	C Elect 2 FC 09 E 20	Exposure on Fundamentals of Electricity, power supplies, electrical machines, circuit breakers and safety aspects need to know working in Industries.
3	Energy Conservation and Demand Side Management	C Elect 3 AC 07 CMI 20	Understanding about Energy scenario, Energy conservation techniques and analysis by Thermodynamics need to optimize the energy consumption in Industries.
4	*Vacuum Technology	C Elect 4.1 M 13 NEW- C 20	Understanding of vacuum physics, its measurement, operation and leak detection and applications.
5	*Statistics for Engineers	C Elect 4.2 NEW- M C 20	Learning about treatment of data, probabilities, random sampling & distribution, testing and control charts.
6	*Corrosion Engineering	C Elect 4.3 EN-615	Understanding electrochemical theory of corrosion& corrosion basics. General principles of corrosion control. Forms of corrosion and its mitigation. Corrosion problems in nuclear industry and its mitigation.

* Optional Subjects (one out of three subjects to be selected)

Practicals /Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

BARC TS NFC Hyderabad Course Outcome
Electrical Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Applied Process Instrumentation and Control	CEM 1 E 50 CEEI-45	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides Instrumentation field buses, sensor technology, introduction to Neural network and Fuzzy logic.
2	Programmable Logic Controllers and Applications	CEM 2 EEI-40	Learning about Programmable controller industrial digital computer which has been adopted for the control of manufacturing processes such as assembly lines or robotic devices or any activity that requires high reliability, ease of programming and process fault diagnosis.
3	Electrical Engineering Practices-I	CEM 3 AC13 E-30	Detailed exposure of Electrical Equipment and selection, Installation and maintenance of equipment in Hazardous areas and electrical protection.
4	Electrical Engineering Practices-II	CEM 4 EEP II E-20	Exposure on Advances in Electrical equipment such as various types of drives, furnaces and Electric welding.
5	Networking Communications	CEM 5 E 61 ETRN-I-20	Understanding Issues in the transport of data and Techniques Satellite Communications Understanding Network Security Concepts Advances in Cryptography and Cryptanalysis.
6	Modern Electronic Control of AC and DC Drives	CEM 6 JNTU-30	Detailed learning about Phase controlled, current and speed, chopper controlled DC motor drives, closed loop operation of DC motor drives, AC drives, it’s controlling mechanism.

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Out come
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Energy Conservation and Demand Side Management	C Elect 2 AC07 CMI-20	Understanding about Energy scenario, Energy conservation techniques and analysis by Thermodynamics , need to optimize the energy consumption in Industries or making
3	Industrial Instrumentation practices and Human Machine Interface	C Elect 3 E51 E50 I-30	Exposure on Reactor C&I& Power Supply Requirements for Instrumentation Understanding Control Room Design and Exposure to Codes & Guides Exposure to Relay & Control Logic Design, Criteria for Relay, PLC & DCS Technologies C&I Cable Requirements
4	*Mechatronics	C Elect 4.1 AC14 EEMI:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering & mechanization, automation and about Industrial robotics.
5	*Robotics	C Elect 4.2 M14 EC:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering, automation, trajectory planning and about Industrial robotics.

* Optional Subjects (one out of two subjects to be selected)

Practicals / Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.
4	PLC Demonstration and working principles	Clear understanding of logical functions, controlling mechanisms and different type of communications through PLC demo unit.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

BARC TS NFC Hyderabad Course Outcome
Electronics Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Applied Process Instrumentation and Control	CEM 1 E 50 CEEI-45	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides Instrumentation field buses, sensor technology, introduction to Neural network and Fuzzy logic.
2	Programmable Logic Controllers and Applications	CEM 2 EEI-40	Learning about Programmable controller industrial digital computer which has been adopted for the control of manufacturing processes such as assembly lines or robotic devices or any activity that requires high reliability, ease of programming and process fault diagnosis.
3	Embedded and computer based system design	CEM 3 E54 Electrn-40	Exposure on overview of Microprocessors and Interfacing Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements Exposure to Computer Communication, Encoding and Technologies Understanding Software Developments for NPP/Accelerator C&I
4	Digital signal, Image processing &Machine vision	CEM 4 New	Learning about digital signal processing system& applications. Discrete Fourier transform, fast Fourier transform. Image processing, image enhancement, image segmentation & analysis, morphological operations.
5	Networking Communications	CEM 5 E 61 ETRN-I-20	Understanding Issues in the transport of data and Techniques Satellite Communications Understanding Network Security Concepts Advances in Cryptography and Cryptanalysis.
6	Modern Electronic Control of AC and DC Drives	CEM 6 JNTU-30	Detailed learning about Phase controlled, current and speed, chopper controlled DC motor drives, closed loop operation of DC motor drives, AC drives, it's controlling mechanism.

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Out come
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Modern control systems	C Elect 2 E52A EC-20	Understanding State Space Techniques, Controllability, Observability, Kalman Criterion and Stability Analysis, Lyapunov Criterion Principles of State Observer, LQR, Ricati Equation
3	Industrial Instrumentation practices and Human Machine Interface	C Elect 3 E51 E50 I-30	Exposure on Reactor C&I& Power Supply Requirements for Instrumentation. Understanding Control Room Design and Exposure to Codes & Guides Exposure to Relay & Control Logic Design, Criteria for Relay, PLC & DCS Technologies C&I Cable Requirements
4	*Mechatronics	C Elect 4.1 AC14 EEMI:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering & mechanization, automation and about Industrial robotics.
5	*Robotics	C Elect 4.2 M14 EC:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering, automation, trajectory planning and about Industrial robotics.

* Optional Subjects (one out of two subjects to be selected)

Practicals / Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.
4	PLC Demonstration and working principles	Clear understanding of logical functions, controlling mechanisms and different type of communications through PLC demo unit.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

BARC TS NFC Hyderabad Course Outcome

Mechanical Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Computational Fluid Dynamics and Heat Transfer	CEM1 E21 CM40	Understanding Kinematics of fluid flow and governing equations Classification of Partial Differential Equations & their discretization Convective heat transfer for internal and external flows. Numerical Solution of fluid flow and heat transfer equations.
2	Basic Process Instrumentation and Control	CEM2 CC03 M20	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides.
3	Pressure Vessel and Piping Design	CEM 3 E20 CC08 M-30	Understanding the Basis of ASME Sec. VIII and Sec. III eqns. For Pressure Vessel and Piping Design Nozzle openings, Vessel design under ext. pressure ANSI/ASMEB31.1and B31.3 piping code NDE Examination of welds, Acceptance standard
4	Engineering Design and Finite Element Methods	CEM 4 AC09	Detailed exposure on Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element. 2Disoparametric formulation. Introduction to Nonlinear problems Finite element applications for design
5	Computer Aided Design and Manufacturing	CEM 5 M-35	Exposure on Microprocessors & Interfacing Techniques Interconnect Buses and Industrial Systems Introduction to HDL and FPGA based System Design Understanding Fault Tolerant Architectures and TMR.
6	Vibrations	CEM 6 E26 M:20	Learning about Single and Multi-degree-of-freedom Systems, Free vibration. Response of Systems To Ground Motion: Earth quake motion. Flow Induced Vibration Vibration Measurement and Signal Analysis

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Outcome
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Mechatronics	C Elect 2 AC14 EEMI:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering & mechanization, automation and about Industrial robotics.
3	Welding and Quality Assurance of Welds	C Elect 3 CC06 M-20	Exposure of various welding processes – Arc welding, Beam welding, hybrid welding Cold bonding/Solid state bonding Welding metallurgy under high cooling rates Types of welding defects and its prevention
4	*Vacuum Technology	C Elect 4.1 M-13 C-20	Understanding of vacuum physics, its measurement, operation and leak detection and applications.
5	*Manufacturing and Industrial Engineering	C Elect 4.2 JNTU M-20	To understand about optimization of complex processes, systems, organizations by developing, improving and implementing integrated systems of people, money, knowledge, information, equipment, energy and materials.
6	*Design of High Temperature Components	C Elect 4.3 Mech-20	Learning about different material properties, life time, corrosion studies, material stability at high temperatures. For the applications in reactors& industries.
7	*Statistics for Engineers	C Elect 4.4 C:20	Learning about treatment of data, probabilities, random sampling & distribution, testing and control charts.

* Optional subjects (one out of four subjects to be selected)

Practicals /Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.
4	Structural Dynamics and Vibration	Practical experience on harmonic & non-harmonic base motions, dynamics of vibrations, seismic wave amplification etc.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

BARC TS NFC Hyderabad Course Outcome
Quality Assurance Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Statistical Quality Control for QA	CEM 1 QA-01	Learning about Measuring errors by using different theories and minimization. Quality control and analysis from raw material to the final product with the help of Standards and standard procedures.
2	NDT & QC of Nuclear Fuel and structural components	CEM 2 QA-02	Learning about various NDT tests and quality checks during fabrication of tubes, components, fuel and structurals.
3	Design of PHWR Fuel and Structurals	CEM 3 QA-03	A Clear understanding of fuels, various structural materials and design of the Reactor, needed to work in Reactors and quality check in Production industries.
4	Engineering Design and Finite Element Methods	CEM 4 AC09	Detailed exposure on Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element. 2Disoparametric formulation. Introduction to Nonlinear problems Finite element applications for design
5	Material Characterization and Applications	CEM 5 EN713	Understanding of microscopy techniques: optical, SEM, TEM, UT, ECT, RT, LPT, MPT, XRD and applications. Analytical TEM and Metrology.
6	Basic Process Instrumentation and Control	CEM 6 CC03 M-20	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Outcome
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Corrosion Engineering	C Elect 2 EN-615	Understanding electrochemical theory of corrosion& corrosion basics General principles of corrosion control Forms of corrosion and its mitigation Corrosion problems in nuclear industry and its mitigation
3	Image Processing and Machine vision	C Elect 3 EN-710	Understanding techniques for Image Processing and Morphological Operations Understanding Image Models for Machine Vision Scene Interpretation and recognition Understanding Robotic Applications
4	*Data Base Management System and Web Technology	C Elect 4.1 EN-705	Understanding SQL and Complex queries Understanding Clusters and Distributed Databases Understanding and Working with Web Technologies Modeling data and design of real data bases
5	*Advanced Computational Techniques	C Elect 4.2 EN-701	Learning about Programming Language C++, Parallel Programming, Scientific, Visualization and Artificial Neural Network.

* Optional subjects (one out of two subjects to be selected)

Practicals /Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

Course Structure:

IV. Courses at IGCAR

Program Code: ENGG00	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors	NR
2	Engineering Mathematics	EM
3	Materials and Metallurgy	MM
4	Fast Reactor Physics and Shielding	RP
5	Reactor Engineering	RE
6	Health Physics and Radiological Safety	HP
7	Project Management	PM

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Nuclear Reactors	NR	Exposure to mechanical aspects of power plant engineering Details understanding of thermal and fast power reactors Introduction to sodium technology
Engineering Mathematics	EM	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering Introduction to numerical methods for solving ordinay and partial differential equations Probability and statistics Different types of transformations
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Reactor Engineering	RE	Basic understanding of core design of LMFBR Coolant circuits of LMFBR and special characteristics of sodium technology
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation Principles of radiation detection and Radiation Protection procedures Familiarization with principles of radiation detection and radiation Protection procedures
Project Management	PM	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(A) MECHANICAL ENGINEERING

(A1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for Pressure Vessels and Piping	ME1
2	High Temperature Design and Inelastic Analysis	ME4
3	Computational Fluid Dynamics	ME6
4	Finite Element Method	ME8
5	Advanced Heat and Mass Transfer	ME10
6	Reliability Engineering	ME13
7	Manufacturing Technology	ME14

(A2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Machine Design	ME3
2	Structural Integrity Assessment Methods and NDE	
3	Vibration Engineering and condition Monitoring	
4	Seismic Design of Nuclear Reactors and Facilities	ME5
5	Plant Dynamics	

6	Experimental Mechanics	
7	Process Control and Instrumentation	ME15

(A3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-001-P
2	Seminar -1,2,3	02ENGG04-001-S

Course Outcomes:

(A1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for Pressure Vessels and Piping	ME1	Understanding of the Design of pressure vessels and piping as well as various codes.
		Understanding of the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles.
		The course also include introduction to tubesheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered. It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
High Temperature Design and Inelastic Analysis	ME4	This course has direct relevance with the design of fast breeder reactor components & piping system. It covers mainly about the role of high-Temperature design concerning FBR programme, significant failure modes and associated design guidelines and advanced inelastic analysis methods. The high temperature design aspect is followed based on the RCC MRx RB procedure. Reliable design of components and piping system operating under high temperature operating conditions should address the additional damage associated with creep, fatigue and creep-fatigue interactions predominantly under thermo-mechanical loadings. There are many unresolved problems in the area of high-temperature

		design such as visco-plasticity behaviour, ratcheting behaviour, high temperature crack initiation behaviour etc. These aspects are addressed in this course with the support of tutorials.
Computational Fluid Dynamics	ME6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis Numerical Solution of Complete Fluid Flow and Energy Equation
Finite Element Method	ME8	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Advanced Heat and Mass Transfer	ME10	Advanced knowledge in heat and mass transfer Laminar boundary layer and forced convective heat, turbulent flow and heat transfer Heat transfer in porous media and heat transfer with phase change Radiation heat transfer
Reliability Engineering	ME13	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Manufacturing Technology	ME14	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles plastic deformation, processes like rolling, forging, extrusion etc in the case of metal forming module. Arc welding process,welding metallurgy, defects, inspection, quality control aspects are covered inwelding module. Extraction of Uranium and Zirconium from ore to final product form is coveed in the material processingmodule.

(A2) ELECTIVES

Name of the Course	Course code	Course Outcome
Machine Design	ME3	Basic concepts in vibrations analysis
Structural Integrity Assessment Methods and NDE		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
Vibration Engineering and condition Monitoring		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	ME5	Introduction to earthquakes, design basis ground motion and IS 1893 spectra Introduction of earthquake engineering and analysis for multi degree freedom systems
Plant Dynamics		Analysis and design of structures, equipments and piping
Experimental Mechanics		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Process Control and Instrumentation	ME15	Understanding the concepts of instrumentation and control for nuclear power plants
		Able to identify and define instrumentation and control needs of a process or machine
		Able to provide indicative choice of instruments in the design

(A3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-001-P	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Seminar -1,2,3	02ENGG04-001-S	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) ELECTRONIC AND INSTRUMENTAL ENGINEERING

(B1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	EL2
2	Nuclear Instrumentation	EL3
3	Reliability Engineering	EL4
4	Software Engineering	EL5
5	Human Machine Interface for Reactor Control Instrumentation	EL8
6	Modern Control of Dynamic Systems	EL10

(B2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence and Digital Signal Processing	EL6
2	Process Instrumentation	EL7
3	Embedded and Computer based systems Design	EL9
4	Analytical Instrumentation	EL11

(B3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-002-P
2	Seminar -1,2,3	02ENGG04-002-S

Course Outcomes:

(B1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	EL2	Understanding of basics of physics of reactor control and kinetics
		Understanding of basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	EL3	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Reliability Engineering	EL4	Introduction to reliability engineering applied to C&I systems
		Basic concepts of reliability, statistics and fault tolerence
		Probabilistic Safety (Risk) Assessment methods in the NPPs
Software Engineering	EL5	Introduction to software engineering and standards
		Software quality assurance, verification and validation
		Software analysis, design and configuration management
Human Machine Interface for Reactor Control Instrumentation	EL8	understanding advanced design in new trends and development philosophy in the area of human machine interface. The student should obtain an overview of technologies implemented for reactor programmes and acquire an insight of the technical background to apply the same in context of reactor applications.
		The course work is framed in order to give an Introduction to various PFBR systems and HMI models in Distributed Digital Control System and their application to process systems such as special supervision systems, component handling systems, Reactor Protection Systems & Reactor Regulating Systems and Incident monitoring & mitigation systems. Learn about PC based process control system, Supervisory Control and Data Acquisition Systems.
		This course includes Familiarisation of plant automation overview, Soft Console versus conventional control panels, Guidelines for design of HMI displays, Building HMI systems, designing plant databases, alarm management techniques,

		Security features, creating process mimics, Trending historical data, Methods of passing data to HMI package etc. The capabilities of commercially available Professional HMI packages will also be explored.
Modern Control of Dynamic Systems	EL10	Introduction to state variable description with examples
		Controllability, observability and control system design

(B2) ELECTIVES

Name of the Course	Course code	Course Outcome
Artificial Intelligence and Digital Signal Processing	EL6	Exposure to fundamentals of digital signal processing algorithms
		Exposure to practical DSP algorithms and its implementation on different platforms
		Exposure to system design using pre conditioning circuits, anti-aliasing filters and digital signal controllers
		Exposure to system design case studies like Condition Monitoring System for rotating equipments And radar signal processing
		After course completion the student will be able to handle practical engineering problems solvable by digital signal processing techniques
		It is a specialised course which will give an introduction to AI techniques.
		It will give a flavour to fuzzy logic, robotics, neural networks, genetic algorithm.
Process Instrumentation	EL7	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Embedded and Computer based systems Design	EL9	Understanding of VME bus and cPCI bus architecture.
		'C' programming with MISRA C compliant.
		Electronics design in analog and digital domain
		Learning of VLSI based design using EDA tools.
		Learning of VHDL based digital design.
		Electronics system design using TMR architecture, fault tolerant design
		Introduction of reliability analysis for electronics system.
Analytical Instrumentation	EL11	Introduction to the principles and applications of modern analytical instruments Sensitivity, precision, and limitations of analytical instruments

(B3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-002-P	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Seminar -1,2,3	02ENGG04-002-S	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(C) CHEMICAL ENGINEERING

(C1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Nuclear Chemical Engineering	CE1
2	Chemical Engineering Thermodynamics	CE2
3	Transport Phenomena	CE3
4	Multi-Phase Flow Systems	CE4
5	Code Design for Pressure Vessels and Piping	CE5
6	Computational Fluid Dynamics and Heat Transfer	CE6
7	Advanced Chemical Reaction Engineering	CE7

(C2) SPECIALIZED COURSES

Sr. No.	Name of the Course	Course code
1	Process Analysis and Control	CE8
2	Advanced Mass Transfer	CE9

(C3) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Preparedness &Response to Nuclear Emergencies Artificial Intelligence Methods &Applications Membrane/ Separation Process and Technology	CEEL

(C4) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-003-P
2	Seminar -1,2,3	02ENGG04-003-S

Course Outcomes:

(C1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Nuclear Chemical Engineering	CE1	Introduction to nuclear chemical engineering for production, processing and management of nuclear materials
		Modelling and Simulation in Nuclear Chemical Engineering
Chemical Engineering Thermodynamics	CE2	Understanding the concepts of Thermodynamics , scope of Classical Thermodynamics, Phase Equilibrium, Chemical Reaction Equilibria.
Transport Phenomena	CE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyze transport problems
		Analyze transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyze transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Multi-Phase Flow Systems	CE4	Introduction to multiphase flow and its classification
		Modeling and Simulation in Nuclear Chemical Engineering
		Applications of two-phase flow in the design of steam generators
		The phenomena of fluidization and its industrial application
Code Design for Pressure Vessels and Piping	CE5	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design

		for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
Computational Fluid Dynamics and Heat Transfer	CE6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer
Advanced Chemical Reaction Engineering	CE7	Understanding of thermodynamics and kinetics of chemical reactions
		Design and analysis of chemical reactors
		Modelling of multiphase reactors

(C2) SPECIALIZATION

Name of the Course	Course code	Course Outcome
Process Analysis and Control	CE8	Understanding of dynamics of chemical process systems and nonlinear process dynamics
		Design of multivariable controllers
Advanced Mass Transfer	CE9	Introduction to theories of mass transfer and advanced mass transfer processes
		Selection and design of contacting equipment in nuclear chemical industries

(C3) ELECTIVES

Name of the Course	Course code	Course Outcome
Preparedness & Response to Nuclear Emergencies	CEEL	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Artificial Intelligence Methods & Applications		
Membrane/ Separation Process and Technology		

(C4) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-003-P	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Seminar -1,2,3	02ENGG04-003-S	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(D) MATERIALS SCIENCE

(D1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	MS1
2	Computational Methods	MS2
3	Materials and Metallurgy	MS3
4	Reactor Physics and Fuel Design	MS4
5	Health Physics	MS5
6	Metallurgical Thermodynamics	MS6
7	Experimental Methods for Materials Research	MS7
8	Structural Materials for Nuclear Reactors	MS8
9	NDE Science and Technology	MS9
10	Physical Metallurgy	MS10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	MS11
12	Introduction to Materials Science and Engineering	MS12
13	Corrosion Science and Engineering	MS13
14	Mechanical Behavior of Engineering Materials	MS14
15	Manufacturing Technology	MS15

Course Outcomes:

(D1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Engineering Mathematics	MS1	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
		Introduction to numerical methods for solving ordinary and partial differential equations
		Probability and statistics
		Different types of transformations
Computational Methods	MS2	Introduction to programming languages such as C# and Matlab
		Exposure to numerical techniques for solving partial differential equations
		Neural network for predictive applications
		Basics of atomis modelling, molecular dynamics and introduction to Monte-carlo simulation
		Introduction to FEM and current trends in modelling and imulation

Materials and Metallurgy	MS3	To develop a basic understanding on the classification of materials
		Mechanical property based selection of materials for nuclear application and standards
		Various fabrication related issues in material including welding and corrosion
		Non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Reactor Physics and Fuel Design	MS4	Introduction to basic nuclear and neutron physics concepts
		Nuclear reactors and fuel design concepts
		Reactor kinetics
Health Physics	MS5	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Metallurgical Thermodynamics	MS6	Introduction to Classical thermodynamics: 1st and 2nd laws and their applications
		Thermodynamic properties of pure substances and mixtures Solution thermodynamics
		Phased equilibria in multicomponent systems and stability
		Chemical reactor equilibria Exposure to experimental methods for determining thermodynamic properties
Experimental Methods for Materials Research	MS7	Exposure to various experimental techniques for materials characterization, including X-ray techniques, electron microscopies, ion-beam techniques, electron spectroscopies nuclear spectroscopies, vibrational spectroscopy and resonance absorption spectroscopies
		Basic understanding of underlying physics
Structural Materials for Nuclear Reactors	MS8	Exposure to the three stage nuclear power programme
		Concept of selection of structural materials for different applications
		Materials for thermal reactors, fast breeder reactors and reprocessing applications
		Materials processing and fabrication of components
NDE Science and Technology	MS9	Introduction to various non-destructive evaluation techniques for safe and reliable operation of structures and components
		Surface, volumetric and Dynamic NDE
Physical Metallurgy	MS10	Basic understanding of crystal structure and microstructure
		Knowledge of origin, construction and classifications of metallurgical phase diagrams

		Understanding of different types of metallurgical phase transformations and underlying principles
		Introduction to microstructural characterization techniques and tools
Fuel Cycle Physics and Introduction to Fuel Cycle	MS11	Introduction of nuclear fuel cycles
		Introduction to exploration, recovery and enrichment and uranium and other nuclear fuel materials
		Different types of nuclear fuels and fuel fabrication
		Recycling the spent fuel, fission products and actinides
Introduction to Materials Science and Engineering	MS12	Introduction to basic structures, bonding and defects in solids and techniques for their characterization
		Physcial properties of materials
		Basics of phase diagram and phase transformations
		Techniques for synthesis of materials
Corrosion Science and Engineering	MS13	Basic understanding of corrosion process, monitoring and preventation
		Introduction to thermodynamics and kinetics of corrosion
		Forms of corrosion and corrosion in nuclear reactor and reprocessing plants
Mechanical Behavior of Engineering Materials	MS14	Introduction to engineering materials
		Elastic and plastic deformation in polycrystalline materials
		Strengthening mechanisms in polycrystalline structural materials
		Exposure to damage mechanisms such as creep, fatigue and also exposure to fracture mechanics
Manufacturing Technology	MS15	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles of plastic deformation, processes like rolling, forging, extrusion etc. in the case of metal forming module.
		Arc welding process, welding metallurgy, defects, inspection, quality control aspects are covered in welding module. Extraction of Uranium and Zirconium from ore to final product form is covered in the material processing module.

(E) FAST REACTOR ENGINEERING – I

(E1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(E2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for pressure vessel and piping	FRE1
2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2
3	Transport Phenomena	FRE3
4	Reliability Engineering	FRE4
5	Process Design and Control	FRE5
6	Vibration Engineering and Condition Monitoring	FRE6
7	Seismic Design of Nuclear Reactors and Facilities	FRE7
8	Emergency Preparedness and Disaster Management	FRE8

(E3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Dynamics and Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva Voce

Course Outcomes:

(E1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(E2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for pressure vessel and piping	FRE1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tube sheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.

Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2	Advanced knowledge in heat and mass transfer
		Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
		Heat transfer in porous media and heat transfer with phase change
		Radiation heat transfer
Transport Phenomena	FRE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyse transport problems
		Analyse transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyse transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Vibration Engineering and Condition Monitoring	FRE6	Basic concepts in vibrations analysis
		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	FRE7	Introduction to earthquakes, design basis ground motion and IS 1893 spectra
		Introduction of earthquake engineering and analysis for multi degree freedom systems
		Analysis and design of structures, equipment and piping
		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(E3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine
		Turbine troubles
Mechanical and Electrical Equipment	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To evaluate the understanding of the subject by the student.

(F) FAST REACTOR ENGINEERING – II

(F1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(F2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	FRE15
2	Nuclear Instrumentation	FRE16
3	Reliability Engineering	FRE4
4	Process Design and Control	FRE5
5	Embedded System Design & Human Machine Interface	FRE17
6	Process Instrumentation	FRE18
7	Emergency Preparedness and Disaster Management	FRE8

(F3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva-Voce

Course Outcomes:

(F1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(F2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	FRE15	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	FRE16	Students learn about basics of interaction of radiation with matter.
		Principle & Techniques to detect and measure ionizing radiation.
		Basics of radiation counting statistics
		Introduction to Neutron Flux Measurement in FBTR and PFBR.
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Embedded System Design & Human Machine Interface	FRE17	Introduction to Microprocessor Based Hardware Design
		Computer Communication and Networks
		Fault Tolerant and Distributed Architectures
		Programmable Logic Controller Design
		Overview of plant automation and Human Machine Interface (HMI)

Process Instrumentation	FRE18	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of various process variables
		Reliability principles, Fail safe design principles
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(F3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine Turbine troubles
Mechanical and Electrical Equipments	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

BACK TO MAIN

Course Structure:

V. Courses at RRCAT

Program Code : ENGG00	Programme Specific Outcome	Impart training to students to increase the knowledge base required for research work
		Enhance analytical and computational skill of the students required for carrying out research work
		Provide training to work with various scientific equipment including sophisticated lasers and radiation available from synchrotron sources Indus-1 and Indus -2

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	03ENGG00-001-C
2	Magnet Physics and Technology	03ENGG00-002-C
3	Laser Physics and Technology	03ENGG00-003-C
4	Electromagnetic Theory	03ENGG00-004-C
5	Accelerator Physics andBeam Diagnostics	03ENGG00-005-C
6	Reactor Physics, Radiation Physics, and Safety Issues	03ENGG00-006-C
7	Numerical and Mathematical Techniques and Scientific	03ENGG00-007-C
8	Materials Science and Technology- I	03ENGG00-008-C
9	Applications of Lasers in Nuclear Science, Industry	03ENGG00-009-C
10	Applications of Accelerators in Nuclear Science, Industry	03ENGG00-010-C
11	Vacuum Physics and Technology	03ENGG00-011-C
12	Quantum Mechanics	03ENGG00-012-C
13	Research Methodology	03ENGG00-013-C

PGD in ENGINEERING SCIENCES (Program Code: ENGG00)

Course Structure:

III. Courses at RRCAT

Program Code : ENGG00	Programme Specific Outcome	Impart training to students to increase the knowledge base required for research work
		Enhance analytical and computational skill of the students required for carrying out research work
		Provide training to work with various scientific equipment including sophisticated lasers and radiation available from synchrotron sources Indus-1 and Indus -2

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	03ENGG00-001-C
2	Magnet Physics and Technology	03ENGG00-002-C
3	Laser Physics and Technology	03ENGG00-003-C
4	Electromagnetic Theory	03ENGG00-004-C
5	Accelerator Physics andBeam Diagnostics	03ENGG00-005-C
6	Reactor Physics, Radiation Physics, and Safety Issues	03ENGG00-006-C
7	Numerical and Mathematical Techniques and Scientific	03ENGG00-007-C
8	Materials Science and Technology- I	03ENGG00-008-C
9	Applications of Lasers in Nuclear Science, Industry	03ENGG00-009-C
10	Applications of Accelerators in Nuclear Science, Industry	03ENGG00-010-C
11	Vacuum Physics and Technology	03ENGG00-011-C
12	Quantum Mechanics	03ENGG00-012-C
13	Research Methodology	03ENGG00-013-C

(B) Elective Courses

Sr. No.	Name of the Course	Course code
1	Power Supplies	03ENGG00-001-E
2	Power Electronics	03ENGG00-002-E
3	Advanced Course on RF and Microwaves	03ENGG00-003-E
4	Advanced Data Acquisition and Control Systems	03ENGG00-004-E
5	Reliability Engineering	03ENGG00-005-E
6	Advanced Course in High Voltage Engineering	03ENGG00-006-E
7	Digital Signal, Image Processing and Applications	03ENGG00-007-E

(C) Laboratory Courses

Sr. No.	Name of the Course	Course code
1	Laser and Applications	03ENGG00-001-L
2	Accelerators related applications	03ENGG00-002-L
3	Electronics	03ENGG00-003-L

(D) Foundation Courses

Sr. No.	Name of the Course	Course code
1	Physics Courses for Engineering Graduates	03ENGG00-001-F
2	Engineering courses for Physics Post-graduates	03ENGG00-002-F

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Engineering Mathematics	03ENGG00-001-C	This course reviews topics in Mathematics which are usually covered at the Master's level and are essential to understand the concepts of science and engineering
		This Course also deals with the advanced topics needed for carrying out research work in different areas of science and engineering
Magnet Physics and Technology	03ENGG00-002-C	Basic understanding of magnetism and its application.
		Analytical approach of magnet design mainly for accelerator application and field measurement technique.
		Fabrication technique and alignment of magnets.
Laser Physics and Technology	03ENGG00-003-C	This course introduces basic mechanism and principles of lasers, beam propagation, and optical resonators
		Introduction to physics and technology of various types of lasers
		This course introduces basic nonlinear optics
Electromagnetic Theory	03ENGG00-004-C	This course is meant for physicists and engineers. It reviews the M. Sc. Level and B. Tech level electromagnetic theory, and further strengthens some of the intricate concepts, and introduces new topics
		It emphasizes basic concepts needed to solve the electromagnetic boundary value problems, and prepares the students to develop better understanding of the computer codes used for that
		Students are expected to develop a better and rigorous understanding of generation of electromagnetic radiation, typically in synchrotron radiation source.
		Students learn about different types of electromagnetic waves – (i) plane waves, including its reflection and refraction at dielectric surface. (ii) Gaussian beams and Bessel beams, (iii) modes in waveguides and cavities, including its transport in

		microwave components and (iv) modes in optical fiber.
Accelerator Physics and Beam Diagnostics	03ENGG00-005-C	The course introduces basic concepts of accelerator physics and beam diagnostics.
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Reactor Physics, Radiation Physics, and Safety Issues	03ENGG00-006-C	Awareness about natural, man-made radiation, dose contribution from various practises, units and quantities, biological effects of radiation exposure and ICRP recommendations on radiation protection
		Awareness about the radiation hazards at work place, safe practises to be followed, exposure control measures, shielding philosophy and radiation detection.
		Understanding the radiation hazards at high energy electron and proton accelerators and laser facilities. Dose build up effects due to electromagnetic and hadronic cascade and its impact on radiation safety and tackling mechanisms
		Gaining fundamental concepts in reactor physics, interaction of various kind of radiation with matter.
Numerical and Mathematical Techniques and Scientific	03ENGG00-007-C	For rigorous and correct analysis of data (which are the outcome of research work), learning numerical and mathematical techniques is absolutely essential.
		This course teaches interpolation, extrapolation, error analysis etc which are integral parts of data analysis. The finite element method is a numerical method for solving problems of applied science and engineering, for example, structural analysis, heat transfer, fluid flow, mass transport etc
		Concept of scientific computing is necessary for numerically analyzing experimental and analytical results. For the same, programming languages (C and fortran) are taught.

		Different operating systems (windows, linux etc), which are taught, also help in understanding the working of computers, in turn, different aspects of scientific computing
Materials Science and Technology- I	03ENGG00-008-C	The course reviews the master's level solid state physics with certain advanced topics
		The advanced topics covered include: nonlinear properties of optical materials, electronic materials for novel applications like spintronics and introduction to symmetry and ferroelectric materials
		Students learn structures of various materials including alloys, ceramics, glasses, polymers, and composites
Applications of Lasers in Nuclear Science, Industry	03ENGG00-009-C	This course covers various applications of lasers in high resolution spectroscopy in metrology and medicine
		This courses exposes application of lasers in material processing
		This course introduces application of lasers in isotope separation
Applications of Accelerators in Nuclear Science, Industry	03ENGG00-010-C	This course aims to expose students to various applications of accelerators.
		Students become aware of applications in accelerator based radiotherapy and radiation processing
Vacuum Physics and Technology	03ENGG00-011-C	This course aims to introduce the basics of theory of vacuum
		Introduces various vacuum systems and components
		Students learn how to design a vacuum system
Quantum Mechanics	03ENGG00-012-C	This course reviews master's level quantum mechanics with more emphasis on problem solving and applications
		This course also covers advanced topics which will enhance understanding in many-electron systems and photo-atom interaction
Research Methodology	03ENGG00-013-C	Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

(B) Elective Courses

Name of the Course	Course code	Course Outcome
Power Supplies	03ENGG00-001-E	This course aims to introduce various concepts of power supplies to the students
		Make students aware of AC-DC and DC-AC converters and principles of feedback control systems
		Students learn about magnet power supplies for accelerators, power supplies for superconducting magnets, and laser/plasma power supplies
Power Electronics	03ENGG00-002-E	This course develops basic understanding of the power electronics
		Course will cover various power semiconductor devices
		Students will learn modelling of various components and carrying out analysis
		Course covers electromagnetic interference related measurement techniques and mitigation techniques
Advanced Course on RF and Microwaves	03ENGG00-003-E	This course develops understanding of the science and technology of RF and microwaves
		Students will learn various generation and transmission of RF waves
		Course covers various components for RF and cavities
		Course makes students learn various measurement techniques for RF and microwave
Advanced Data Acquisition and Control Systems	03ENGG00-004-E	Process control and Data Acquisition elements and models
		Continuous time domain controllers and digital controllers
		Feed-back and Feed-forward control systems
		Z-transform based Deadbeat and Dahlin algorithms, real time systems and scheduling methods, buses for instrument networks and communication protocols
Reliability Engineering	03ENGG00-005-E	This course aims to introduce various concepts and techniques for evaluating reliability and assessing quality of engineering processes

		Review of basic statistics and probability applied to reliability analysis
		Students will learn various concepts of quality assurance and reliability
		Students will learn topics related to total quality management
Advanced Course in High Voltage Engineering	03ENGG00-006-E	This course aims to introduce concepts and materials related to high voltage engineering
		Students learn about various dielectric materials relevant for high voltage applications
		Students learn various techniques for generating and measuring high voltages
		Course introduces aspects of designing high voltage circuits and safety issue associated with high votages
Digital Signal, Image Processing and Applications	03ENGG00-007-E	Basic understanding of machine vision systems and their specific application areas related to nuclear engineering
		Understanding of camera types, lenses, illumination, Component Selection of a machine vision system
		Understanding of the concept of digital image, basic definitions, image operators, and functions used in digital image processing software
		Applying functions for accomplishing particular image processing task according to application

(C) Laboratory Courses

Name of the Course	Course code	Course Outcome
Laser and Applications	03PHYS04-001-L	To provide first-hand experience in handling various lasers and related optics
		To provide training to carry out spectroscopic studies using laser
Accelerators related applications	03PHYS04-002-L	Students get first-hand experience in handling various instruments needed for accelerator technology
Electronics	03PHYS04-003-L	Students get first-hand experience in handling various instruments required for electronics, image processing, and RF components

		Students are also expected to learn and handle GUI software and communication protocols

(D) Foundation Courses

Name of the Course	Course code	Course Outcome
Physics Courses for Engineering Graduates	03ENGG00-001-F	This is a bridge course which introduces engineering graduates to some specialized subjects of physics
		These subjects helps graduates to understand aspects of lasers, accelerators, and materials sciences
Engineering courses for Physics Post-graduates	03ENGG00-002-F	This is a bridge course which introduces physics post-graduates to some specialized subjects of engineering
		These subjects helps candidates to understand mechanical, electronics, and electrical engineering aspects of lasers and accelerators

BACK TO MAIN

PGD in LIFE SCIENCES
(Program Code: LIFE00)

Course Structure:

I. Courses at BARC

Program Code : LIFE00	Programme Specific Outcome	Basic knowledge on Physics, Mathematics and Chemistry
		Detailed knowledge on different statistical tools
		Thorough knowledge on Theoretical and practical aspects of different branches of Life Sciences
		Ability to write, initiate and carry out research projects

(A) Core courses

Sr. No.	Name of the Course	Course code
1	PHYSICS, MATHEMATICS and STATISTICS	BS502
2	CHEMISTRY and RADIOCHEMISTRY	BS501
3	BIOCHEMISTRY	BS601
4	MOLECULAR BIOLOGY	BS608
5	CELL BIOLOGY	BS603
6	CROP SCIENCE	BS604
7	MICROBIOLOGY & BIOTECHNOLOGY	BS607
8	HUMAN GENETICS	BS606
9	BIOINFORMATICS	BS602
10	RADIATION BIOLOGY	BS609
11	FOOD TECHNOLOGY	BS605

12	RESEARCH METHODOLOGIES	BS592
13	SEMINARS	BS594
14	AUDIT LECTURES	
15	ELECTIVE COURSES	BS701 - BS714

(B) Elective Courses:

Sr. No.	Name of the Course	Course code
1	ADVANCES IN ENZYME TECHNOLOGY	BS701
2	ASSESSMENT OF HEALTH EFFECTS FROM EXPOSURE TO LOW LEVELS OF IONIZING RADIATION	BS702
3	BIOLOGY OF STRESS AND ADAPTIVE RESPONSE IN BACTERIA	BS703
4	CHALLENGES FOR SUSTAINABLE AND CLEAN ENVIRONMENT	BS704
5	FOOD BORNE PATHOGENS	BS705
6	IMMUNOLOGICAL METHODS IN BIOCHEMICAL AND CHEMICAL ANALYSIS	BS706
7	MOLECULAR MARKERS AND GENOMICS FOR CROP IMPROVEMENT	BS707
8	OXIDATIVE STRESS AND REDOX MODIFIERS IN DISEASE MANAGEMENT	BS708
9	CANCER- HALLMARKS, PATHOGENESIS, MICROENVIRONMENT AND THERAPEUTICS (PREVIOUSLY *OVERVIEW OF CANCER*)	BS709
10	PLANT GENETIC ENGINEERING	BS710
11	ADVANCES IN GENOME BIOLOGY	BS711
12	PRINCIPLE AND PRACTICES IN STRUCTURAL BIOLOGY	BS712
13	ADVANCED INSTRUMENTATION FOR BIOANALYSIS AND IMAGING	BS713
14	MOLECULAR BIOLOGY METHODS IN TUBERCULOSIS AND THYROID CANCER	BS714

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
PHYSICS, MATHEMATICS and STATISTICS	BS502	To make them understand the basic concepts of physics including mechanics, optics and interaction of matter with radioactivity.
		Introduction to different tools of mathematics and statistics
		Hands on training for using different biostatics software for data analysis
CHEMISTRY and RADIOCHEMISTRY	BS501	Building foundation for understanding of biochemical reactions, weak interactions and free radicals in radiation biology.
		Introduction to radiolabelling techniques and applications of radiopharmaceuticals in diagnosis & therapy
		Fundamentals of bio-organic synthesis and secondary metabolites
BIOCHEMISTRY	BS601	Helps to understand the interaction of metabolic pathways through their linkages and establish their important roles in various cellular metabolic processes.
		How proteins and their post-translational modifications lead to diverse structure and function
		Understanding organisation of the enzyme complex and their role. Understanding and application of non-aqueous enzymology
		How biological oxidation and reduction contribute towards electron transport and energy transduction
MOLECULAR BIOLOGY	BS608	Fundamentals of central dogma of molecular biology
		Overview of DNA structure dynamics and regulation of DNA replication in different systems and its implications.
		Understanding of gene expression and its regulation at different levels
		Comprehensive overview of RNA biology including biogenesis and functioning of ncRNAs and RNPs
CELL BIOLOGY	BS603	Understanding of experimental basis of current models of cell cycle/apoptosis
		Knowledge about various signalling pathways and how they were experimentally determined
		Interpretation of flow cytometry data
		Approaches for setting up cell biology experiments with appropriate controls
CROP SCIENCE	BS604	Understanding the basic concepts of genetics, helping students to develop their analytical, quantitative and problem-solving skills from classical to molecular genetics
		To impart theoretical knowledge and practical skills about plant breeding objectives,

		mode of reproduction and genetic consequences, breeding methods for crop improvement.
		To impart theoretical knowledge and computation skills regarding component of variation and variances, scales, mating designs and gene effects.
		To apprise about various abiotic and biotic stresses influencing crop yield, mechanisms and genetics of resistance and methods to breed stress resistant varieties.
MICROBIOLOGY & BIOTECHNOLOGY	BS607	Understanding the microbial diversity
		To apprise about industrial applications of microbes
		To make them learn bacterial and viral genetics and various tools of gene mutation.
HUMAN GENETICS	BS606	Understanding of chromosomal rearrangements in human genetic diseases & syndromes and its implications to human health.
		Learning human genome mapping and role of molecular genetic markers in diseases association studies and pharamacogenetics.
		Learning mendelian and multifactorial inheritance in pedigrees and implications in screening the human population for genetic disorders.
		Learning human genome project goals & achievements using high throughput genomic technologies and their application towards disease identification, treatment and health care.
BIOINFORMATICS	BS602	How databases can be queried for retrieval of meaningful biological data
		Application of sequence analysis techniques for inferring gene or protein functions
		Application of structural bioinformatics approaches such as modelling to drug design
		Tackle real world biological problems through data mining and bioinformatics approaches
RADIATION BIOLOGY	BS609	Understanding the concept of radiation units, radiation protection standards, and dose effect relationships
		Physical and biological dosimetry.
		Molecular basis of cellular radio-sensitivity, radio/ chemo-sensitization of tumor cells, and principles of radiotherapy.
		Understanding biological effects of free radicals and cellular defense mechanisms against free radicals.
		Identifying chronic/acute, genetic and immune effects of radiation.
		General principles of monitoring, assessment and control of radiation hazards in nuclear fuel cycle facilities, and emergency preparedness.
FOOD TECHNOLOGY	BS605	Nutritional & functional properties of food
		Conventional and advanced food preservation methods
		Radiation processing of food products
		Role of microbes in food safety and shelf-life
	BS592	Learning of experimental design

RESEARCH METHODOLOGIE S	BS592	Learning of experimental design
		Planning and execution of experiments
		Data interpretation and data presentation
		Special training in handling of radioactive materials in biological experiments
		Hands on experience of latest instrumentation.
		This course would impart latest and relevant practical approach to address the biological research problems.
		To cultivate the art of communication and presentation
		To make them understand and present scientific papers
		To add professional ability and personality development in trainees.
AUDIT LECTURES		To give the idea of nuclear energy
		To explain them various types of nuclear reactors
		To make them aware about biosafety and animal ethics in biological research

(B) Elective Courses

Name of the Course	Course code	Course Outcome
ADVANCES IN ENZYME TECHNOLOGY	BS701	Gaining knowledge on industrial applications of enzyme, matrix designing, bioprocess development & 'Design of Experiment' (statistical approach)
		Building concepts on biosensors and their applications
		Understanding about enzyme role in remediation
		Exposure to molecular docking and molecular dynamic simulations for understanding enzymes-substrate interactions
ASSESSMENT OF HEALTH EFFECTS FROM EXPOSURE TO LOW LEVELS OF IONIZING RADIATION	BS702	Risk assessment due to low dose and low dose rate radiation effects on human health in high background radiation areas, A-bomb survivor, Chernobyl and Fukushima studies.
		Biological mechanisms relevance to human health due to low dose radiation exposures.
		Integration of biology and epidemiology for evaluation of cancer risk in human population using DNA damage, repair and immune response.
		Evaluating occupational, medical and environmental radiation exposures using

		risk models and its application to radiological protection science.
BIOLOGY OF STRESS AND ADAPTIVE RESPONSE IN BACTERIA	BS703	Understanding the known mechanisms of the abiotic stress responses in bacteria
		Experimental approaches to identifying the proteins responsible for stress tolerance, and their biochemical functions
		Estimation of metal bioremediation by cells
		Zymogram of proteins
CHALLENGES FOR SUSTAINABLE AND CLEAN ENVIRONMENT	BS704	Understanding different methods of waste processing/management.
		Transforming fundamental research to technologies for societal applications.
		Methodology of technology and product development.
		Comparison of waste management processes across major cities of world.
FOOD BORNE PATHOGENS	BS705	Learning types of foodborne pathogens
		Distribution and control of these pathogens
		Detection and identification of pathogens
		In death understanding of molecular mechanism of pathogenicity
IMMUNOLOGICAL METHODS IN BIOCHEMICAL AND CHEMICAL ANALYSIS	BS706	To demonstrate antigen-antibody interactions in imuunoassays
		To make learn radioiodination, QC-QA in immunoassays
		To explain Tg assays and Scatchard plot
		Non-isotopic immunoassays
MOLECULAR MARKERS AND GENOMICS FOR CROP IMPROVEMENT	BS707	Introduction to the different molecular markers techniques and their application in plant breeding
		Concept of reverse genetics and TILLING
		QTLs and their role in plant breding
		Demonstration of different techniques in MAS
OXIDATIVE STRESS AND REDOX MODIFIERS IN DISEASE MANAGEMENT	BS708	To make them understand the role and significance of ROS/RNS
		Demonstration of detection and measurement of free radicals
		To discuss the role of antioxidants in food and therapy
CANCER- HALLMARKS, PATHOGENESIS, MICROENVIRONMENT AND THERAPEUTICS (PREVIOUSLY *OVERVIEW OF CANCER*)	BS709	Understanding of the pathogenesis of cancer
		Observation of bulk tumor tissues and their processing for preservation and sectioning

		Methodologies to study cancer cell lines in tissue culture/animal models
		Understanding of the tumor microenvironment and therapeutics
PLANT GENETIC ENGINEERING	BS710	Understanding of genetic engineering principles including cloning of DNA fragments in different vectors
		Understanding the methods of gene transfer in plant systems such as banana, tobacco etc.
		Understanding gene expression, gene silencing, related molecular biology techniques such as genome editing tools ex; CRISPR –Cas9 system in plants
		Useful lectures and practical in crop improvement though recombinant DNA technology
ADVANCES IN GENOME BIOLOGY	BS711	To impart the importance of genome structure and organization
		Understanding the genome maintenance and segregation
		To make them understand the usefulness of genomic alterations in plant and bacterial systems
PRINCIPLE AND PRACTICES IN STRUCTURAL BIOLOGY	BS712	Understanding the known mechanisms of the abiotic stress responses in bacteria
		Experimental approaches to identifying the proteins responsible for stress tolerance, and their biochemical functions
		Estimation of metal bioremediation by cells
		Zymogram of proteins
ADVANCED INSTRUMENTATION FOR BIOANALYSIS AND IMAGING	BS713	Provides current perspectives on advanced instrumentation for bioanalysis and imaging
		How the different instruments work and what information can be obtained and interpreted to analyse the biological samples
		Acquiring skills and developing interest to employ various instrumentation techniques for solving research problem in biology
		Encouraging innovativeness and adopting new techniques to further biological research
MOLECULAR BIOLOGY METHODS IN TUBERCULOSIS AND THYROID CANCER	BS714	Importance of molecular diagnostics in infectious diseases and cancer
		To understand the importance of phylogeny in tuberculosis

		Introduction to thyroid cancer, diagnostics and treatment
PRINCIPLES AND PRACTICES OF MUTATION BREEDING	BS715	Basis of mutagenesis in crop plants
		Handling of mutagens and plant population
		Invitro mutagenesis technique
		Molecular technique for characterizing induced mutants

PGD. in PHYSICAL SCIENCES (Program Code: PHYS00)

Course Structure:

I. Courses at BARC

Program Code : PHYS00	Programme Specific Outcome	Apply principles of basic science concepts in understanding, analysis and prediction of physical systems.
		Introduce advanced ideas and techniques required in emergent areas of Physics.
		Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.
		Understand the basic concepts of research, data collection and presentation, scientific report writing, and ethics in research
		Gain an overall practical experience to decide and apply the appropriate method in future experimental investigations.
		Get the exposure to the steps needed towards completing a focused topic as well as the research areas of thesis supervisor.

(A) Foundation Courses

Sr. No.	Name of the Course	Course code
1	MATHEMATICAL PHYSICS	PH 501
2	QUANTUM MECHANICS	PH 502

3	STATISTICAL PHYSICS	PH 503
4	ELECTROMAGNETIC THEORY	PH 504
5	COMPUTATIONAL PHYSICS	PH 505

(B) Core Courses:

Sr. No.	**Name of the Course**	**Course code**
1	Nuclear Physics	PH 601
2	Atomic, Molecular & Laser Physics	PH 602
3	Plasma Physics & Technology	PH 603
4	Physics of Materials and Surfaces	PH 604
5	Reactor Physics & Technology	PH 605
6	Accelerator Physics & Technology	PH 606
7	Astrophysics	PH 607
8	Electronics	PH 608
9	Health Physics and Radiation Detectors	PH 609

(C) Experimental and Lab Courses

Sr. No.	**Name of the Course**	**Course code**
1	Engineering Drawing & Workshop Practices	PH 610
2	Research Methodologies and Methods of Experimental Physics	PH 611

(D) Elective Courses

Sr. No.	**Name of the Course**	**Course code**
1	Special topics in Mathematical Physics	PY 701

2	Selected Topics in Classical Mechanics	PY 702
3	Chaos and Nonequilibrium Statistical Mechanics	PY 703
4	Nonlinear Dynamics	PY 704
5	Advanced Computational Physics	PY 705
6	Stochastic Physics	PY 706
7	Selected Topics in Nuclear Physics	PY 707
8	Advanced Accelerator Physics & Technology	PY 708
9	Introduction to Neutrino Physics	PY 709
10	High Energy Astrophysics	PY 710
11	Synchrotron Radiation and its Applications	PY 711
12	Selected Topics in Atomic and Molecular Physics	PY 712
13	Advanced Photonics	PY 713
14	Quantum Optics and Information	PY 714
15	High Power Lasers and Applications	PY 715
16	Laser-Matter Interactions and Applications to Advanced Material Processing	PY 716
17	Computational Plasma Physics: Introduction to Particle in Cell (PIC) Technique	PY 717
18	Nonlinear Plasma Theory	PY 718
19	Modeling and Simulations in Physics	PY 719
20	Selected topics in Condensed Matter Theory	PY 720
21	Organic Semiconductor Devices	PY 721
22	Single Crystal Growth and Devices	PY 722
23	Advanced Magnetism and Superconductivity	PY 723
24	Neutron as a Probe of Condensed Matter	PY 724
25	Structure and Crystallography of Biomolecules	PY 725
26	Advanced Reactor Physics	PY 726

27	High Energy Density Physics: Theory	PY 727
28	High Energy Density Physics: Experimental	PY 728
29	Nuclear Data Physics for Advanced Nuclear Applications	PY 729
30	Advanced Computational Methods for Steady State and Transient Behaviour of Neutron Transport	PY 730
31	Accelerator Driven Systems	PY 731

Course Outcomes:

(A) Foundation Courses

Name of the Course	Course code	Course Outcome
MATHEMATICAL PHYSICS	PH 501	Understand and apply mathematical techniques for describing and deeper understanding of physical systems.
QUANTUM MECHANICS	PH 502	Understand and apply principles of Quantum mechanics for understanding the physical systems in quantum realm.
STATISTICAL PHYSICS	PH 503	Understand and apply statistical methods for describing the classical and quantum particles in various physical systems and processes.
ELECTROMAGNETIC THEORY	PH 504	Gain knowledge in understanding the principles and dynamic phenomena of electromagnetism that occur in the case of time-varying sources (local charges and currents). Equips the students with the necessary mathematical knowledge for a detailed and accurate description of these phenomena and for solving related problems.
COMPUTATIONAL PHYSICS	PH 505	Gain knowledge in basic concepts in computational & numerical skills and apply them for understanding and describing complex physical systems.

(B) Core Courses:

Name of the Course	Course code	Course Outcome
Nuclear Physics	PH 601	Understand the properties and structure of nuclei, nuclear reaction mechanisms and their role in formation of universe consisting of different elements.
Atomic, Molecular & Laser Physics	PH 602	Understand the role of atoms and molecules in the structure and properties of mater. Describe different types of atomic and molecular spectra with and without external field.
Plasma Physics & Technology	PH 603	Describe basic concept of plasma, its physical parameters and applications. Describe basic processes in plasma and associated theory and solve simple plasma physics problems.
Physics of Materials and Surfaces	PH 604	Able to formulate basic models for electrons and lattice vibrations for describing the physics of crystalline materials; and understand band structure and electrical/optical properties, magnetism, superconductivity and surface structure of a material, .
Reactor Physics & Technology	PH 605	Understand the basic principle of nuclear power generation and physics design of a reactor.
Accelerator Physics & Technology	PH 606	Understand working principles and design concepts of different accelerators and their applications in industry and research in basic and applied sciences.
Astrophysics	PH 607	Able to identify and explain the properties of different astrophysical objects, learn experimental techniques to study them, understand the fundamentals of radiative transfers, theory of accretion and jets & outflows.
Electronics	PH 608	Understand how an analog signal is processed through different electronics modules and converted to digital signals,

		stored in memory and transferred to another deivice.
Health Physics and Radiation Detectors	PH 609	Gain basic knowledge of different types of radiations, doses, shielding, health effects and safety

(C) Experimental and Lab Courses:

Name of the Course	Course code	Course Outcome
Engineering Drawing & Workshop Practices	PH 610	Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.
Research Methodologies and Methods of Experimental Physics	PH 611	Understand the basic concepts of research, data collection and presentation, scientific report writing, and ethics in research

(D) Elective Courses:

Name of the Course	Course code	Course Outcome
Special topics in Mathematical Physics	PY 701	Learn about a few special topics in mathematical methods- difference equations, local analysis and global analysis.
Selected Topics in Classical Mechanics	PY 702	Learn about transformation theory of mechanics, integrable systems, canonical perturbation theory and near–integrable systems
Chaos and Nonequilibrium Statistical Mechanics	PY 703	Learn about Chaos and non-linear statistical mechanics involving Boltzmann and Liouville equation, Green-Kubo formulae, nonlinear maps, open systems and dynamical foundation of Boltzmann equation
Nonlinear Dynamics	PY 704	Learn about instabilities and chaos of periodically forced nonlinear oscillators, bifurcations and chaos in laboratory-scale systems, control and synchronization of

		nonlinear phenomena, experiments and numerical projects
Advanced Computational Physics	PY 705	Learn different programming languages and able to solve physics problems using advanced computer programming and/or Monte-Carlo simulation.
Stochastic Physics	PY 706	Learn about classical theory of Brownian motion, nucleation and coagulation theory and growth models.
Selected Topics in Nuclear Physics	PY 707	Learn about theoretical tools and techniques of advanced nuclear physics research areas and topics of current interest.
Advanced Accelerator Physics & Technology	PY 708	Learn about proton and heavy ion advanced accelerators, Giga-watt pulsed power & industrial accelerators, beam dynamics and design of advanced accelerators.
Introduction to Neutrino Physics	PY 709	Able to appreciate the intense activity worldwide in the field of neutrino physics. Get a brief exposition of a non-invasive method of monitoring fissile materials using neutrinos.
High Energy Astrophysics	PY 710	Able to identify and explain the properties of different astrophysical objects, learn experimental techniques to study them, understand the fundamentals of radiative transfers, theory of accretion and jets & outflows.
Synchrotron Radiation and its Applications	PY 711	Learn about the basic of production of Synchrotron radiation, beam line instrumentation and experimental techniques to study atomic, molecular and cluster physics
Selected Topics in Atomic and Molecular Physics	PY 712	Learn about coherent spectroscopy, physics with trapped ions and atoms, and behaviour of atoms and molecules under intense fields.
Advanced Photonics	PY 713	Learn the basics of LASER, fibre and non-linear optics, and get exposed to nano-photonics and meta-materials.

Quantum Optics and Information	PY 714	Learn about quantum theory of radiation, light atom interaction, ultra-cold atoms, quantum degenerate gases, and elements of atom optics and quantum information.
High Power Lasers and Applications	PY 715	Learn about non-linear optical processes, Laser dynamics and pulse generation, ultra-short pulse generation, amplification & compression and their applications.
Laser-Matter Interactions and Applications to Advanced Material Processing	PY 716	Learn about laser matter interaction, surface characterization, measurement & diagnostic techniques, and applications to advanced material processing
Computational Plasma Physics: Introduction to Particle in Cell (PIC) Technique	PY 717	Make mathematical modelling of a particle in a cell and solve Maxwell's equations.
Nonlinear Plasma Theory	PY 718	Learn about non-linear waves, non-linear wave-wave interaction and wave-particle interaction.
Modeling and Simulations in Physics	PY 719	Learn about electronic structure theory and modelling & simulations using Monte Carlo and Cluster Molecular dynamics
Selected topics in Condensed Matter Theory	PY 720	Learn about the application of quantum mechanical and atomistic lattice dynamics and computer simulations to model, understand, and predict the properties of real materials.
Organic Semiconductor Devices	PY 721	Learn about the techniques of preparation of organic thin films and their characterization, molecular electronics, organic electronics, organic solar cells and organic gas sensors.
Single Crystal Growth and Devices	PY 722	Learn about the techniques of single crystal growth, their characterization and applications
Advanced Magnetism and Superconductivity	PY 723	Learn about magnetism, magnetic exchange interaction, spintronics and superconductivity.
Neutron as a Probe of Condensed Matter	PY 724	Learn about neutron scattering, crystal structure study using neutron diffraction technique, neutron reflectometry and dynamics in condensed matter.

Structure and Crystallography of Biomolecules	PY 725	Learn about the computational and experimental methods of determining 3D structures in protein and nucleic acid, macromoleculer crystallisation and characterization, diffraction data collection and data processing
Advanced Reactor Physics	PY 726	Learn about neutron transport theory, numerical methods for solution of the multi-group neutron diffusion equation, reactor dynamics and reactor noise and its applications
High Energy Density Physics: Theory	PY 727	Learn about hydrodynamic and shock wave, equation of state and radiation opacities, radiation hydrodynamic instabilities and inertial confinement fusion.
High Energy Density Physics: Experimental	PY 728	Learn about the physics of high energy density effects in matter, energy storage systems, energetic materials and applications, diagnostic techniques and data interpretation.
Nuclear Data Physics for Advanced Nuclear Applications	PY 729	Learn about nuclear physics data, representation of nuclear data, nuclear data processing, multi-grouping, concept of critical facility and exposure to error propagation and sensitivity studies.
Advanced Computational Methods for Steady State and Transient Behaviour of Neutron Transport	PY 730	Learn about solution of transport equation, neutron thermalization, treatment of resonances, solution of time dependent transport equation and solution of the fuel depletion equations.
Accelerator Driven Systems	PY 731	Learn about spallation neutron sources, sub-critical reactor, accelerator driven systems and waste transmutation

BACK TO MAIN

Course Structure:

II. Courses at IGCAR

Program Code : PHYS00	Programme Specific Outcome	Able to serve as reactor Physicist at both thermal and Fast breeder reactors
		Trained to carryout research on advanced materials for Nuclear reactor applications
		Ability to handle robotics for non-destructive testing of radioactive materials

Course Structure:

Sr. No.	Name of the Course	Course code
1	Mathematical Methods	PY1
2	Computational Methods	PY2
3	Introductory Reactor Physics and Engineering	PY3
4	Nuclear Physics and Nuclear Data	PY4
5	Engineering Drawing and Laboratory Practices and Experimental Methods	PY5
6	Reactor Materials	PY6
7	Radiation Detection and Measurements	PY7
8	Reactor Types and Advanced Reactor Concepts	PY8
9	Radiation Shielding Design and Protection	PY9
10	Reactor Dynamics and Safety Analysis	PY10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	PY11
12	Fluid Dynamics and Thermal Hydraulics	PY12
13	Advanced Computational Methods in Reactor Physics	PY13
14	Experimental and Operational Reactor Physics	PY14
15	Design Methods in Thermal and Fast Reactors and Computer codes	PY15
16	In Core of Fuel Management	PY16

Course Outcomes:

Name of the Course	Course code	Course Outcome
Mathematical Methods	PY1	Students learn vector spaces, Hilbert space, matrix methods, eigen value problems, differential and integral equations, complex variables.
Computational Methods	PY2	Since some complex equations cannot be solved analytically, numerical and computational methods are important. Students study the basics of computer architecture - hardware and software,
		Learn Various numerical methods
		Programming in Fortran and C
Introductory Reactor Physics and Engineering	PY3	Learn neutron physics, reactor physics including fast reactors; reactor kinetics and reactor control, all needed for working with nuclear reactors.
Nuclear Physics and Nuclear Data	PY4	Learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, nuclear models, nuclear data evaluation and processing which are Needed to work with nuclear reactors and for nuclear research.
Engineering Drawing and Laboratory Practices and Experimental Methods	PY5	Machine Drawings Projections, drafting, Autocad other material in this course are essential for engineers to produce accurate drawing for fabrication of small and large components for nuclear reactors and associated facilities.
Reactor Materials	PY6	Properties of nuclear fuels such as uranium, uranium oxide, plutonium, carbide and nitride fuels, MOX fuel, fuel fabrication, structural materials and clad materials, zirconium and alloys, moderators, Mechanical properties of materials, Radiation effects in materials, corrosion of metals and related topics makes this course a very important one for nuclear scientists and engineers.
		Ability to Solve unforeseen materials problems in operational reactors
		Ability to look for future candidate materials
Radiation Detection and Measurements	PY7	Required for radiation, safety workers and related scientists: Interaction of radiation

		with matter, radiation detectors including gas, semiconductor and scintillation detectors; ionization chambers; high resolution gamma spectroscopy, Monte Carlo simulations
Reactor Types and Advanced Reactor Concepts	PY8	Students will learn about different type of reactors such as Thermal reactors, fast reactors, High Temperature Reactor(HTR) and Advanced Heavy Water Reactor (AHWR). Metal fuelled FBR and Accelerator driven systems (ADS); Indian reactors APSARA, CIRUS, DHRUVA, PHWR, FTBR AND PFBR
Radiation Shielding Design and Protection	PY9	Students will study Radiation sources, its interaction with matter; summary of basic interaction mechanisms of alpha, beta, gamma/x -rays and neutrons with matter; radiation dosimetry; Interaction of radiation with biological matter; Radiation toxicity, Risk factors; radiation protection, shielding, and nuclear emergency management
Reactor Dynamics and Safety Analysis	PY10	Neutron kinetics and thermal effects. Feedback effects; Description of main reactor systems. Coolant system behaviour. Plant dynamics; safety systems; Reliability and Probabilistic Safety Analysis and related topics are taught in this course
Fuel Cycle Physics and Introduction to Fuel Cycle	PY11	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India. Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Issues related recycling – Effective fissile content of discharged fuel for next cycle; re-fabrication of fuel for the next cycle Activity and toxicity of discharged fuel
Fluid Dynamics and Thermal Hydraulics	PY12	Fluid continuum – Properties of fluids – Methods of describing fluid motion – Kinematics of fluid streamlines; Navier Stokes equations; Hydrostatics – Manometry; Fluids subjected to uniform linear acceleration and uniform rotation; Thermal hydraulics.

		Important specialisation for understanding behaviour of reactor coolants (liquid sodium and water) for safe reactor operation
Advanced Computational Methods in Reactor Physics	PY13	Students will learn Methods of solving neutron Diffusion equation; Finite element method- its advantages and disadvantages. Coarse mesh rebalancing. Methods of solving neutron transport equation; (a) PN method (b) Discrete ordinates method (c) Collision probabilities methods; Detailed burnup chain with all minor actinides. Solution of the burnup equations. Constant flux and constant power approximations.
Experimental and Operational Reactor Physics	PY14	In-depth exposure and develop expertise to experiential aspects of Reactor operations
		Dynamical methods to evaluate and monitor reactivity measurements
		Expertise to monitor delayed neutron counting and noble gas fission products to detect early stages of fuel failures.
		Exposure to operation aspects of various types of reactors
Design Methods in Thermal and Fast Reactors and Computer codes	PY15	Exposure to model and design of both thermal and fast reactors using neutron production, transport and reactions
		Expertise to use various design and validation codes for neutronics
In Core of Fuel Management	PY16	Develop expertise in various safety aspects of in-core fuel handling and management in different types of reactors
		Exposure to reactor specific fuel handling methods and controls
		Exposure to specialised computer codes for in-core fuel handling

M.Tech.
(Program Code: ENGG01)

Course Structure:

I. Courses at BARC

Program Code : ENGG01	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Accelerator Physics and Technology	EN501
2	Engineering Mathematics	EN502-505
3	Health Physics and Rad & Indl Safety	EN506
4	Nuclear Fuel Cycle Technology	EN508
5	NPP & Advanced Reactor Concepts	EN509
6	Reactor Physics and Engineering	EN510

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Accelerator Physics and Technology	EN501	The course introduces basic concepts of accelerator physics, Vacuum and cryogenic systems
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Engineering Mathematics	EN502-505	Advanced knowledge in computational data analysis, data fitting and error analysis

		Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
Health Physics and Rad & Indl Safety	EN506	Learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Nuclear Fuel Cycle Technology	EN508	Familiarisation with font and back end of nuclear fuel cycle technology
		Knowledge of radioactive waste generation on nuclear fuel burning and its processing
NPP & Advanced Reactor Concepts	EN509	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts
		Familiarization with reactor physics design challenges
Reactor Physics and Engineering	EN510	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with nuclear reactors.

(A) MECHANICAL COURSES

(A1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Code design for PVP	EN610
2	Computational fluid Dynamics and Heat Transfer	EN611
3	Finite Element Method	EN621
4	Fracture Mechanics	EN622
5	Mechanics of Solids	EN624

(A2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Machine Design	EN711
4	Material Science in Nuclear Engineering	EN712
5	Multi-scale material modelling	EN715
6	Nuclear Emergencies	EN716
7	Reliability Engineering	EN718
8	Vibration	EN721

(A3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(A1) Core Engineering

Name of the Course	Course code	Course Outcome
Code design for PVP	EN610	Basis of ASME Sec.VIII and Sec.III eqns. for Pressure Vessel and Piping Design
		Nozzle openings, Vessel design under ext. pressure
		ANSI / ASME B31.1 and B31.3 piping code
		NDE Examination of welds, Acceptance standard
Computational fluid Dynamics and Heat Transfer	EN611	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer

Finite Element Method	EN621	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Fracture Mechanics	EN622	LEFM and EPFM, Material fracture props. determination
		PTS event of RPV and Master Curve Concept
		Computational Fracture Mechanics
		Fracture Mechanisms
Mechanics of Solids	EN624	Principles and Fundamental Equations of Elasticity
		Analysis of Stress and Strain, Thermal Stresses
		Introduction to Plasticity
		Theory of Plates and Shells

(A2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Programming Language C++
		Parallel Programming
		Scientific Visualization
		Artificial Neural Network
Fluid Power Technology	EN709	Basic principles of hydraulics and pneumatics, pressure control
		Fluid power pumps and compressors, Fluid experiments
		Directional and flow control valves, Fluid Logic & Control
		Advanced Hydraulic Control Circuits, Electronics and Instrumentation for Hydraulics
Machine Design	EN711	Basic Principles of Machine Design, Design and Drawing Practices
		Sealing Methods
		Special Dimensional Inspection Techniques
		Advanced Manufacturing Techniques
Material Science in Nuclear Engineering		Metallurgy of steels
		Nuclear Materials

	EN712	Advanced Polymeric materials and Composites
		Corrosion
Multi-scale material modelling	EN715	Atomistic models: Molecular dynamics, Monte Carlo methods
		Inter-atomic potentials, Mesoscopic methods
		Modeling at microscale
		Bridging the scale gaps between different simulation levels
Nuclear Emergencies	EN716	Radiation Shielding, Nuclear Waste Management
		Nuclear Accidents/emergencies, Effects of Hiroshima & Nagasaki bombing
		Medical decontamination with demonstration
		Monitoring of High radiation field area
Reliability Engineering	EN718	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Vibration	EN721	Single and Multi-degree-of-freedom Systems, Free vibration
		Response of Systems To Ground Motion: Earthquake motion
		Flow Induced Vibration
		Vibration Measurement and Signal Analysis

(A3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
MiniProject		To provide a hands-on experience of working in an

	EN593	ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		To aquare skills in formulating and executing a research problem and communicating the results in writing and orally.

(B) CHEMISTRY COURSES

(B1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Chemical Reaction Engineering	EN601
2	Advanced Mass Transfer	EN604
3	Code design for PVP	EN610
4	Computational Fluid Dynamics and Heat Transfer	EN611
5	Nuclear Chemical Engineering	EN628
6	Process Dynamics and Control	EN634
7	Process Modeling, Simulation and Optimization	EN635

(B2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Material Science in Nuclear Engineering	EN712
4	Membrane Technology	EN714

(B3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591

2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(B1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Chemical Reaction Engineering	EN601	Fundamentals of Non-ideal reactors & RTD studies
		Understanding Non-isothermal effects & dynamical behaviour
		Overview of Heterogeneous reactions
		Approaches in Advanced reaction engineering & reactor design
Advanced Mass Transfer	EN604	Understanding Mass transfer with and without chemical reactions
		Rate based approaches for design
		Selection and design of various contacting equipment
		Process intensification approaches
Code design for PVP	EN610	Overview of Theories for pressure vessel design
		ASME Sec. VIII Div. 1 and Div - II equations
		Pressure vessel design as per ASME
		Design of piping as per B31.1 piping code.
Computational Fluid Dynamics and Heat Transfer	EN611	Understanding Kinematics of fluid flow and governing equations
		Classification of Partial Differential Equations & their discretization
		Convective heat transfer for internal and external flows
		Numerical Solution of fluid flow and heat transfer equations
Nuclear Chemical Engineering	EN628	Overview of Recovery and processing of nuclear materials
		Uranium conversion and reconversion

		Isotope Separation
		Nuclear Waste Management
Process Dynamics and Control	EN634	Introduction to process control & control loop dynamics
		Fundamentals of state-space controls, state, measurement equations
		General solution of the state equation
		Multi-variable controls, de-coupling, relative gain array
Process Modeling, Simulation and Optimization	EN635	Formulation of Dynamic and steady state models
		Flow sheet Analysis & Plant Simulation
		General Approaches for Non-Linear Systems
		Plant optimisation by Genetic Algorithms and Neural Nets

(B2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Understanding Programming Language C++
		Finite difference, finite volume, finite element discretization, grid generation, artificial neural network
		Parallel Programming, Message Passing Interface and MPI communications
		Scientific Visualization methods
Fluid Power Technology	EN709	Basic principles of Hydraulics and pneumatics
		Properties of hydraulic fluids and pneumatic air
		Roto-dynamic pumps, pressure and flow control
		Approaches in Hydraulic Circuit Design
Material Science in Nuclear Engineering	EN712	Overview of Nuclear Materials & their classifications
		Structure and properties of nuclear materials
		Processing of Nuclear Materials

		Material characterization techniques
Membrane Technology	EN714	Overview of Novel Membranes
		Preparation and Characterization
		Membrane Technologies
		Applications of Membrane Technology

(B3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering

(C) METALLURGY

(C1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Corrosion	EN615

2	Extractive Metallurgy	EN620
3	Mechanical Metallurgy	EN623
4	Nuclear Materials	EN628
5	Nuclear Metallurgy	EN629
6	Physical Metallurgy	EN630
7	Process Control & Instrumentation	EN631

(C2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Digital Signal Processing & Image Processing	EN706
3	Image processing and Machine Vision	EN710
4	Materials Characterization	EN713
5	Multi scale Material Modeling	EN715
6	Nuclear Chemical Engineering	EN628
7	Nuclear Emergencies	EN716
8	Welding Science & Technology	EN723

(C3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(C1) Core Engineering

Name of the Course	Course code	Course Outcome
Corrosion	EN615	Understanding electrochemical theory of corrosion & corrosion basics
		General principles of corrosion control
		Forms of corrosion and its mitigation
		Corrosion problems in nuclear industry and its mitigation
Extractive Metallurgy	EN620	Thermodynamics and kinetics of metal extraction
		Advanced material processing techniques
		Process metallurgy of rare metals, special materials and alloys
		Process metallurgy of U, Th, Pu, Be, Zr, Hf, Nb, Ta & rare earths
Mechanical Metallurgy	EN623	Exposure to stress tensor, state of stress, principal stress, hydrostatic, deviatoric stress
		Dislocations and deformation behaviour
		Creep & creep law, deformation mechanism map
		Fracture mechanics and fatigue of metals
Nuclear Materials	EN628	Vacuum melting & solidification, controlling casting defects of U, Zr and Ti alloys
		Cold & hot working, dynamic recovery, recrystallization of fuel tube, texture microstructure control
		Powder metallurgy of oxide, mixed oxide, carbide, intermetallic nuclear fuel material
		Applications of powder metallurgy in applications relevant to DAE
Nuclear Metallurgy	EN629	Fabrication of different types of fuel for research and power reactors

		Health physics, radioactivity and safety aspects of Pu handling
		Effects of irradiation on nuclear fuel and structural materials, hydriding related problems in Zr alloys
		Post irradiation examination (PIE) of nuclear fuel and structural material
Physical Metallurgy	EN630	Understanding basics of crystallography, crystal defects during irradiation
		Thermodynamics, phase equilibria & phase transformation
		Diffusion mechanism, equations & solutions
		Recovery, Recrystalization and Grain Growth
Process Control & Instrumentation	EN631	Understanding basic principles of measurement
		Sensors, transducers & transmission methods for pressure, vacuum, flow, level
		Principles of Automatic Control Systems
		Fail safe principles, simple logic circuits, ladder circuits for control action

(C2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Exposure to programming languages: C and C++
		Application of finite difference, finite volume, finite element techniques, ANN etc. in DAE
		Introduction to parallel programming concepts
		Data storage & visualisation techniques and case studies
Digital Signal Processing & Image Processing	EN706	Introduction to digital signal processing system & applications
		Discrete Fourier transform, fast Fourier transform

		Image processing, image enhancement, image segmentation & analysis, morphological operations
Image processing and Machine Vision	EN710	Introduction to digital image model representation, image sensor, digitizer, computer, standard file format
		Image enhancement segmentation and analysis, restoration
		Morphological operations and image compression
		Machine vision & introduction to image understanding
Materials Characterization	EN713	Introduction to microscopy techniques: optical, SEM, TEM, AFM, STEM, EBSD, FIM
		XRD and applications, basics of SIMS, RBS
		Analytical TEM, chemical analysis in materials science
		Thermal expansion and conductivity, TGA/DTA/DSC, mechanical properties
Multi scale Material Modeling	EN715	Introduction to types of models and multiscale approaches
		Atomistic models – molecular dynamics
		Basics of Monte Carlo methods
		Analysis of simulation results, bridging scale gap between different simulation levels
Nuclear Chemical Engineering	EN628	Recovery & processing of U, Th, Zr, rare earths from from ores / intermediates
		Uranium Conversion/reconversion
		Isotope Separation
		Nuclear Waste Management
Nuclear Emergencies	EN716	Introduction to nuclear fuel cycle, transportation of radioactive material
		Radiological accidents / emergencies
		Effects of nuclear detonation, testing nuclear weapons
		Emergency Response methodology/ Philosophy

Welding Science & Technology	EN723	Overview of various welding processes - arc welding, beam welding, hybrid welding
		Cold Bonding/Solid State Bonding
		Welding metallurgy under high cooling rates
		Types of welding defects and its prevention

(C3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I & VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
Mini Project	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		To acqure skills in formulating and executing a research problem and communicating the results in writing and orally.

(D) CIVIL ENGINEERING

(D1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1

2	Civil Engg Design of Concrete & Steel Strct II	EN608.2
3	Design Basis Hazards & Geotechnical Engg	EN621
4	Earthquake Engineeing & Structural Dyanmics	EN609
5	Finite Element Method	EN626
6	Mechanics of Solids	EN624

(D2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Struct Dynamics & Earthquake Engg	EN724
2	Construction Materials, Management & Quality	EN614
3	Safety & Reliability of Civil Engineering	EN722
4	Project Management	EN717

(D3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(D1) Core Engineering

Name of the Course	Course code	Course Outcome
Civil Engg Design of Concrete & Steel Strct I	EN608.1	Various structures of nuclear facilities; safety, seismic, design and quality classifications of structures
		Design loads on structures and load combinations as per BIS, ACI and AERB standards
		Design of RC structures; fracture mechanics concept in RC design

		Shallow and deep foundation design; machine foundation design
Civil Engg Design of Concrete & Steel Strct II	EN608.2	Design of prestressed concrete structures
		Design of lined and unlined reactor containment structures using RCC-G/BPEL/BAEL and ASME codes
		Design of steel structures using BIS, AERB and AISC standards
		Design of underground and overhead water retaining structures; design of natural draft cooling tower
Design Basis Hazards & Geotechnical Engg	EN621	Siting of nuclear facilities; hazards due to internal and external events; design basis natural hazards, such as, seismic, flood, wind, snow and solar radiations
		Human-induced design basis hazards, such as, aircraft/missile impact, explosions/blast, and toxic gas release
		Soils and its classifications; laboratory and field tests on soils and rock; compaction of soils; bearing capacity of soils and rocks
		Stages of geotechnical investigations; soil and rock sampling; geophysical investigations; seismic refraction survey, cross-hole seismic test; ERT; liquefaction potential of sites
Earthquake Engineeing & Structural Dyanmics	EN609	Seismic waves and wave propagation; time history; response spectra; seismic instrumentation
		Dynamic loadings; dynamic response of SDOF and MDOF systems; dynamics of continuum system
		Response spectra and time history approaches for determining seismic structural

		response; SSI and FSI; structural response in frequency domain
		Seismic requalification of existing installations; retrofitting techniques
Finite Element Method	EN626	Basis of FEM; energy principles; shape function requirements; C0 and C1 continuity
		Derivation of stiffness matrix and load vector for bar, beam, 2D plane and 2D iso-parametric elements; evaluation of strain and stress
		Incompatible quadrilateral elements; Tetrahedron, and hexahedron elements; plate bending elements; shell elements; patch test; adoptive meshing; error analysis
		Non-linear problems; material and geometric non-linearity
Mechanics of Solids	EN624	Concepts of elasticity; Equilibrium equations; Solution of 1-D boundary value problem; tensors algebra
		Analysis of stress and strain; transformation using direction cosines; principal planes; octahedral plane; state of pure shear; strain deviator tensor
		Strain displacement relationship; Isotropy and Anisotropy; Strain energy; Plane stress and plane strain problems; solution for beam bending problem; solution in polar co-ordinates; thermal stresses
		Analysis of thin and thick plates; shear deformation theories; membrane theory of shells of revolution and translation; bending analysis of shells; application to cylindrical, spherical and conical shells; introduction to plasticity

(D2) Electives

Name of the Course	Course code	Course Outcome
Advanced Struct Dynamics & Earthquake Engg	EN724	Concept of performance based seismic design; seismic demand; capacity of structures; performance levels
		Concept of seismic and vibration control; passive control; semi-active control; active control; base isolation techniques
		Methods of testing; qualification of system by testing; seismic instrumentation; measurement of displacement, velocity, acceleration
		Fluid-structure interaction techniques; multibody dynamics
Construction Materials, Management & Quality	EN614	Construction materials, such as, concrete, reinforcement, structural steel, paints, water-proofing materials
		Design of formworks; slip forms; prestressing systems
		QA in civil design, materials, construction, O&M, and regulatory inspection
		Dewatering; rock excavation, construction safety and JHA; mode of tendering; contract clauses; dispute adjudication
Safety & Reliability of Civil Engineering	EN722	Statistics and probability; discrete and continuous random variables; probability distributions
		Concept of structural safety; limit states; MVFOSM; Hasofer Lind reliability index; Cornell reliability index; Monte Carlo simulation
		Probabilistic safety assessment; seismic fragility analysis; seismic risk; health assessment of existing concrete and steel structures; rehabilitation and retrofitting

		techniques; service life prediction
		Concept of industrial safety; fire hazard analysis; safety in handling machinery, equipment and tools; fitness and protection of personnel
Project Management	EN717	Type, cost and schedule of nuclear power projects; resources of project; project organization chart; delegation of power
		Scheduling in a project by PERT, CPM, precedence diagram method; project management software for planning, scheduling and monitoring
		Preparation of target plan, updating of progress, monitoring variance and reporting; physical and financial monitoring; capital budgeting and expenditure control
		Contingency plan; construction management; project management; SWOT analysis; problem solving techniques

(D3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
Mini Project	EN5A93	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg.

(E) ELECTRICAL ENGINEERING

(E1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design I	EN602
2	Computer Based System Design I	EN612
3	Electrical Systems for Nuclear Power Plants	EN618
4	Modern Control Systems Design and Simulation	EN625
5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(E2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design II	EN702
2	Artificial Intelligence and its Applications	EN703
3	Computer Based System Design II	EN704
4	Digital Signal Processing & Image Processing	EN706
5	Image Processing & Machine Vision	EN710
6	Signal Conditioning, Recovery and EMI Aspects	EN719
7	Software Engineering	EN720

(E3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(E1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design I	EN602	Materials and Electrical Properties, NDT, MFL
		Superconducting Properties
		Understanding Control Techniques of Electrical Motors and Electronics
		FEM and Applications
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Electrical Systems for Nuclear Power Plants	EN618	Recapitulation of Power System Design Analysis
		Basics of Switchyard Design Principles
		Understanding Protection Systems
		Exposure to Electrical Systems in NPP
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity

		Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(E2) Electives

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design II	EN702	Understanding Vector Control of PM Synchronous Motors
		Exposure to Design and Applications of Variable Reluctance Stepper Motors and Switched Reluctance
		Understanding Pulse Power Techniques
		High Voltage Systems
Artificial Intelligence and its Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies

		Understanding Reinforcement Learning and Dynamic Programming
Computer Based System Design II	EN704	Exposure to Data Communication Interfaces for Control Applications, Fieldbuses
		Understanding Real Time System Design Principles
		Understanding IPC mechanisms in RTOS
		Exposure to Safety System Design Regulations
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics

		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(E3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(F) ELECTRONICS ENGINEERING

(F1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electronic Circuit Design Techniques	EN603
2	Advanced Nuclear Instrumentation	EN605
3	Embedded & Computer Based Sys. Design	EN619
4	Modern Control Systems Design and Simulation	EN625

5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(F2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Digital Signal Processing & Image Processing	EN706
3	Embedded Electronics Software	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720
7	Artificial Intelligence & Applications	EN703

(F3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(F1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electronic Circuit Design Techniques	EN603	Introduction to VLSI Design Flow, HDL, Design and Simulation of HPD
		Understanding Semiconductor Detectors , MEMS Desin
		Introduction to RF Electronics

		Understanding Transmission Lines, Waveguides, RF Amplifiers,
Advanced Nuclear Instrumentation	EN605	Understanding Electronics in Spectroscope Design
		Nuclear Instruments, Alpha, Beta and Gamma Detectors, Scintillation Counters
		Introduction to Accelerator Instrumentation
		Understanding Reactor Neutronic Instruments and Signal Processing
Embedded & Computer Based Sys. Design	EN619	Overview of Microprocessors and Interfacing
		Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements
		Exposure to Computer Communication, Encoding and Technologies
		Understanding Software Developments for NPP/Accelerator C&I
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters

		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(F2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models

		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

(F3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(G)INSTRUMENTATION ENGINEERING

(G1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Applied Process Instrumentation	EN607
2	Computer Based System Design I	EN612
3	Modern Control Systems Design and Simulation	EN625
4	Reactor C&I and Human Machine Interface	EN636
5	Reactor Control Engineering and Instrumentation	EN637-8
6	Reliability Engineering	EN639

(G2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Computer Based System Design II	EN706
3	Digital Signal Processing & Image Processing	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720

(G3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(G1) Core Engineering

Name of the Course	Course code	Course Outcome
Applied Process Instrumentation	EN607	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation
		Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and

		Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Reactor C&I and Human Machine Interface	EN636	Overview of Reactor C&I & Power Supply Requirements for Instrumentation
		Understanding Control Room Design and Exposure to Codes & Guides
		Exposure to Relay & Control Logic Design, Critera for Relay, PLC & DCS Technologies
		C&I Cable Requirements
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(G2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

Computer Based System Design II	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Digital Signal Processing & Image Processing	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(G3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(H)COMPUTER SCIENCE AND ENGINEERING

(H1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Operating Systems	EN606
2	Computer Graphics & Visualisation	EN613
3	Distributed Computing	EN616
4	Networking & Information Security	EN627
5	Reactor Control Engineering	EN637
6	Software Engineering and Formal Methods	EN640

(H2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Data Base Management System & Web Technology	EN705
3	Digital Signal Processing & Image Processing	EN706
4	Embedded Electronics Software	EN707
5	Feedback Control System	EN708
6	Image Processing & Machine Vision	EN710

(H3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(H1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Operating Systems	EN606	Understanding IPC Calls
		Shell Programming
		Understanding Distributed File Systems
		Applications of System Calls
Computer Graphics & Visualisation	EN613	Understanding Geometric Transformations
		Applications of Geometric Projections
		Techniques for Hidden Surface Removals
		Applications of Scientific Visualisation
Distributed Computing	EN616	Understanding modern CPU Architectures
		Understanding Interconnect Techniques
		Understanding and Applications of HPC

		Understanding Grid Computing and Workflows
Networking & Information Security	EN627	Understanding Issues in the transport of data and Techniques
		Satellite Communications
		Understanding Network Security Concepts
		Advances in Cryptography and Cryptanalysis
Reactor Control Engineering	EN637	Understanding Physics behind Rector Control
		Understanding Point Kinetics Model and Reactor Periods
		Understanding Issues with Large Reactor Control and Modelling
		Understanding Control Requirements for PWR, PHWR, BWR and FBR
Software Engineering and Formal Methods	EN640	Understanding Techniques for modelling software
		Application of Model Checking and Theorem Proving
		Understanding Agile Programming
		Understanding Software Testing

(H2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Data Base Management System & Web Technology	EN705	Understanding SQL and Complex queries
		Understanding Clusters and Distributed Databases
		Understanding and Working with Web Technologies
		Modelling data and design of real data bases

Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Feedback Control System	EN708	State Space Representation and Applications
		Time Domain Analysis
		Appreciating need for Stability Analysis & Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications

(H3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life

<table>
<tr><td>Practicals</td><td>EN592</td><td>Enhancing skills and reporting</td></tr>
<tr><td rowspan="2">Mini Project</td><td rowspan="2">EN593</td><td>Enhancing Skill Set for handling real life problems</td></tr>
<tr><td>To acquire skills in formulating and executing a research problem and communicating the results in writing and orally.</td></tr>
</table>

M.Tech. in GEOLOGY & GEOPHYSICS (Program Code: ENGG01)

CORE COURSE:

I. Courses at BARC - AMD:

Program Code: ENGG01	Program Specific Outcome	
		Thorough knowledge on geological aspects of exploration for uranium and other atomic minerals.
		Inter-disciplinary approach and application of geophysical, geochemical and radiometric methods in exploration.
		Field and laboratory data generation techniques, geological modeling and resource estimation
		Giving research orientation to the young minds, training in formulation and implementation of research projects.

COMMON COURSES:

Sr. No.	Name of the Course	Course Code
1	Nuclear Physics	102
2	Remote Sensing and GIS	110
3	Airborne Geophysics	209
4	Nuclear Reactor and Fuel Cycle	212

Course Outcome:

Name of the Course	Course Code	Course Outcome
Nuclear Physics	102	The course introduces nucleus, it's properties, natural radioactivity, decay, equilibrium, natural decay series, fission and fusion
		Learning principles and types of radiation detectors, and their characteristics
		Familiarization of gamma ray spectrometry, gamma ray logging and sample analysis techniques used in exploration, Instrumental Neutron Activation Analysis.

		The course also introduces radon emanometry, methods for measurement of Radon
Remote Sensing and GIS	110	The course introduces concepts of Remote Sensing, mineral and rock spectra and use in geological studies, available sensors, and types of resolutions
		Learning fundamentals of image interpretation, digital image processing, enhancement techniques, image classification for geological interpretation.
		Introduction to GIS, spatial and attribute data, coordinates and map projections.
		The course also teaches GIS analysis, data integration and modeling techniques in mineral exploration using various software.
Airborne Geophysics	209	The course introduces airborne survey design and survey parameters, type of geophysical surveys carried out.
		Students are acquainted with airborne survey instruments, navigation aids and procedures in data acquisition.
		Learning processing and presentation of airborne data, identification of anomalous zones and conductors.
		The course also teaches QA & QC and validation of data sets, geological interpretation, depth estimates, delineation of alteration zones, forward and inverse modeling, and procedures for obtaining licenses for flying,
Nuclear Reactor and Fuel Cycle	212	Understanding nuclear energy, Indian scenario, fission and fusion
		Reactor systems, types of nuclear reactors, moderator and coolant, control systems, behaviour and safety systems.
		Nuclear fuel cycle options for various types of reactors, mining, processing, manufacturing, usage and burning of fuel, quality control, storage and transportation, enrichment, reprocessing and management of waste.
		Environment, legislation and controls, EIA requirements.

SUBJECTS FOR GEOLOGY:

Sr. No.	Name of the Course	Course Code
1	Mathematics for Geologists	101
2	Geophysics for Geologists	103
3	Uranium Geology	105
4	Drilling and Mining Techniques	106
5	Geochemical Exploration	108
6	Exploration for Beach Sand and RM&RE	202
7	Petrographic Techniques	206
8	Mineral Process Engineering	208
9	Analytical Techniques	210
10	Ore Reserve Estimation (Covered as part of 9 weeks field training in the months of December, January and February)	204

Course Outcome:

Name of the Course	Course Code	Course Outcome
Mathematics for Geologists	101	To introduce the students on concepts of Geostatistics and basic Mathematical techniques.
		Apply principles of Geostatistics and mathematical methods for analysis and predictions in Geoscience research and Geomodelling.
		Development of skill set necessary for solving complex problems in the field of Geoscience.
		Expose the young students to state-of-the art modelling techniques applicable to the Uranium exploration programme and build a strong foundation.
Geophysics for Geologists	103	The course introduces geophysical methods, their role in mineral exploration and geophysical signatures of uranium deposits.
		Learning gravity and magnetic fields, it's variation across the earth, instruments, data collection, processing and application.
		Understanding various electrical and electro-magnetic methods, electrical properties of rocks, instrumentation, data collection, processing and interpretation.
		The course also introduces seismic methods and borehole logging methods in exploration.
Uranium Geology	105	The course imparts knowledge on distribution of uranium in crust, rocks and minerals, time bound character and classification of uranium deposits.
		The course also deals with geological aspects of various types of uranium deposits, world and Indian deposits, controls of mineralization, exploratory guides.
		Students also learn stages of uranium exploration,

		survey methodologies, sampling techniques, drilling, borehole logging techniques
		Training on interpretation of exploratory data, correlation of mineralized intercepts, estimation of resources, recent trends in exploration, status of uranium supply and demand
Drilling and Mining Techniques	106	Understanding types and techniques of drilling used in atomic mineral exploration
		Learning about rock drilling, diamond drilling, controlled directional drilling, types of drilling used in the department.
		The course also introduces mining, mining terminologies, types of mining.
		Students learn techniques in open cast and underground mining, blasting, economic feasibility, milling and waste disposal.
Geochemical Exploration	108	The course introduces geochemistry as branch of geology, elements - primary geochemical differentiation, classification and associations, major, minor, trace, REE and uranium geochemistry.
		Students learn geochemical thermodynamics, standard states, non-ideal solutions and phase diagrams.
		Hydro-geochemical concepts, pH and Eh, physico-chemical environment of ore genesis under various geological environments.
		Types of geochemical surveys for mineral exploration, primary and secondary dispersions, geochemical maps, processing and interpretation of geochemical data.
Exploration for Beach Sand and RM&RE	202	Introduces placer minerals and environments, processes controlling formation of placer minerals, transportation and deposition.
		Learning exploration of beach sands, sampling, analysis, methods of estimation and classification of resources, mining methods and processing, world resource scenario.
		The course also introduces Rare Metal and Rare Earth minerals, their geochemistry, mineralogy. Geology of Rare Metal bearing granites, pegmatites, carbonatites.
		Study of exploration techniques, geochemical methods, sampling, resource estimation and recovery.
Petrographic Techniques	206	Study of minerals and rocks under transmitted and reflected light, polarising microscope, thin sections and polished sections.
		Learn petromineralogical techniques, optical properties of minerals, microindentation hardness, radioactive, rare earth element and rare metal bearing minerals, mineralogical expression of radioactivity, EPMA analysis.
		Study of petrography, paragenesis, learning modal analysis and norm calculation.

		Presentation and preservation of data and assessment
Mineral Process Engineering	208	The course introduces basic principles of mineral processing unit operations and hydrometallurgy with special emphasis on atomic minerals
		The curriculum familiarizes with flowsheet development for low grade uranium ores of Indian origin and beneficiation of beach sand minerals.
Analytical Techniques	210	The course introduces principles and instruments of analytical methods used in atomic mineral exploration.
		X-ray diffraction technique for identification of minerals and cell parameters, WD & EDXRF, ICP, AAS, flourimetry and other chemical methods for analysis of geological materials
		Concepts and use of radiometric dating methods, stable isotope studies for understanding geological processes.
Ore Reserve Estimation (Covered as part of field training)	204	Resource database generation, geological model, density factor, sampling issues, validation of data.
		Ore body configuration, traditional and geostatistical methods of resource estimation
		Resource categories, feasibility studies, environmental issues

SUBJECTS FOR GEOPHYSICS:

Sr. No.	Name of the Course	Course Code
1	Geology for Geophysicists	104
2	Theory of Fields	107
3	Seismic Methods	109
4	Computational Geophysics	201
5	Signal Processing & Inversion Techniques	203
6	Gravity and Magnetic Methods	205
7	Electrical & Electromagnetic Methods	207
8	Well logging Techniques	211

Course Outcome:

Name of the Course	Course Code	Course Outcome
Geology for Geophysicists	104	The course introduces structure and composition of the earth, surface and internal processes, rock structures, stratigraphy principles and elements of Indian stratigraphy.
		Gives brief introduction to rock forming and ore minerals, common igneous, sedimentary and metamorphic rocks, structures and textures.
		Learn dynamic earth, continental drift, plate tectonics and associated mineral deposits.
		The course also introduces ore forming processes and

		mode of occurrence of common ore deposits.
Theory of Fields	107	The Course introduces the basic concepts of the mathematics and physics of Potential Field theory.
		The topics covered in this course are gravitational, magnetic, electrical & electromagnetic fields of the earth and their derivations from potential functions with applications.
		The course also discusses about theorems of Laplace, Poisson's, Gauss and Green and their applications to geophysics. Computations of numerical problems
Seismic Methods	109	Familiarization of the basic concepts and principles of seismic prospecting. Reflection, refraction and diffraction from multilayered media, Seismic wave propagation, Factors affecting seismic wave velocities discussed.
		Energy sources, geophone, hydrophone, noise profile analysis and Source -detector arrays. Seismic reflection & refraction methods, geometry of waves and interaction with two layer and multilayer media. Field layouts, Static corrections, NMO, Migration, Common Depth Point techniques. Vertical seismic profiling; 3D and 4D seismic exploration, Seismic tomography
		Processing and interpretation of seismic refraction and reflection data. Determination of velocities and depths to the layers.
Computational Geophysics	201	The course provides an introduction to different numerical methods applied to geophysical problems. Partial differential equations in geophysics .The course offer hands-on experience in numerically solving partial differential equations, statistical data and variance Analysis in geophysics.
		The finite-difference (FDM) & finite-element methods (FEM) applied to basic geophysical problems. Explicit and Implicit finite difference methods, Error and stability analysis. Fundamentals of FEM, interpolation functions, method of weighted residuals, Laplace and Poisson equation, Numerical integration
Signal Processing & Inversion Techniques	203	Application of advance signal processing techniques in geophysics. Various integral transforms – Fourier, Hilberet, Hankel, Walsh, Laplace and Z transforms. Digital filtering, sampling and designing filters.
		Application of inversion techniques in geophysical data processing. Fundamental concepts of Inversion with discrete and continuous models. Optimization techniques and algorithms, generalized and constrained inversion. Singular value decomposition, Backus-Gilbert Inverse problem
Gravity and Magnetic Methods	205	The course discusses in detail the theoretical concepts of Earth's gravitational field and geomagnetic field. Theory and principles of Gravimeter and magnetometers.
		Data acquisition and corrections applied to gravity and magnetic data are explained in detail with data. Processing of data and application of time domain and frequency domain filters and various data enhancement techniques.

		Computation of gravity and magnetic anomalies due to regular shaped bodies. Spectral analysis of potential field data. Modeling and inversion of gravity and magnetic data.
Electrical & Electromagnetic Methods	207	Electrical properties of rocks and minerals. Electrical conduction in rocks and earth materials. Familiarization of the concepts of electrical and electromagnetic prospecting. Classification of Electrical and Electromagnetic methods
		Resistivity and Induced Polarization techniques – Theory, Practice and applications with case studies. Electromagnetic methods – Frequency domain, Time Domain and Natural Source EM methods – Equipment, field procedures
		Interpretation techniques of Electrical and Electromagnetic data – Vertical Electrical Sounding, Pseudo-sections, VLF, HLEM, TURAM and TEM sounding data.
Well logging Techniques	211	Learning the basic concepts, characteristics of borehole conditions, reservoir properties, principles and instrumentation of well logging techniques.
		The course introduces the different types of electrical, nuclear, sonic, EM and other logging techniques and their application in mineral exploration. Operational survey procedures and interpretation of various logs.
		Identification of sub - surface formations based on interpretation. Computation of various parameters from the log data.

BARC TS NFC Hyderabad Course Outcome

Chemical Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Computational Fluid Dynamics and Heat Transfer	CEM1 E21 CM40	Understanding Kinematics of fluid flow and governing equations Classification of Partial Differential Equations & their discretization Convective heat transfer for internal and external flows. Numerical Solution of fluid flow and heat transfer equations.
2	Basic Process Instrumentation and Control	CEM2 CC03 M20	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides.
3	Process Dynamics, Analysis and Control	CEM3 E31 E29:50	Introduction to process control & control loop dynamics Fundamentals of state-space controls, state, measurement equations General solution of the state equation Multi-variable controls, de-coupling, relative gain array.
4	Advanced Mass Transfer, Equipment Design and Solvent Extraction and Equipment design	CEM4 E32 AC03:C45	Understanding Mass transfer with and without chemical reactions Rate based approaches for design Selection and design of various contacting equipment Process intensification approaches.
5	Process Modeling, Simulation and Optimization	CEM5 E 33 C20	Formulation of Dynamic and steady state models Flow sheet Analysis & Plant Simulation General Approaches for Non-Linear Systems. Plant optimization by Genetic Algorithms and Neural Nets.
6	Advanced Chemical Reaction Engineering	CEM6 E30 C25	Fundamentals of Non-ideal reactors & RTD studies Understanding Non-isothermal effects & dynamical behavior. Overview of Heterogeneous reactions Approaches in Advanced reaction engineering & reactor design.

Core Electives Module:

Sl. No.	Name of the Course	Course Code	Course Outcome
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Electrical Engineering Practices in Process Industries	C Elect 2 FC 09 E 20	Exposure on Fundamentals of Electricity, power supplies, electrical machines, circuit breakers and safety aspects need to know working in Industries.
3	Energy Conservation and Demand Side Management	C Elect 3 AC 07 CMI 20	Understanding about Energy scenario, Energy conservation techniques and analysis by Thermodynamics need to optimize the energy consumption in Industries.
4	*Vacuum Technology	C Elect 4.1 M 13 NEW- C 20	Understanding of vacuum physics, its measurement, operation and leak detection and applications.
5	*Statistics for Engineers	C Elect 4.2 NEW- M C 20	Learning about treatment of data, probabilities, random sampling & distribution, testing and control charts.
6	*Corrosion Engineering	C Elect 4.3 EN-615	Understanding electrochemical theory of corrosion& corrosion basics. General principles of corrosion control. Forms of corrosion and its mitigation. Corrosion problems in nuclear industry and its mitigation.

* Optional Subjects (one out of three subjects to be selected)

Practicals /Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

BARC TS NFC Hyderabad Course Outcome
Electrical Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Applied Process Instrumentation and Control	CEM 1 E 50 CEEI-45	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides Instrumentation field buses, sensor technology, introduction to Neural network and Fuzzy logic.
2	Programmable Logic Controllers and Applications	CEM 2 EEI-40	Learning about Programmable controller industrial digital computer which has been adopted for the control of manufacturing processes such as assembly lines or robotic devices or any activity that requires high reliability, ease of programming and process fault diagnosis.
3	Electrical Engineering Practices-I	CEM 3 AC13 E-30	Detailed exposure of Electrical Equipment and selection, Installation and maintenance of equipment in Hazardous areas and electrical protection.
4	Electrical Engineering Practices-II	CEM 4 EEP II E-20	Exposure on Advances in Electrical equipment such as various types of drives, furnaces and Electric welding.
5	Networking Communications	CEM 5 E 61 ETRN-I-20	Understanding Issues in the transport of data and Techniques Satellite Communications Understanding Network Security Concepts Advances in Cryptography and Cryptanalysis.
6	Modern Electronic Control of AC and DC Drives	CEM 6 JNTU-30	Detailed learning about Phase controlled, current and speed, chopper controlled DC motor drives, closed loop operation of DC motor drives, AC drives, it's controlling mechanism.

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Out come
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Energy Conservation and Demand Side Management	C Elect 2 AC07 CMI-20	Understanding about Energy scenario, Energy conservation techniques and analysis by Thermodynamics , need to optimize the energy consumption in Industries or making
3	Industrial Instrumentation practices and Human Machine Interface	C Elect 3 E51 E50 I-30	Exposure on Reactor C&I& Power Supply Requirements for Instrumentation Understanding Control Room Design and Exposure to Codes & Guides Exposure to Relay & Control Logic Design, Criteria for Relay, PLC & DCS Technologies C&I Cable Requirements
4	*Mechatronics	C Elect 4.1 AC14 EEMI:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering & mechanization, automation and about Industrial robotics.
5	*Robotics	C Elect 4.2 M14 EC:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering, automation, trajectory planning and about Industrial robotics.

* Optional Subjects (one out of two subjects to be selected)

Practicals / Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.
4	PLC Demonstration and working principles	Clear understanding of logical functions, controlling mechanisms and different type of communications through PLC demo unit.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Learning communication of research results orally and in writing.

BARC TS NFC Hyderabad Course Outcome
Electronics Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Applied Process Instrumentation and Control	CEM 1 E 50 CEEI-45	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides Instrumentation field buses, sensor technology, introduction to Neural network and Fuzzy logic.
2	Programmable Logic Controllers and Applications	CEM 2 EEI-40	Learning about Programmable controller industrial digital computer which has been adopted for the control of manufacturing processes such as assembly lines or robotic devices or any activity that requires high reliability, ease of programming and process fault diagnosis.
3	Embedded and computer based system design	CEM 3 E54 Electrn-40	Exposure on overview of Microprocessors and Interfacing Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements Exposure to Computer Communication, Encoding and Technologies Understanding Software Developments for NPP/Accelerator C&I
4	Digital signal, Image processing &Machine vision	CEM 4 New	Learning about digital signal processing system& applications. Discrete Fourier transform, fast Fourier transform. Image processing, image enhancement, image segmentation & analysis, morphological operations.
5	Networking Communications	CEM 5 E 61 ETRN-I-20	Understanding Issues in the transport of data and Techniques Satellite Communications Understanding Network Security Concepts Advances in Cryptography and Cryptanalysis.
6	Modern Electronic Control of AC and DC Drives	CEM 6 JNTU-30	Detailed learning about Phase controlled, current and speed, chopper controlled DC motor drives, closed loop operation of DC motor drives, AC drives, it's controlling mechanism.

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Out come
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Modern control systems	C Elect 2 E52A EC-20	Understanding State Space Techniques, Controllability, Observability, Kalman Criterion and Stability Analysis, Lyapunov Criterion Principles of State Observer, LQR, Ricati Equation
3	Industrial Instrumentation practices and Human Machine Interface	C Elect 3 E51 E50 I-30	Exposure on Reactor C&I& Power Supply Requirements for Instrumentation. Understanding Control Room Design and Exposure to Codes & Guides Exposure to Relay & Control Logic Design, Criteria for Relay, PLC & DCS Technologies C&I Cable Requirements
4	*Mechatronics	C Elect 4.1 AC14 EEMI:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering & mechanization, automation and about Industrial robotics.
5	*Robotics	C Elect 4.2 M14 EC:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering, automation, trajectory planning and about Industrial robotics.

* Optional Subjects (one out of two subjects to be selected)

Practicals / Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.
4	PLC Demonstration and working principles	Clear understanding of logical functions, controlling mechanisms and different type of communications through PLC demo unit.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Learning communication of research results orally and in writing.

BARC TS NFC Hyderabad Course Outcome
Mechanical Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Computational Fluid Dynamics and Heat Transfer	CEM1 E21 CM40	Understanding Kinematics of fluid flow and governing equations Classification of Partial Differential Equations & their discretization Convective heat transfer for internal and external flows. Numerical Solution of fluid flow and heat transfer equations.
2	Basic Process Instrumentation and Control	CEM2 CC03 M20	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides.
3	Pressure Vessel and Piping Design	CEM 3 E20 CC08 M-30	Understanding the Basis of ASME Sec. VIII and Sec. III eqns. For Pressure Vessel and Piping Design Nozzle openings, Vessel design under ext. pressure ANSI/ASMEB31.1and B31.3 piping code NDE Examination of welds, Acceptance standard
4	Engineering Design and Finite Element Methods	CEM 4 AC09	Detailed exposure on Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element. 2Disoparametric formulation. Introduction to Nonlinear problems Finite element applications for design
5	Computer Aided Design and Manufacturing	CEM 5 M-35	Exposure on Microprocessors & Interfacing Techniques Interconnect Buses and Industrial Systems Introduction to HDL and FPGA based System Design Understanding Fault Tolerant Architectures and TMR.
6	Vibrations	CEM 6 E26 M:20	Learning about Single and Multi-degree-of-freedom Systems, Free vibration. Response of Systems To Ground Motion: Earth quake motion. Flow Induced Vibration Vibration Measurement and Signal Analysis

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Outcome
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Mechatronics	C Elect 2 AC14 EEMI:20	Exposure under mechatronics regarding pneumatic control engineering, Hydraulic control engineering, Electrical & Electronics engineering & mechanization, automation and about Industrial robotics.
3	Welding and Quality Assurance of Welds	C Elect 3 CC06 M-20	Exposure of various welding processes – Arc welding, Beam welding, hybrid welding Cold bonding/Solid state bonding Welding metallurgy under high cooling rates Types of welding defects and its prevention
4	*Vacuum Technology	C Elect 4.1 M-13 C-20	Understanding of vacuum physics, its measurement, operation and leak detection and applications.
5	*Manufacturing and Industrial Engineering	C Elect 4.2 JNTU M-20	To understand about optimization of complex processes, systems, organizations by developing, improving and implementing integrated systems of people, money, knowledge, information, equipment, energy and materials.
6	*Design of High Temperature Components	C Elect 4.3 Mech-20	Learning about different material properties, life time, corrosion studies, material stability at high temperatures. For the applications in reactors& industries.
7	*Statistics for Engineers	C Elect 4.4 C:20	Learning about treatment of data, probabilities, random sampling & distribution, testing and control charts.

* Optional subjects (one out of four subjects to be selected)

Practicals /Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.
4	Structural Dynamics and Vibration	Practical experience on harmonic & non-harmonic base motions, dynamics of vibrations, seismic wave amplification etc.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee.

BARC TS NFC Hyderabad Course Outcome
Quality Assurance Engineering

Nuclear Engineering Module

Sl. No.	Subject Name	Course Code	Course Outcome
1	Engineering Mathematics	NE1 E02	Advanced knowledge in computational data analysis, data fitting and error analysis. Analytic and Theoretical calculation and its practical implementation. Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering.
2	Nuclear and Reactor Physics	NE2 E07	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with Nuclear reactors.
3	Reactor Engineering and Radiation Shielding	NE3 E13	Good understanding of Thermal, Fast Breeder and advanced reactor Engineering concepts Learning the interaction of ionizing radiation with variety of materials like metals, non-metals, glass & plastic, all needed for working with Nuclear reactors.
4	Health Physics, Chemical Plant Safety and Environmental Engineering	NE4 FC02 E06 CC09	Learning the interaction of ionizing radiation with matter, Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation. Principles of radiation detection and Radiation Protection procedures. Learn about Hazardous properties of chemicals, safely handling of Hazardous chemicals, All needed for working in Radiation environment, various Hazardous areas.
5	Nuclear Power Plant Engineering	NE5	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts. Familiarization with reactor physics design challenges Advanced reactor concepts with passive safety features.
6	Material Science in Nuclear Engineering	NE6	Overview of Nuclear materials & their classifications. Structure and properties of nuclear materials. Processing of nuclear materials. Material characterization techniques.
7	Nuclear Fuel Cycle and Water Chemistry I & II	NE7 FC07 FC08 CMEI-50	Familiarisation with front and back end of nuclear fuel cycle technology. Knowledge of radioactive waste generation on nuclear fuel burning and its processing. Knowledge of Isotope separation process and Heavy water production. Need to know working in HWP, BARC facilities etc.

Core Engineering Module

Sl. No.	Subject	Course code	Course Outcome
1	Statistical Quality Control for QA	CEM 1 QA-01	Learning about Measuring errors by using different theories and minimization. Quality control and analysis from raw material to the final product with the help of Standards and standard procedures.
2	NDT & QC of Nuclear Fuel and structural components	CEM 2 QA-02	Learning about various NDT tests and quality checks during fabrication of tubes, components, fuel and structurals.
3	Design of PHWR Fuel and Structurals	CEM 3 QA-03	A Clear understanding of fuels, various structural materials and design of the Reactor, needed to work in Reactors and quality check in Production industries.
4	Engineering Design and Finite Element Methods	CEM 4 AC09	Detailed exposure on Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element. 2Disoparametric formulation. Introduction to Nonlinear problems Finite element applications for design
5	Material Characterization and Applications	CEM 5 EN713	Understanding of microscopy techniques: optical, SEM, TEM, UT, ECT, RT, LPT, MPT, XRD and applications. Analytical TEM and Metrology.
6	Basic Process Instrumentation and Control	CEM 6 CC03 M-20	Detailed exposure to Flow, Pressure, Level, Temperature Understanding Analytical Instrumentation P/I & I/P Converters, Impulse Tubing Exposure to P&I Diagrams and Design Guides

Core Electives Module

Sl. No.	Name of the Course	Course Code	Course Outcome
1	Systems Management: A, B, C, D and E (Project, Maintenance, Operation & Quality management, Reliability Engineering)	C Elect 1 AC 06 AC 08 CC 10 CEEIM 50	Learning under system management project life cycle, project scheduling, resource planning, analysis; ISO system principles, auditing of QMS &EMS, planning, organizing & controlling; objectives of maintenance functions, component life time, process of failures, routine maintenance, productive maintenance, total quality maintenance; Understanding Reliability Principles and Applications to Nuclear Reactor Systems Overview of Statistical Methods Exposure to Fault Tolerance, Fault Avoidance Techniques.
2	Corrosion Engineering	C Elect 2 EN-615	Understanding electrochemical theory of corrosion& corrosion basics General principles of corrosion control Forms of corrosion and its mitigation Corrosion problems in nuclear industry and its mitigation
3	Image Processing and Machine vision	C Elect 3 EN-710	Understanding techniques for Image Processing and Morphological Operations Understanding Image Models for Machine Vision Scene Interpretation and recognition Understanding Robotic Applications
4	*Data Base Management System and Web Technology	C Elect 4.1 EN-705	Understanding SQL and Complex queries Understanding Clusters and Distributed Databases Understanding and Working with Web Technologies Modeling data and design of real data bases
5	*Advanced Computational Techniques	C Elect 4.2 EN-701	Learning about Programming Language C++, Parallel Programming, Scientific, Visualization and Artificial Neural Network.

* Optional subjects (one out of two subjects to be selected)

Practicals /Experiments

Sl. No	Subject	Course Outcome
1	Material Science in Nuclear Engineering and Corrosion Engineering	Better understanding about selection of material and their properties in Nuclear engineering.
2	Health Physics	Enhancing hands on practical experience on Radiation measurement & precautions on safe handling methods.
3	Process Control and Instrumentation	Practical experience on calibration of different type of process instruments, demonstration of field instruments and different type of process controls.

Non-Subject Assignments

Sl. No.	Name of the Course	Course Out come
1	Viva Voce –I,II &III	Assessment of grasp of the basic concepts in the courses covered. Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains.
2	Mini Project	To provide a hands-on experience of working in an ongoing project of the Department. Gaining experience in formulating and executing a scientific/technical problem. Learning communication of research results orally and in writing.

Course Structure:

IV. Courses at IGCAR

Program Code: ENGG01	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors	NR
2	Engineering Mathematics	EM
3	Materials and Metallurgy	MM
4	Fast Reactor Physics and Shielding	RP
5	Reactor Engineering	RE
6	Health Physics and Radiological Safety	HP
7	Project Management	PM

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Nuclear Reactors	NR	Exposure to mechanical aspects of power plant engineering Details understanding of thermal and fast power reactors Introduction to sodium technology
Engineering Mathematics	EM	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering Introduction to numerical methods for solving ordinay and partial differential equations Probability and statistics Different types of transformations
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Reactor Engineering	RE	Basic understanding of core design of LMFBR Coolant circuits of LMFBR and special characteristics of sodium technology
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation Principles of radiation detection and Radiation Protection procedures Familiarization with principles of radiation detection and radiation Protection procedures
Project Management	PM	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(A) MECHANICAL ENGINEERING

(A1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for Pressure Vessels and Piping	ME1
2	High Temperature Design and Inelastic Analysis	ME4
3	Computational Fluid Dynamics	ME6
4	Finite Element Method	ME8
5	Advanced Heat and Mass Transfer	ME10
6	Reliability Engineering	ME13
7	Manufacturing Technology	ME14

(A2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Machine Design	ME3
2	Structural Integrity Assessment Methods and NDE	
3	Vibration Engineering and condition Monitoring	
4	Seismic Design of Nuclear Reactors and Facilities	ME5
5	Plant Dynamics	

6	Experimental Mechanics	
7	Process Control and Instrumentation	ME15

(A3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-001-P
2	Seminar -1,2,3	02ENGG04-001-S

Course Outcomes:

(A1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for Pressure Vessels and Piping	ME1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles.
		The course also include introduction to tubesheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered. It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
High Temperature Design and Inelastic Analysis	ME4	This course has direct relevance with the design of fast breeder reactor components & piping system. It covers mainly about the role of high-Temperature design concerning FBR programme, significant failure modes and associated design guidelines and advanced inelastic analysis methods. The high temperature design aspect is followed based on the RCC MRx RB procedure. Reliable design of components and piping system operating under high temperature operating conditions should address the additional damage associated with creep, fatigue and creep-fatigue interactions predominantly under thermo-mechanical loadings. There are many unresolved problems in the area of high-temperature

		design such as visco-plasticity behaviour, ratcheting behaviour, high temperature crack initiation behaviour etc. These aspects are addressed in this course with the support of tutorials.
Computational Fluid Dynamics	ME6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis Numerical Solution of Complete Fluid Flow and Energy Equation
Finite Element Method	ME8	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Advanced Heat and Mass Transfer	ME10	Advanced knowledge in heat and mass transfer Laminar boundary layer and forced convective heat, turbulent flow and heat transfer Heat transfer in porous media and heat transfer with phase change Radiation heat transfer
Reliability Engineering	ME13	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Manufacturing Technology	ME14	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles plastic deformation, processes like rolling, forging, extrusion etc in the case of metal forming module. Arc welding process,welding metallurgy, defects, inspection, quality control aspects are covered inwelding module. Extraction of Uranium and Zirconium from ore to final product form is coveed in the material processingmodule.

(A2) ELECTIVES

Name of the Course	Course code	Course Outcome
Machine Design	ME3	Basic concepts in vibrations analysis
Structural Integrity Assessment Methods and NDE		Basics of rotor dynamics and rotor balancing Flow induced vibrations Response of systems to earthquake
Vibration Engineering and condition Monitoring		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	ME5	Introduction to earthquakes, design basis ground motion and IS 1893 spectra Introduction of earthquake engineering and analysis for multi degree freedom systems
Plant Dynamics		Analysis and design of structures, equipments and piping
Experimental Mechanics		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Process Control and Instrumentation	ME15	Understanding the concepts of instrumentation and control for nuclear power plants
		Able to identify and define instrumentation and control needs of a process or machine
		Able to provide indicative choice of instruments in the design

(A3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-001-P	training in formulating and executing a research problem.
Seminar -1,2,3	02ENGG04-001-S	learning oral communication of research results and improving presentation skills.

(B) ELECTRONIC AND INSTRUMENTAL ENGINEERING

(B1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	EL2
2	Nuclear Instrumentation	EL3
3	Reliability Engineering	EL4
4	Software Engineering	EL5
5	Human Machine Interface for Reactor Control Instrumentation	EL8
6	Modern Control of Dynamic Systems	EL10

(B2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence and Digital Signal Processing	EL6
2	Process Instrumentation	EL7
3	Embedded and Computer based systems Design	EL9
4	Analytical Instrumentation	EL11

(B3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-002-P
2	Seminar -1,2,3	02ENGG04-002-S

Course Outcomes:

(B1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	EL2	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	EL3	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Reliability Engineering	EL4	Introduction to reliability engineering applied to C&I systems
		Basic concepts of reliability, statistics and fault tolerence
		Probabilistic Safety (Risk) Assessment methods in the NPPs
Software Engineering	EL5	Introduction to software engineering and standards
		Software quality assurance, verification and validation
		Software analysis, design and configuration management
Human Machine Interface for Reactor Control Instrumentation	EL8	The subject is aimed on advanced design in new trends and development philosophy in the area of human machine interface. The student should obtain an overview of technologies implemented for reactor programmes and acquire an insight of the technical background to apply the same in context of reactor applications.
		The course work is framed in order to give an Introduction to various PFBR systems and HMI models in Distributed Digital Control System and their application to process systems such as special supervision systems, component handling systems, Reactor Protection Systems & Reactor Regulating Systems and Incident monitoring & mitigation systems. Learn about PC based process control system, Supervisory Control and Data Acquisition Systems.
		This course includes Familiarisation of plant automation overview, Soft Console versus conventional control panels, Guidelines for design of HMI displays, Building HMI systems, designing plant databases, alarm management techniques,

		Security features, creating process mimics, Trending historical data, Methods of passing data to HMI package etc. The capabilities of commercially available Professional HMI packages will also be explored.
Modern Control of Dynamic Systems	EL10	Introduction to state variable description with examples
		Controllability, observability and control system design

(B2) ELECTIVES

Name of the Course	Course code	Course Outcome
Artificial Intelligence and Digital Signal Processing	EL6	Exposure to fundamentals of digital signal processing algorithms
		Exposure to practical DSP algorithms and its implementation on different platforms
		Exposure to system design using pre conditioning circuits, anti-aliasing filters and digital signal controllers
		Exposure to system design case studies like Condition Monitoring System for rotating equipments And radar signal processing
		After course completion the student will be able to handle practical engineering problems solvable by digital signal processing techniques
		It is a specialised course which will give an introduction to AI techniques.
		It will give a flavour to fuzzy logic, robotics, neural networks, genetic algorithm.
Process Instrumentation	EL7	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Embedded and Computer based systems Design	EL9	Understanding of VME bus and cPCI bus architecture.
		'C' programming with MISRA C compliant.
		Electronics design in analog and digital domain
		Learning of VLSI based design using EDA tools.
		Learning of VHDL based digital design.
		Electronics system design using TMR architecture, fault tolerant design
		Introduction of reliability analysis for electronics system.
Analytical Instrumentation	EL11	Introduction to the principles and applications of modern analytical instruments Sensitivity, precision, and limitations of analytical instruments

(B3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-002-P	training in formulating and executing a research problem.
Seminar -1,2,3	02ENGG04-002-S	learning oral communication of research results and improving presentation skills.

(C) CHEMICAL ENGINEERING

(C1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Nuclear Chemical Engineering	CE1
2	Chemical Engineering Thermodynamics	CE2
3	Transport Phenomena	CE3
4	Multi-Phase Flow Systems	CE4
5	Code Design for Pressure Vessels and Piping	CE5
6	Computational Fluid Dynamics and Heat Transfer	CE6
7	Advanced Chemical Reaction Engineering	CE7

(C2) SPECIALIZED COURSES

Sr. No.	Name of the Course	Course code
1	Process Analysis and Control	CE8
2	Advanced Mass Transfer	CE9

(C3) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Preparedness &Response to Nuclear Emergencies Artificial Intelligence Methods &Applications Membrane/ Separation Process and Technology	CEEL

(C4) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-003-P
2	Seminar -1,2,3	02ENGG04-003-S

Course Outcomes:

(C1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Nuclear Chemical Engineering	CE1	Introduction to nuclear chemical engineering for production, processing and management of nuclear materials
		Modelling and Simulation in Nuclear Chemical Engineering
Chemical Engineering Thermodynamics	CE2	Understanding the concepts of Thermodynamics , scope of Classical Thermodynamics, Phase Equilibrium, Chemical Reaction Equilibria.
Transport Phenomena	CE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyze transport problems
		Analyze transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyze transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Multi-Phase Flow Systems	CE4	Introduction to multiphase flow and its classification
		Modeling and Simulation in Nuclear Chemical Engineering
		Applications of two-phase flow in the design of steam generators
		The phenomena of fluidization and its industrial application
Code Design for Pressure Vessels and Piping	CE5	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design

		for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
Computational Fluid Dynamics and Heat Transfer	CE6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer
Advanced Chemical Reaction Engineering	CE7	Understanding of thermodynamics and kinetics of chemical reactions
		Design and analysis of chemical reactors
		Modelling of multiphase reactors

(C2) SPECIALIZATION

Name of the Course	Course code	Course Outcome
Process Analysis and Control	CE8	Understanding of dynamics of chemical process systems and nonlinear process dynamics
		Design of multivariable controllers
Advanced Mass Transfer	CE9	Introduction to theories of mass transfer and advanced mass transfer processes
		Selection and design of contacting equipment in nuclear chemical industries

(C3) ELECTIVES

Name of the Course	Course code	Course Outcome
Preparedness & Response to Nuclear Emergencies	CEEL	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Artificial Intelligence Methods & Applications		
Membrane/ Separation Process and Technology		

(C4) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-003-P	training in formulating and executing a research problem.
Seminar -1,2,3	02ENGG04-003-S	learning oral communication of research results and improving presentation skills.

(D) MATERIALS SCIENCE

(D1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	MS1
2	Computational Methods	MS2
3	Materials and Metallurgy	MS3
4	Reactor Physics and Fuel Design	MS4
5	Health Physics	MS5
6	Metallurgical Thermodynamics	MS6
7	Experimental Methods for Materials Research	MS7
8	Structural Materials for Nuclear Reactors	MS8
9	NDE Science and Technology	MS9
10	Physical Metallurgy	MS10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	MS11
12	Introduction to Materials Science and Engineering	MS12
13	Corrosion Science and Engineering	MS13
14	Mechanical Behavior of Engineering Materials	MS14
15	Manufacturing Technology	MS15

Course Outcomes:

(D1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Engineering Mathematics	MS1	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
		Introduction to numerical methods for solving ordinary and partial differential equations
		Probability and statistics
		Different types of transformations
Computational Methods	MS2	Introduction to programming languages such as C# and Matlab
		Exposure to numerical techniques for solving partial differential equations
		Neural network for predictive applications
		Basics of atomis modelling, molecular dynamics and introduction to Monte-carlo simulation
		Introduction to FEM and current trends in modelling and imulation

Materials and Metallurgy	MS3	To develop a basic understanding on the classification of materials
		Mechanical property based selection of materials for nuclear application and standards
		Various fabrication related issues in material including welding and corrosion
		Non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Reactor Physics and Fuel Design	MS4	Introduction to basic nuclear and neutron physics concepts
		Nuclear reactors and fuel design concepts
		Reactor kinetics
Health Physics	MS5	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Metallurgical Thermodynamics	MS6	Introduction to Classical thermodynamics: 1st and 2nd laws and their applications
		Thermodynamic properties of pure substances and mixtures Solution thermodynamics
		Phased equilibria in multicomponent systems and stability
		Chemical reactor equilibria Exposure to experimental methods for determining thermodynamic properties
Experimental Methods for Materials Research	MS7	Exposure to various experimental techniques for materials characterization, including X-ray techniques, electron microscopies, ion-beam techniques, electron spectroscopies nuclear spectroscopies, vibrational spectroscopy and resonance absorption spectroscopies
		Basic understanding of underlying physics
Structural Materials for Nuclear Reactors	MS8	Exposure to the three stage nuclear power programme
		Concept of selection of structural materials for different applications
		Materials for thermal reactors, fast breeder reactors and reprocessing applications
		Materials processing and fabrication of components
NDE Science and Technology	MS9	Introduction to various non-destructive evaluation techniques for safe and reliable operation of structures and components
		Surface, volumetric and Dynamic NDE
Physical Metallurgy	MS10	Basic understanding of crystal structure and microstructure
		Knowledge of origin, construction and classifications of metallurgical phase diagrams

		Understanding of different types of metallurgical phase transformations and underlying principles
		Introduction to microstructural characterization techniques and tools
Fuel Cycle Physics and Introduction to Fuel Cycle	MS11	Introduction of nuclear fuel cycles
		Introduction to exploration, recovery and enrichment and uranium and other nuclear fuel materials
		Different types of nuclear fuels and fuel fabrication
		Recycling the spent fuel, fission products and actinides
Introduction to Materials Science and Engineering	MS12	Introduction to basic structures, bonding and defects in solids and techniques for their characterization
		Physcial properties of materials
		Basics of phase diagram and phase transformations
		Techniques for synthesis of materials
Corrosion Science and Engineering	MS13	Basic understanding of corrosion process, monitoring and preventation
		Introduction to thermodynamics and kinetics of corrosion
		Forms of corrosion and corrosion in nuclear reactor and reprocessing plants
Mechanical Behavior of Engineering Materials	MS14	Introduction to engineering materials
		Elastic and plastic deformation in polycrystalline materials
		Strengthening mechanisms in polycrystalline structural materials
		Exposure to damage mechanisms such as creep, fatigue and also exposure to fracture mechanics
Manufacturing Technology	MS15	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles of plastic deformation, processes like rolling, forging, extrusion etc. in the case of metal forming module.
		Arc welding process, welding metallurgy, defects, inspection, quality control aspects are covered in welding module. Extraction of Uranium and Zirconium from ore to final product form is covered in the material processing module.

(E) FAST REACTOR ENGINEERING – I

(E1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(E2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for pressure vessel and piping	FRE1
2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2
3	Transport Phenomena	FRE3
4	Reliability Engineering	FRE4
5	Process Design and Control	FRE5
6	Vibration Engineering and Condition Monitoring	FRE6
7	Seismic Design of Nuclear Reactors and Facilities	FRE7
8	Emergency Preparedness and Disaster Management	FRE8

(E3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Dynamics and Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical’s	FRE14
7		Viva Voce

Course Outcomes:

(E1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(E2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for pressure vessel and piping	FRE1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tube sheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.

Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2	Advanced knowledge in heat and mass transfer
		Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
		Heat transfer in porous media and heat transfer with phase change
		Radiation heat transfer
Transport Phenomena	FRE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyse transport problems
		Analyse transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyse transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Vibration Engineering and Condition Monitoring	FRE6	Basic concepts in vibrations analysis
		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	FRE7	Introduction to earthquakes, design basis ground motion and IS 1893 spectra
		Introduction of earthquake engineering and analysis for multi degree freedom systems
		Analysis and design of structures, equipment and piping
		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(E3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine
		Turbine troubles
Mechanical and Electrical Equipment	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(F) FAST REACTOR ENGINEERING – II

(F1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(F2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	FRE15
2	Nuclear Instrumentation	FRE16
3	Reliability Engineering	FRE4
4	Process Design and Control	FRE5
5	Embedded System Design & Human Machine Interface	FRE17
6	Process Instrumentation	FRE18
7	Emergency Preparedness and Disaster Management	FRE8

(F3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva-Voce

Course Outcomes:

(F1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(F2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	FRE15	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	FRE16	Students learn about basics of interaction of radiation with matter.
		Principle & Techniques to detect and measure ionizing radiation.
		Basics of radiation counting statistics
		Introduction to Neutron Flux Measurement in FBTR and PFBR.
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Embedded System Design & Human Machine Interface	FRE17	Introduction to Microprocessor Based Hardware Design
		Computer Communication and Networks
		Fault Tolerant and Distributed Architectures
		Programmable Logic Controller Design
		Overview of plant automation and Human Machine Interface (HMI)

Process Instrumentation	FRE18	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of various process variables
		Reliability principles, Fail safe design principles
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(F3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine Turbine troubles
Mechanical and Electrical Equipments	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	Assignment of the understanding of the subject by the student and its application in problem solving.

Course Structure:

V. Courses at RRCAT- M.Tech.

Program Code : ENGG01	Programme Specific Outcome	Impart training to students to increase the knowledge base required for research work
		Enhance analytical and computational skill of the students required for carrying out research work
		Provide training to work with various scientific equipment including sophisticated lasers and radiation available from synchrotron sources Indus-1 and Indus -2

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	03ENGG01-001-C
2	Magnet Physics and Technology	03ENGG01-002-C
3	Laser Physics and Technology	03ENGG01-003-C
4	Electromagnetic Theory	03ENGG01-004-C
5	Accelerator Physics andBeam Diagnostics	03ENGG01-005-C
6	Reactor Physics, Radiation Physics, and Safety Issues	03ENGG01-006-C
7	Numerical and Mathematical Techniques and Scientific	03ENGG01-007-C
8	Materials Science and Technology- I	03ENGG01-008-C
9	Applications of Lasers in Nuclear Science, Industry	03ENGG01-009-C
10	Applications of Accelerators in Nuclear Science, Industry	03ENGG01-010-C
11	Vacuum Physics and Technology	03ENGG01-011-C
12	Quantum Mechanics	03ENGG01-012-C
13	Research Methology	03ENGG01-013-C

(B) Elective Courses

Sr. No.	Name of the Course	Course code
1	Power Supplies	03ENGG01-001-E
2	Power Electronics	03ENGG01-002-E
3	Advanced Course on RF and Microwaves	03ENGG01-003-E
4	Advanced Data Acquisition and Control Systems	03ENGG01-004-E
5	Reliability Engineering	03ENGG01-005-E
6	Advanced Course in High Voltage Engineering	03ENGG01-006-E
7	Digital Signal, Image Processing and Applications	03ENGG01-007-E

(C) Laboratory Courses

Sr. No.	Name of the Course	Course code
1	Laser and Applications	03ENGG01-001-L
2	Accelerators related applications	03ENGG01-002-L
3	Electronics	03ENGG01-003-L

(D) Foundation Courses

Sr. No.	Name of the Course	Course code
1	Physics Courses for Engineering Graduates	03ENGG01-001-F
2	Engineering courses for Physics Post-graduates	03ENGG01-002-F

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Engineering Mathematics	03ENGG01-001-C	This course reviews topics in Mathematics which are usually covered at the Master's level and are essential to understand the concepts of science and engineering
		This Course also deals with the advanced topics needed for carrying out research work in different areas of science and engineering
Magnet Physics and Technology	03ENGG01-002-C	Basic understanding of magnetism and its application.
		Analytical approach of magnet design mainly for accelerator application and field measurement technique.
		Fabrication technique and alignment of magnets.
Laser Physics and Technology	03ENGG01-003-C	This course introduces basic mechanism and principles of lasers, beam propagation, and optical resonators
		Introduction to physics and technology of various types of lasers
		This course introduces basic nonlinear optics
Electromagnetic Theory	03ENGG01-004-C	This course is meant for physicists and engineers. It reviews the M. Sc. Level and B. Tech level electromagnetic theory, and further strengthens some of the intricate concepts, and introduces new topics
		It emphasizes basic concepts needed to solve the electromagnetic boundary value problems, and prepares the students to develop better understanding of the computer codes used for that
		Students are expected to develop a better and rigorous understanding of generation of electromagnetic radiation, typically in synchrotron radiation source.
		Students learn about different types of electromagnetic waves – (i) plane waves, including its reflection and refraction at dielectric surface. (ii) Gaussian beams and Bessel beams, (iii) modes in waveguides and cavities, including its transport in

		microwave components and (iv) modes in optical fiber.
Accelerator Physics and Beam Diagnostics	03ENGG01-005-C	The course introduces basic concepts of accelerator physics and beam diagnostics.
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Reactor Physics, Radiation Physics, and Safety Issues	03ENGG01-006-C	Awareness about natural, man-made radiation, dose contribution from various practises, units and quantities, biological effects of radiation exposure and ICRP recommendations on radiation protection
		Awareness about the radiation hazards at work place, safe practises to be followed, exposure control measures, shielding philosophy and radiation detection.
		Understanding the radiation hazards at high energy electron and proton accelerators and laser facilities. Dose build up effects due to electromagnetic and hadronic cascade and its impact on radiation safety and tackling mechanisms
		Gaining fundamental concepts in reactor physics, interaction of various kind of radiation with matter.
Numerical and Mathematical Techniques and Scientific	03ENGG01-007-C	For rigorous and correct analysis of data (which are the outcome of research work), learning numerical and mathematical techniques is absolutely essential.
		This course teaches interpolation, extrapolation, error analysis etc which are integral parts of data analysis. The finite element method is a numerical method for solving problems of applied science and engineering, for example, structural analysis, heat transfer, fluid flow, mass transport etc
		Concept of scientific computing is necessary for numerically analyzing experimental and analytical results. For the same, programming languages (C and fortran) are taught.

		Different operating systems (windows, linux etc), which are taught, also help in understanding the working of computers, in turn, different aspects of scientific computing
Materials Science and Technology- I	03ENGG01-008-C	The course reviews the master's level solid state physics with certain advanced topics
		The advanced topics covered include: nonlinear properties of optical materials, electronic materials for novel applications like spintronics and introduction to symmetry and ferroelectric materials
		Students learn structures of various materials including alloys, ceramics, glasses, polymers, and composites
Applications of Lasers in Nuclear Science, Industry	03ENGG01-009-C	This course covers various applications of lasers in high resolution spectroscopy in metrology and medicine
		This courses exposes application of lasers in material processing
		This course introduces application of lasers in isotope separation
Applications of Accelerators in Nuclear Science, Industry	03ENGG01-010-C	This course aims to expose students to various applications of accelerators.
		Students become aware of applications in accelerator based radiotherapy and radiation processing
Vacuum Physics and Technology	03ENGG01-011-C	This course aims to introduce the basics of theory of vacuum
		Introduces various vacuum systems and components
		Students learn how to design a vacuum system
Quantum Mechanics	03ENGG01-012-C	This course reviews master's level quantum mechanics with more emphasis on problem solving and applications
		This course also covers advanced topics which will enhance understanding in many-electron systems and photo-atom interaction
Research Methodology	03ENGG01-013-C	Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

(B) Elective Courses

Name of the Course	Course code	Course Outcome
Power Supplies	03ENGG01-001-E	This course aims to introduce various concepts of power supplies to the students
		Make students aware of AC-DC and DC-AC converters and principles of feedback control systems
		Students learn about magnet power supplies for accelerators, power supplies for superconducting magnets, and laser/plasma power supplies
Power Electronics	03ENGG01-002-E	This course develops basic understanding of the power electronics
		Course will cover various power semiconductor devices
		Students will learn modelling of various components and carrying out analysis
		Course covers electromagnetic interference related measurement techniques and mitigation techniques
Advanced Course on RF and Microwaves	03ENGG01-003-E	This course develops understanding of the science and technology of RF and microwaves
		Students will learn various generation and transmission of RF waves
		Course covers various components for RF and cavities
		Course makes students learn various measurement techniques for RF and microwave
Advanced Data Acquisition and Control Systems	03ENGG01-004-E	Process control and Data Acquisition elements and models
		Continuous time domain controllers and digital controllers
		Feed-back and Feed-forward control systems
		Z-transform based Deadbeat and Dahlin algorithms, real time systems and scheduling methods, buses for instrument networks and communication protocols
Reliability Engineering	03ENGG01-005-E	This course aims to introduce various concepts and techniques for evaluating reliability and assessing quality of engineering processes

		Review of basic statistics and probability applied to reliability analysis
		Students will learn various concepts of quality assurance and reliability
		Students will learn topics related to total quality management
Advanced Course in High Voltage Engineering	03ENGG01-006-E	This course aims to introduce concepts and materials related to high voltage engineering
		Students learn about various dielectric materials relevant for high voltage applications
		Students learn various techniques for generating and measuring high voltages
		Course introduces aspects of designing high voltage circuits and safety issue associated with high votages
Digital Signal, Image Processing and Applications	03ENGG01-007-E	Basic understanding of machine vision systems and their specific application areas related to nuclear engineering
		Understanding of camera types, lenses, illumination, Component Selection of a machine vision system
		Understanding of the concept of digital image, basic definitions, image operators, and functions used in digital image processing software
		Applying functions for accomplishing particular image processing task according to application

(C) Laboratory Courses

Name of the Course	Course code	Course Outcome
Laser and Applications	03PHYS04-001-L	To provide first-hand experience in handling various lasers and related optics
		To provide training to carry out spectroscopic studies using laser
Accelerators related applications	03PHYS04-002-L	Students get first-hand experience in handling various instruments needed for accelerator technology
Electronics	03PHYS04-003-L	Students get first-hand experience in handling various instruments required for electronics, image processing, and RF components

		Students are also expected to learn and handle GUI software and communication protocols

(D) Foundation Courses

Name of the Course	Course code	Course Outcome
Physics Courses for Engineering Graduates	03ENGG01-001-F	This is a bridge course which introduces engineering graduates to some specialized subjects of physics
		These subjects helps graduates to understand aspects of lasers, accelerators, and materials sciences
Engineering courses for Physics Post-graduates	03ENGG01-002-F	This is a bridge course which introduces physics post-graduates to some specialized subjects of engineering
		These subjects helps candidates to understand mechanical, electronics, and electrical engineering aspects of lasers and accelerators

BACK TO MAIN

Course Structure:

VI. Courses at IPR

Program Code: ENGG01	Programme Specific Outcome	Learn about Plasma basics, its diagnostics and its applications.
		Learn Plasma and Fusion Technologies to build a device.
		Get detailed information on specific subject related to Fusion technology according to the stream of student i.e. Physics , mechanical etc.

T1. FUNDAMENTAL

Sr. No.	Name of the Course	Course code
1	Basic Plasma Physics	FC1
2	Experimental Plasma Physics	FC2
3	Tokamaks	FC3
4	Fusion Plasma Diagnostics	FC4
5	Measurement Techniques	FC5
6	Numerical Methods	FC6
7	Mathematical Methods	FC7
8	Vacuum, Cryogenics and Magnets	FC8

T2. CORE SUBJECTS

Sr. No.	Name of the Course	Course code
1	Fusion Neutronics	AS1
2	Plasma Facing Components: First Wall, Divertors, Blankets	AS2
3	Fusion Materials	AS3
4	RF, Current Drive and Neutral Beam Heating	AS4

T3. ELECTIVES

(A) PHYSICS

Sr. No.	Name of the Course	Course code
1	Magneto Hydro Dynamics	PH1
2	Kinetic Theory and Statistical Mechanics	PH2
3	Advanced Heat Transfer and Cryogenics	PH3/ME5
4	Tokamak Related Code	PH4

(B) MECHANICAL

Sr. No.	Name of the Course	Course code
1	Code Design for Internal and External Pressure Vessel	ME1
2	Finite Element and Volume Methods	ME2
3	Mechanics of Solid/Vibration/Remote Handling	ME3
4	Advanced Manufacturing Technologies	ME4
5	Advanced Heat Transfer and Cryogenics	ME5

(C) ELECTRICAL

Sr. No.	Name of the Course	Course code
1	Advanced Data Acquisition System	EE1
2	Advanced Tokamak controls	EE2
3	High Voltage, DC& AC/ Power Supplies	EE3
4	Signal Conditioning and EMI/EMC Aspects	EE4
5	Computer Based System Design	EE5
6	Digital Signal Processing and Image Processing	EE6

T4. MINI PROJECT (MP)

Sr. No.	Name of the Course	Course code
1	Mini Project	06ENGG01-001-MP

T5. PROJECT (P)

Sr. No.	Name of the Course	Course code
1	Project	06ENGG01-001-P

Course Outcomes:

T1. FUNDAMENTAL

Name of the Course	Course code	Course Outcome
Basic Plasma Physics	FC1	Course provides detailed information on: • Definition of plasma, description of collective behaviour in contrast to single particle behaviour. • Lorentz force equation, nonrelativistic motion of a charged particle in constant electric and magnetic field. • Fluid Description of Plasma, Waves in Plasma and MHD Description.
Experimental Plasma Physics	FC2	Course provides detailed information on: • Fundamental Gas Processes i.e. Maxwell-Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization, • Charged Particles in a Gas. • Self-sustaining Discharge i.e. Glow Discharge, Breakdown under Special Conditions, Arc Discharge. • Plasma Sheath and Diagnostics Experimental Plasma Devices.
Tokamaks	FC3	Course provides detailed information on: • Introduction to Thermonuclear Fusion reactions, Power Balance and Lawson Criteria, Tokamak as Fusion reactor, • Equilibrium and Transport i.e. Tokamak Equilibrium, Grad-Shafranov Equation, Safety Factor, q and Plasma Beta, Shafranov Shift and Plasma position control, Classical Transport, • Heating i.e. Ohmic Heating, Neutral Beam Heating, Wave Heating, Lower Hybrid Heating and Current Drive, Ion Cyclotron

		Resonance Heating, Electron Cyclotron Resonance Heating. • MHD Stability i.e. Ideal Kink modes, Ideal internal modes, Resistive tearing modes, Mirnov Oscillations, Saw-tooth oscillations, ELMs, Disruption scenarios. • Tokamak and Other Fusion Devices
Fusion Plasma Diagnostics	FC4	Course provides detailed information on, • Introduction to Tokomak diagnostics , Electrical diagnostics, Magnetic diagnostics • Measurements of plasma density and electron temperature i.e. Thomson scattering diagnostics, Reflectometery, Interferometry: ECE diagnostics. • Measurement of ion temperatures i.e. Charge exchange recombination spectroscopy (CXRS), X –ray crystal spectroscopy. • Measurements of Radiated power and Measurements of operational parameters i.e. Bolometers, Imaging Diagnostics and Beam emission spectroscopy.
Measurement Techniques	FC5	Course provides detailed information on, • Measurement system architecture, Computer based measurement systems, Errors in measurements, Measurement Units, Standard used in measurements. • Sensitivity, Resolution, Nonlinearity, Saturation, Dynamic Range, Offset, Drift, Electromagnetic Compatibility, Reliability. • Measurement of Electrical Parameters: Voltage, Current, Resistance, Capacitance, Impedance, Frequency, Phase shift, Power. • Sensors/Transducers and Their Applications to Physical Measurements , Introduction to Data Acquisition and Noise in Measurement System.
Numerical Methods	FC6	Course provides detailed information on, • Mathematical modeling, numerical methods and problem solving, Introduction to MATLAB programming, Error analysis methods, Case study. • Solutions of Linear Algebraic equations. • Numerical Differentiation and Integration • Roots, optimization and nonlinear sets of Equations. • Application of Ordinary Differential equations. • Application of Partial Differential equations.

		• Application of Curve fitting methods.
Mathematical Methods	FC7	Course provides detailed information on,
		• Vector analysis: vector identities, Use of Levi Civita and Kronecker delta functions for the derivation of vector identities, Notion of gradient, divergence and curl
		• Classification of matrices; Elementary operations; Determinant, rank and inverse of a matrix; Solution of linear equations; Eigenvalues and eigenvectors
		• Complex variables, function of a complex variable, continuity and differentiability, Cauchy-Riemann conditions, Analytic functions, Taylor and Laurent Series,
		• First and second order differential equations with constant and variable coefficients; Linear differential equations
Vacuum, Cryogenics and Magnets	FC8	Course provides detailed information on,
		• Fundamental of vacuum i.e. The vacuum and its applications, Gas laws, Pressure and mean free path, Flow regimes, Conductance, Throughput and pumping speed, Ultimate pressure and pump down time, Outgassing and permeation. Exposure to pumps and gauges.
		• Design of a vacuum system
		• Fundamental of cryogenics i.e. Cryogens properties, Heat loads in Cryogenic systems, Basic Thermodynamics and Cryogenic Processes, Material properties at low temperatures.
		• Design of cryogenics system i.e. Design aspects of Cryostat, Dewars and Cryolines. Fundamentals of Thermo-hydraulics and distribution network, Economics of Cryogens, Recovery of Helium and Thermal insulation.
		• Applications of Cryogenics Engineering in Fusion machines.
		• Fundamentals of Magnet system
		• Design and fabrication of magnet system

T2. CORE SUBJECTS

Name of the Course	Course code	Course Outcome
Fusion Neutronics	AS1	Course provides detailed information on, • Fusion Neutronics Principles, neutron production & detection techniques, nuclear interaction processes. • Particle transport phenomena in matter and Basics of fusion neutronics & blanket neutronics. • Principles of Neutron & Fusion product diagnostics, Radiation and licensing and Radiation damage & transmutation.
Plasma Facing Components: First Wall, Divertors, Blankets	AS2	Course provides detailed information on, • First Wall, Firstwall Concepts, Loads on Firswtall and Challenges for Firstwall. • Divertor Concepts , Loads on Divertor , Challenges for Divertor , Divertor Testing and Novel Divertor Concepts • Blanket Concept, Shield Blanket, Breeding Blanket, Liquid Metal (Pb Li) Technology, Fusion Fuel Cycle and Blanket Safety.
Fusion Materials	AS3	Course provides detailed information on, • Fundamentals of Material Science • Fusion Materials Requirements & Issues • Material Development and Joining Technologies • Material Characterization & Qualification
RF, Current Drive and Neutral Beam Heating	AS4	Course provides detailed information on, • Heating and current drive physics by neutral beam • Neutral beam injector system design and engineering • Introduction to RF heating • RF devices and Design tools i.e. ICRH, ECRH and LHCD.

T3. ELECTIVES

(A) PHYSICS

Name of the Course	Course code	Course Outcome
Magneto Hydro Dynamics	PH1	Course provides detailed information on, • Physical description of electrically conducting fluids .Derivation of basic MHD equations: Continuity, Equation of

		motion, Energy flow, Ohm's law, Validity of MHD equations.
		• The low frequency dynamics of the electromagnetic field. Some properties of MHD: Ideal MHD equations, The Frozen Flux theorem, The effect of • resistivity, Similarity scaling, The Wöltjer invariants and helicity
		• Equilibrium general considerations, The Virial Theorem, Examples of simple equilibria: - pinch, Z-pinch, screw pinch, Poloidal , paramagnetic and diamagnetic states, Force-free fields, Toroidal equilibrium: the Grad-Shafranov equation, nonlinearity, Definition of q, beta, plasm a shape, etc.
Kinetic Theory and Statistical Mechanics	PH2	Course provides detailed information on,
		• Gas dynamic way of describing an uncharged fluid – heuristic
		• Recollect derivation of basic MHD equations – one fluid only (Continuity, Eqn of motion, Energy equation [thermodynamic closure], Electron equation of motion [Ohm's Law])
		• Introduce ideas of Phase Space (x,v) and distribution functions f(x,v,t)
		• Langmuir Oscillations and Waves – Vlasov-Poisson dispersion
		• Examples of GK formalism and obtained transport and Very cursory introduction to Onsager relationships
Advanced Heat Transfer and Cryogenics	PH3/ME5	Computational Fluid Dynamics
		Heat Transfer : Conduction
		Heat Transfer : Convection:
		Heat Transfer : Radiation:
		Cryogenics
		Gas Liquefaction and Refrigeration Systems
Tokamak Related Code	PH4	Course provides detailed information on,
		• Plasma core modelling i.e. Plasma equilibrium IPREQ , Plasma transport TSC , Plasma stability ERATO, PEST2 , ICRH heating TORIC , NBI heating NUBEAMS , Plasma start up model , Reactor system code , Eddy current analysis.
		• Edge-SOL studies i.e. 2D blob transport, Divertor study SOLPS (B2+ERINE) , 3D plasma study ERINE-3D

		• First principle simulations i.e. Low frequency (w/wc <<1) transport – what is Gyrokinetic method? , What are the transport processes neglected by gyrokinetic formalism?

(B) MECHANICAL

Name of the Course	Course code	Course Outcome
Code Design for Internal and External Pressure Vessel	ME1	Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and tori spherical end closures.
		Thick cylinder, sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div. – II equations for cylindrical / Spherical shell and conical, ellipsoidal and tori spherical end closures.
		Bending of circular plates and determination of stresses in simply supported and clamped Circular plate. Basis of ASME equation for flat closures.
		Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3.
Finite Element and Volume Methods	ME2	Introduction to FEM: Weighted residual method, Galerkin's methods, Weak form formulation , piecewise approximations. Basis of Finite Element Method, Variation principles, energy principles in structural mechanics, Element libraries
		Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements
		2D plane elements – 3 node triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
		Finite element applications for design: Finite element modelling and discretization criterion,

		h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.
Mechanics of Solid/Vibration/Remote Handling	ME3	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Laminar Boundary Layer and Forced Convective Heat
		Turbulent Flow and Heat Transfer
		Natural Convection
		Numerical Solution of Complete Fluid Flow and Energy Equation
Advanced Manufacturing Technologies	ME4	Advance manufacturing processes i.e. mechanical energy based processes , electrical energy based processes, chemical and electro-chemical energy based processes.
		Advanced materials joining and testing i.e. bolting , riveting , soldering , blazing ,adhesive bonding , diffusion bonding , mechanical joining, fusion welding, oxyacetylene welding , smaw , gtaw , gmaw , fcaw ,saw , esw, high energy beam welding.
		Responses of materials to welding i.e. microstructural changes , distortion , defects, undercuts ,overlaps , grain growth , blowholes , inclusions.
		Destructive and non-destructive tests for welds.
Advanced Heat Transfer and Cryogenics	ME5	Computational Fluid Dynamics
		Heat Transfer : Conduction
		Heat Transfer : Convection:
		Heat Transfer : Radiation:
		Cryogenics
		Gas Liquefaction and Refrigeration Systems
		Cryogenic Insulations
		Instrumentation in Cryogenics

(C) ELECTRICAL

Name of the Course	Course code	Course Outcome
Advanced Data Acquisition System	EE1	Course provides detailed information on,
		• Theory of Quantization , Advanced Data Acquisition Systems
		• Data Acquisition Interface , Analog Input/output
		• DAQ Clock and Trigger , Synchronization
		• SST-1 Data Acquisition System

Advanced Tokamak controls	EE2	Course provides detailed information on, • Fundamentals of Control System i.e. Terminology and basic structure of control system , Open loop and Closed loop systems, servomechanism, regulatory system, analogous systems, electrical analogy of physical systems, Physical Systems. • Different types of Control Systems • Introduction to Plasma Control • ITER Instrumentation & Control • SST-1 Operation &Control • Monitoring and Control of Auxiliary Systems
High Voltage, DC& AC/ Power Supplies	EE3	Course provides detailed information on, • Overview of Electrical systems in Fusion machines i.e. Basic introduction to electrical systems in Tokamak, Stellarator and Z-machine; Tokamak as a transformer, Electrical systems for plasma formation – Ohmic discharge, Arc discharge, RF discharge, MW discharge; Electrical systems for plasma confinement. • High Voltage Generation, High AC, DC and Impulse Voltages, High Voltage Components, Basic design features of High Voltage Power Transformer: Basic design of HV Transformer, Transformer insulation requirements, dielectric strength and voltage conditions, winding arrangements, surge behavior, behavior of liquid dielectric, electrode surface phenomena, gas evolution, processing techniques, construction of EHV transformer, short circuit behavior. • Linear and switching power supplies, DC to DC converters and their operating characteristics, Selection of Power Semiconductor Devices, Power supplies for pulsed gas discharge tubes, High current power supplies. Power supplies for heating and current drive, Requirement for arc fault protection, Protection by crowbar. • Power Electronics and design through modelling & simulation i.e. AC-DC Converters; Forced commutation;

		synchronous link converters, DC-AC converters, buck, boost, buck-boost, cuk, flyback configuration, resonant converters, PWM inverters; active filters. Machine modelling, DC machines, induction motor and synchronous machines.
Signal Conditioning and EMI/EMC Aspects	EE4	Course provides detailed information on, • Analog Signal Conditioning i.e. Principles of Analog Signal Conditioning, Signal Conditioning Configuration, Signal Conditioning Functions, Amplification, Transducer Excitation, Filtering, Isolation. • Signal Processing and Applications i.e. Review of signals and systems: Introduction, advantages and limitations of Analog and Digital Signal Processing, Advantages and Disadvantages of Digital Filters over Analog Filters. • EMI/EMC i.e. Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling Inductance Coupling, Shielding. • EMI Modelling i.e. Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns.
Computer Based System Design	EE5	Course provides detailed information on, • Personal computer architecture, memory organization, industrial PC, Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications. • Asynchronous and synchronous communication, • Local Area Networks, OSI 7 layer model and TCP/IP reference model, Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth, Networking hardware – cables, hub, switch, router etc. • Real-time Systems, their characteristics and applications, Real-time Operating Systems Concepts of Process and threads, Concurrency, Latency, context switching, scheduling policies.
Digital Signal Processing and Image Processing	EE6	Course provides detailed information on, • Basic elements of a digital signal processing system, Fourier series and Fourier transform, z transform Convolution, Correlation, Sampling

		theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.
		• Discrete Fourier Transform, Interpretation of DFT, Properties of DFT, DFT of real signals, Fast Fourier Transform Digital filters, DSP Applications.
		• Digital image model representation, Image sensor, Digitizer, Computer, Standard file format.
		• Image Enhancement i.e. Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Color image processing.
		• Image Segmentation and Analysis i.e. Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation, Boundary extraction and representation.
		• Morphological operations i.e. Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy based Methods, Image Compression Models, Error free compression, Lossy compression, Standards.

T4. MINI PROJECT (MP)

Name of the Course	Course code	Course Outcome
Mini Project	06ENGG01-001-MP	Student learns**:**
		• Literature Survey
		• Study of a small section of the major project based on either simulation or fabrication to realize the criticality and requirements to build a component for plasma application.
		• Practise for thesis writing

T5. PROJECT (P)

Name of the Course	Course code	Course Outcome
Project	06ENGG01-001-P	• Complete understanding about the criticality of a particular component to be built for plasma application.
		• Development of a component for a plasma application and get hands on experience.
		• Thesis report.

M.Phil. in CHEMICAL SCIENCES

(Program Code: CHEM02)

Course Structure:

I. Courses at BARC

Program Code : CHEM02	Programme Specific Outcome	Firm foundation in the fundamentals and application of current chemical and scientific theories including those in Analytical, Inorganic, Nuclear and Physical Chemistry.
		Ability to design and carry out scientific experiments as well as accurately record and analyze the results of such experiments.
		Skill development in problem solving, critical thinking and analytical reasoning as applied to scientific problems.
		Ability to clearly communicate the results of scientific work in oral, written and electronic formats to both scientists and the public at large.
		Appreciate the central role of chemistry in DAE programmes and use this as a basis for ethical behavior in issues facing chemists including an understanding of safe handling of chemicals, environmental issues and key issues facing our society in energy, health and medicine.

(A) FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Mathematics, Quantum Chemistry & Computational Methods	CY501
2	Analytical Chemistry	CY502
3	Material Science	CY503
4	Radiation Detection and Measurements	CY504
5	Nuclear and Radiochemistry	CY505
6	Thermodynamics	CY506

(B) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Lasers	CY601
2	Electronics & Chemical Instrumentation	CY602
3	Production and Applications of Radioisotopes	CY603
4	Reactor Physics and Reactor Chemistry	CY604
5	Molecular Structure & Spectroscopy	CY605
6	Radiation and Photochemistry	CY606
7	Chemistry in Nuclear Fuel Cycles	CY607
8	Advanced Chemical Kinetics & Dynamics	CY608
9	Health Physics and Radiation Biology	CY609
10	Research Methodology	CY610
11	Safety in Chemical and Radiochemical labs	CY 611

(C) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Nanomaterials, Chemical Sensors	CY701
2	Soft Condensed Matters	CY702
3	Nuclear Probes for Material Characterization	CY703
4	Molecular Bioorganics	CY704
5	Laser Spectroscopy	CY705
6	Actinide Chemistry	CY706
7	Computational Chemistry	CY707
8	Advanced NMR Spectroscopy	CY708
9	Atmospheric Chemistry	CY709
10	Statistical Analysis	CY710

(D) NON-SUBJECT ASSIGNMENTS

Sr. No.	Name of the Course	Course code
1	Viva Voce	CY591
2	Mini Project	CY592
3	Seminar	CY593

Course Outcomes:

(A) FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Mathematics, Quantum Chemistry & Computational Methods	CY501	Learn foundations of quantum mechanics to understand the difference between classical and quantum phenomena.
		Understanding the role of rotational and spin angular momenta in chemistry.
		Develop expertise in molecular orbital theory that helps in understanding structure of polyatomic molecules.
		Understanding molecular symmetry to predict the chemical reactions of atoms and molecules.
		Calculation and interpretation of errors in numerical computation.
Analytical Chemistry	CY502	Acquaintance with various analytical techniques
		Idea on how to tackle an analytical problem, pertaining to DAE and other industries.
		Acquaintance with theories of various matrix separation techniques
		Acquaintance with statistical treatment of analytical data
		The course gives sufficient expertise leading to enhanced employability
Material Science	CY503	Ability to analyse the Powder X-ray diffraction pattern for solving crystallographic structures
		Description of specific crystal structures by applying basic crystallographic concepts
		Establishing correlation between electrical behavior and crystal structure
		Understanding different types of defects and their effect on the functional properties
		Understanding the concept of solid solution formation for fine tuning the properties
Radiation Detection and Measurements	CY504	Expertise to choose a particular detector for a specific application
		Expertise to carry out identification and quantification of radionuclides
		Knowledge base to understand safety aspects while working with radioactivity
		Basic knowledgebase for orientation towards working in areas involving applications of nuclear techniques
		Basic knowledge to develop need-based measurement systems

Nuclear and Radiochemistry	CY505	Identifying the factors that affect nuclear stability
		Explain the different kinds of radioactive decay and interpret a radioactive decay series, apply radiotracer principles
		Calculate the specific activity of the produced radionuclides, estimate the conditions required for producing important isotopes
		Understand the basic concepts in fission and the production yields of different radioactive isotopes during fission
		Identify the nuclear analytical techniques useful for analysing the samples (neutron activation, Ion beam analysis techniques)
Thermodynamics	CY506	Analyze thermal effects on a chemical process
		Understanding that change in environmental conditions can change the process itself.
		Important concepts on Carnot engine and energy conversion efficiencies
		Thermodynamics of nuclear materials
		Idea about experimental thermodynamics

(B) CORE COURSES

Name of the Course	Course code	Course Outcome
Lasers	CY601	Understanding of the operation of laser
		Understanding the principle behind the selection of specific laser for a specific application in the field of laser spectroscopy
		Knowledge of different classes of laser and their applications in different fields.
Electronics & Chemical Instrumentation	CY602	Understanding the principle of operation of common laboratory instruments
		Setting up / wiring of components for furnace, thermocouple, temperature controller etc.
		Ability to do simple trouble-shooting related to instruments (checking fuse, voltage, resistance etc.)
		Application of noise reduction techniques during measurements
Production and Applications of Radioisotopes	CY603	Knowledge of different processes employed for the production and radiochemical processing of important artificially produced radionuclides
		Understanding how the radiation and radioisotopes can be employed to divulge the useful information regarding different human ailments as well as how to

		treat various diseases specifically cancer
		Appreciate how the radiation and radioisotopes have emerged as an essential tool in various industries
		Expected to comprehend the important roles radiation technologies are playing in various processes
		Appreciate that radiation and radioisotopes are boon for the development of nation and mankind
Reactor Physics and Reactor Chemistry	CY604	Understand various designs of nuclear reactors and its components.
		Gain insight about the details of reactor physics calculations which are required for designing a nuclear reactor.
		Become conversant with the purification techniques used for the preparation of demineralized water at large scale and also about the variation in its thermo-physical properties with temperature and pressure.
		Develop the understanding of the behaviour of various materials of construction in their operational environment of nuclear power plants.
		Understanding the guiding principles for evolving the chemistry control process and the actual practice been adopted for the various heat transport systems of the nuclear power plants.
Molecular Structure & Spectroscopy	CY605	Understand the general characteristics of the d and f block elements
		Thorough knowledge of the different theories to explain the bonding in coordination compounds
		Improve the level of understanding of the chemistry of lanthanides and actinides
		Develop understanding of various advanced spectroscopic techniques for analyzing complex compounds.
		Thorough knowledge of the fundamentals of microwave, infrared, Raman, electronic and magnetic resonance spectroscopy, X-ray photoelectron spectroscopy.
Radiation and Photochemistry	CY606	Awareness of radiation induced reactions and its applications
		Expertise to analyse and quantify radiation/photochemical induced chemical reactions
		Trained man power for using various radiation and photochemical sources and state-of art experimental facilities
		Hands-on experience and research training during project work

		Knowledge development in the DAE relevant activities and planning for future R&D programs
Chemistry in Nuclear Fuel Cycles	CY607	Knowledge of processes involved in recovery of nuclear material from ores
		Understanding the chemistry involved in different stages of nuclear fuel cycle
		Understanding of fabrication and quality control of nuclear fuel
		Knowledge in physico-chemical characterization of nuclear fuel, irradiation behaviour
		Understanding of reprocessing of spent fuel and waste management
Advanced Chemical Kinetics & Dynamics	CY608	Learn difference between chemical kinetics and dynamics, and their applications in real systems
		Predict the energy state of a reaction product, and required reactant states to obtain a desired product for a simple reaction.
		Learn the importance of energy transfer affecting the population inversion in a gas laser.
		Expertise developed in carrying out research in relevant area of chemical physics with acquired knowledge.
		The course gives sufficient expertise leading to enhanced employability
Health Physics and Radiation Biology	CY609	Basic knowledge of handling hazards of various radioactive materials
		Knowledge of radiation protection aspects in nuclear and radiation facilities
		Radiation Protection Aspects in Designing of Nuclear and Radiation Facilities
		Design of advanced radiation monitoring equipments
		Management of Nuclear/Radiological Emergencies in facilities
Research Methodology	CY610	Demonstrate knowledge of research processes (reading, evaluating, and developing)
		Perform literature reviews using print and online databases
		Identify, explain, compare, and prepare the key elements of a research proposal/report
		Knowledge of writing reports and thesis
		Idea about following ethical practices in research
Safety in Chemical and Radiochemical labs	CY 611	Develop an understanding of the principle of chemical/radiochemical safety.
		Acquire the ability to apply the safety concepts in to practice when they work in chemical /radiological laboratories.

		Inculcate a culture of safety which shall benefit the organization.
		Knowledge about various safety aspects including good laboratory practices.
		Awareness about various emergencies and the need of emergency preparedness plans.

(C) ELECTIVES

Name of the Course	Course code	Course Outcome
Nanomaterials, Chemical Sensors	CY701	Idea about different synthesis methods for nanomaterials,
		Knowledge about modern techniques like pulsed laser deposition, spray pyrolysis etc.
		The concepts of Chemical sensors are taught which comprise of various per-requisites of a sensor material.
		Idea about several characterization techniques which are very useful for research work in this area.
		Theory behind the unique properties exhibited by nano-materials help the students to rationally design these materials.
Soft Condensed Matters	CY702	Students get to know about the physical basis of soft condensed matter systems
		Learn interpretation of rheological properties of soft matter with specific examples relevant to pharmaceutical formulations
		Learn about how to choose appropriate amphiphiles for emulsification
		Learn about tools for kinetic stabilization of colloidal systems
		Get an overview of application of soft matter systems in industry
Nuclear Probes for Material Characterization	CY703	Idea about defects using positron annihilation spectroscopy (PAS)
		Free volume structure characterization of amorphous material using PAS
		Compositional characterization using Ion beam techniques
		Phase structure, pore structure, Dynamics, magnetic structure using neutron scattering techniques
		Analysis of local structure of amorphous and crystalline materials using X-ray absorption methods

Molecular Bioorganics	CY704	Knowledge about synthetic design, and to enable a student to devise a synthetic route for a target molecule
		Knowledge about the various strategies in organic synthesis
		Knowledge about the green strategies, and the know-how of applying the same in organic synthesis
		Knowledge about the most recent advancements in organic synthesis
		Knowledge about the use of functional materials used in nuclear fuel cycle in DAE
Laser Spectroscopy	CY705	Skill development in handling high power ultra-short pulsed laser
		Application of time-resolved and nonlinear laser spectroscopy techniques in chemistry, biology and material science
		Expertise in indigenous development of novel spectroscopy techniques using Lasers
Actinide Chemistry	CY706	Understanding of the fuel cycle operations including reprocessing and waste management.
		Idea about environmental aspects of actinide migration in case of accident
		Pursue further areas of study such as transactinides and ‘atom at a time chemistry’
Computational Chemistry	CY707	Calculation of transition state structure and understand reaction mechanism
		Interpretation of IR and UV-Vis spectra of a system
		Band structure calculations of solids and analyze results
		Planning theoretical calculation to explain experimental results and predict molecular properties
		MD simulation and analysis of simulation results
Advanced NMR Spectroscopy	CY708	Student can learn how to validate the experimental results of synthesis and purity in a fast and efficient way.
		Determination of solution structure with the help of 1H and multi-nuclear NMR spectra
		Student can analyze the inter-molecular interactions and dynamics in solution state
		Familiarise the student to use solid state NMR technique for solving problems in Materials science
Atmospheric Chemistry	CY709	Idea about structure of atmosphere and atmospheric radiation
		Knowledge about various photochemical cycles

		Knowledge about various atmospheric pollutants and their harmful effects
		Idea about experimental methods to study reactions of importance in the atmosphere
Statistical Analysis	CY710	Knowledge of various terminologies used in Statistics
		Understanding of various statistical tools which can help in decision making
		Ways to improve quality in analytical data
		Proper way of representing analytical data

(D) NON-SUBJECT ASSIGNMENTS

Name of the Course	Course code	Course Outcome
Viva Voce	CY591	To evaluate the understanding of subject
		To judge the thinking process
Mini Project	CY592	Idea about how to do literature survey on a given topic
		Idea about planning and execution of an experiment
		Data analysis
		Writing project report
		Presentation of data and results
Seminar	CY593	Idea about how to do literature survey on a given topic
		Dissemination of information available in literature
		Practical experience of preparing presentation slides
		Practical experience of discussing scientific results in front of a knowledgeable audience

Course Structure:

II. Courses at IGCAR

Program Code : CHEM02	Programme Specific Outcome	Theoretical work for understanding solvent – metal ion interactions.
		Matrix isolation spectroscopy to understand conformers and weak molecular attractions
		Solvent development for reprocessing of nuclear fuels.
		Novel sensor materials development and characterization for sensor applications
		Materials development for matrices for nuclear waste immobilization

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Mathematical and Computational Methods, Numerical Analysis and Computer Programming	CH1
2	Chemical Thermodynamics	CH2
3	Electrochemistry	CH3
4	Introduction to Materials Science and Engineering	CH4
5	Analytical Chemistry for Nuclear Fuel Cycle	CH5
6	Chemical Instrumentation and Laboratory Techniques	CH6
7	Health Physics and Radiation Sciences	CH7
8	Introductory Reactor Physics and Fuel Design	CH8
9	Chemistry of Fuel Cycle - I	CH9
10	Chemistry of Fuel Cycle - II	CH10
11	Materials for Nuclear Reactors and Fuel Cycle Processing Systems	CH11
12	Nuclear and Radiochemistry	CH12
13	Corrosion Science and Engineering	CH13
14	Quantum Chemistry & Group Theory	CH-14
15	Molecular Spectroscopy	CH-15
16	Lasers and Application	CH-16
17	Nanomaterials and Advanced Chemical Sensors	CH-17
18	Course on Research Methodology	CH-RM

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Mathematics and Computational methods	CH-1	Practical applications of mathematical and computational methods are taught; besides these, computational software packages are introduced. The course basically prepares students to apply these aspects in their research areas for solving problems.
Chemical Thermodynamics	CH-2	This course helps students to understand various processes employed in chemical industries. Experimental methods to determine thermodynamic properties and phase diagram investigations are unique to this course. Estimation of thermodynamic properties and thermodynamic modelling study helps for a career in research and industry.
Electrochemistry and Corrosion Science	CH-3	Fundamentals and practical applications of electrochemistry are discussed. Advanced electrochemical techniques, pyrochemical process are taught. Aqueous corrosion and engineering help students to take up career in research and industry.
Introduction to Materials Science and Engineering	CH-4	Various characterisation techniques are taught. Material synthesis methods e.g. sol-gel are discussed extensively. Students handle various characterisation tools e.g. XRD, and Thin-film deposition followed by characterisation.
Analytical Chemistry for Nuclear Fuel Cycle	CH-5	Handling and learning about various sophisticated analytical techniques and instrumentation. Students are exposed to latest analytical techniques. Methodology for development of analytical technqiues for various materials is discussed. This Course prepare students for both research and industry.
Chemical Instrumentation and Laboratory Techniques	CH-6	This course helps students to have flair for setting-up of facility and analytical instruments.

Health Physics and Radiation Sciences	CH-7	Specialised course for students to work on radiation and associated safety aspects. Basics of interaction of radiation with matter. Introduces theory of various nuclear radiation detectors and their practical applications Introduces Biological Effects, Radiation Protection and Regulation procedure, Emergency Preparedness and Management
Chemistry of Fuel Cycle-I	CH-9	This course gives basic introduction to nuclear materials and thermodynamic properties of fuel at higher temperature. Many theories and concepts taught will be directly applied to nuclear plants.
Chemistry of Fuel Cycle-II: Actinide chemistry and separation science	CH-10	This course gives basic introduction to nuclear reactors and fuels. Many theories and concepts of re-use of nuclear fuel, need for nuclear energy are dealt extensively.
Materials for Nuclear Reactors and Fuel Cycle Processing Systems	CH-11	Brief overview of nuclear reactors in India and across the world. Details of nuclear materials are dealt extensively.
Nuclear and Radiochemistry	CH-12	Advanced course in nuclear chemistry. Helps students to understand and appreciate various fundamental aspects of radioactivity. Practicals help students to develop expertise in handling radioactive materials. Students measure half-life of radioactive nuclides. The fundamentals and applications taught helps in preparing students for various out-reach programs.
Corrosion Science and Engineering	CH-13	Fundamentals and practical applications of corrosion science and engineering help students to take up career in research. Also prepares students for a career in industry.
Quantum Chemistry & Group Theory	CH-14	Train students to gain expertise in theoretical chemistry. Students are trained to handle modelling software packages. Students apply these for metal-

		complexation, weak intermolecular interactions, thermodynamic calculations.
Molecular Spectroscopy	CH-15	Train students to gain expertise in theoretical chemistry. Besides applied experimental spectroscopy is taught which helps candidate in research career and subsequent job prospects. Special techniques such as matrix isolation spectroscopy, laser-Raman techniques are taught with experimental demonstration.
Lasers and Application	CH-16	(a) Both fundamentals and general applications of Lasers are taught. (b) Students handle lasers in the practical for technological applications. (c) Students handle lasers for various analytical chemistry applications.
Nanomaterials and Advanced Chemical Sensors	CH-17	The fundamental knowledge gained in this course had helped to (a) understanding and development of materials (b) tailor made materials for preparation of chemical sensors (c) indigenous sensors (d) special sensors (for e.g. in-sodium) which have to be developed - which will not be supplied by commercial sources.
Course on Research Methodology	CH-RM	Ethics in research, plagiarism, manuscript writing, Data analysis, presentation of results are dealt extensively. Ensure students are ready for taking up research work.

M.Phil. in PHYSICAL SCIENCES (Program Code: PHYS02)

Course Structure:

I. Courses at BARC

Program Code : PHYS02	Programme Specific Outcome	Apply principles of basic science concepts in understanding, analysis and prediction of physical systems.
		Introduce advanced ideas and techniques required in emergent areas of Physics.
		Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.
		Understand the basic concepts of research, data collection and presentation, scientific report writing, and ethics in research
		Gain an overall practical experience to decide and apply the appropriate method in future experimental investigations.
		Get the exposure to the steps needed towards completing a focused topic as well as the research areas of thesis supervisor.

(A) Foundation Courses

Sr. No.	Name of the Course	Course code
1	MATHEMATICAL PHYSICS	PH 501
2	QUANTUM MECHANICS	PH 502

3	STATISTICAL PHYSICS	PH 503
4	ELECTROMAGNETIC THEORY	PH 504
5	COMPUTATIONAL PHYSICS	PH 505

(B) Core Courses:

Sr. No.	**Name of the Course**	**Course code**
1	Nuclear Physics	PH 601
2	Atomic, Molecular & Laser Physics	PH 602
3	Plasma Physics & Technology	PH 603
4	Physics of Materials and Surfaces	PH 604
5	Reactor Physics & Technology	PH 605
6	Accelerator Physics & Technology	PH 606
7	Astrophysics	PH 607
8	Electronics	PH 608
9	Health Physics and Radiation Detectors	PH 609

(C) Experimental and Lab Courses

Sr. No.	**Name of the Course**	**Course code**
1	Engineering Drawing & Workshop Practices	PH 610
2	Research Methodologies and Methods of Experimental Physics	PH 611

(D) Elective Courses

Sr. No.	**Name of the Course**	**Course code**
1	Special topics in Mathematical Physics	PY 701

2	Selected Topics in Classical Mechanics	PY 702
3	Chaos and Nonequilibrium Statistical Mechanics	PY 703
4	Nonlinear Dynamics	PY 704
5	Advanced Computational Physics	PY 705
6	Stochastic Physics	PY 706
7	Selected Topics in Nuclear Physics	PY 707
8	Advanced Accelerator Physics & Technology	PY 708
9	Introduction to Neutrino Physics	PY 709
10	High Energy Astrophysics	PY 710
11	Synchrotron Radiation and its Applications	PY 711
12	Selected Topics in Atomic and Molecular Physics	PY 712
13	Advanced Photonics	PY 713
14	Quantum Optics and Information	PY 714
15	High Power Lasers and Applications	PY 715
16	Laser-Matter Interactions and Applications to Advanced Material Processing	PY 716
17	Computational Plasma Physics: Introduction to Particle in Cell (PIC) Technique	PY 717
18	Nonlinear Plasma Theory	PY 718
19	Modeling and Simulations in Physics	PY 719
20	Selected topics in Condensed Matter Theory	PY 720
21	Organic Semiconductor Devices	PY 721
22	Single Crystal Growth and Devices	PY 722
23	Advanced Magnetism and Superconductivity	PY 723
24	Neutron as a Probe of Condensed Matter	PY 724
25	Structure and Crystallography of Biomolecules	PY 725
26	Advanced Reactor Physics	PY 726

27	High Energy Density Physics: Theory	PY 727
28	High Energy Density Physics: Experimental	PY 728
29	Nuclear Data Physics for Advanced Nuclear Applications	PY 729
30	Advanced Computational Methods for Steady State and Transient Behaviour of Neutron Transport	PY 730
31	Accelerator Driven Systems	PY 731

Course Outcomes:

(A) Foundation Courses

Name of the Course	Course code	Course Outcome
MATHEMATICAL PHYSICS	PH 501	Understand and apply mathematical techniques for describing and deeper understanding of physical systems.
QUANTUM MECHANICS	PH 502	Understand and apply principles of Quantum mechanics for understanding the physical systems in quantum realm.
STATISTICAL PHYSICS	PH 503	Understand and apply statistical methods for describing the classical and quantum particles in various physical systems and processes.
ELECTROMAGNETIC THEORY	PH 504	Gain knowledge in understanding the principles and dynamic phenomena of electromagnetism that occur in the case of time-varying sources (local charges and currents). Equips the students with the necessary mathematical knowledge for a detailed and accurate description of these phenomena and for solving related problems.
COMPUTATIONAL PHYSICS	PH 505	Gain knowledge in basic concepts in computational & numerical skills and apply them for understanding and describing complex physical systems.

(B) Core Courses:

Name of the Course	Course code	Course Outcome
Nuclear Physics	PH 601	Understand the properties and structure of nuclei, nuclear reaction mechanisms and their role in formation of universe consisting of different elements.
Atomic, Molecular & Laser Physics	PH 602	Understand the role of atoms and molecules in the structure and properties of mater. Describe different types of atomic and molecular spectra with and without external field.
Plasma Physics & Technology	PH 603	Describe basic concept of plasma, its physical parameters and applications. Describe basic processes in plasma and associated theory and solve simple plasma physics problems.
Physics of Materials and Surfaces	PH 604	Able to formulate basic models for electrons and lattice vibrations for describing the physics of crystalline materials; and understand band structure and electrical/optical properties, magnetism, superconductivity and surface structure of a material, .
Reactor Physics & Technology	PH 605	Understand the basic principle of nuclear power generation and physics design of a reactor.
Accelerator Physics & Technology	PH 606	Understand working principles and design concepts of different accelerators and their applications in industry and research in basic and applied sciences.
Astrophysics	PH 607	Able to identify and explain the properties of different astrophysical objects, learn experimental techniques to study them, understand the fundamentals of radiative transfers, theory of accretion and jets & outflows.
Electronics	PH 608	Understand how an analog signal is processed through different electronics modules and converted to digital signals,

		stored in memory and transferred to another deivice.
Health Physics and Radiation Detectors	PH 609	Gain basic knowledge of different types of radiations, doses, shielding, health effects and safety

(C) Experimental and Lab Courses:

Name of the Course	Course code	Course Outcome
Engineering Drawing & Workshop Practices	PH 610	Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.
Research Methodologies and Methods of Experimental Physics	PH 611	Understand the basic concepts of research, data collection and presentation, scientific report writing, and ethics in research

(D) Elective Courses:

Name of the Course	Course code	Course Outcome
Special topics in Mathematical Physics	PY 701	Learn about a few special topics in mathematical methods- difference equations, local analysis and global analysis.
Selected Topics in Classical Mechanics	PY 702	Learn about transformation theory of mechanics, integrable systems, canonical perturbation theory and near–integrable systems
Chaos and Nonequilibrium Statistical Mechanics	PY 703	Learn about Chaos and non-linear statistical mechanics involving Boltzmann and Liouville equation, Green-Kubo formulae, nonlinear maps, open systems and dynamical foundation of Boltzmann equation
Nonlinear Dynamics	PY 704	Learn about instabilities and chaos of periodically forced nonlinear oscillators, bifurcations and chaos in laboratory-scale systems, control and synchronization of

		nonlinear phenomena, experiments and numerical projects
Advanced Computational Physics	PY 705	Learn different programming languages and able to solve physics problems using advanced computer programming and/or Monte-Carlo simulation.
Stochastic Physics	PY 706	Learn about classical theory of Brownian motion, nucleation and coagulation theory and growth models.
Selected Topics in Nuclear Physics	PY 707	Learn about theoretical tools and techniques of advanced nuclear physics research areas and topics of current interest.
Advanced Accelerator Physics & Technology	PY 708	Learn about proton and heavy ion advanced accelerators, Giga-watt pulsed power & industrial accelerators, beam dynamics and design of advanced accelerators.
Introduction to Neutrino Physics	PY 709	Able to appreciate the intense activity worldwide in the field of neutrino physics. Get a brief exposition of a non-invasive method of monitoring fissile materials using neutrinos.
High Energy Astrophysics	PY 710	Able to identify and explain the properties of different astrophysical objects, learn experimental techniques to study them, understand the fundamentals of radiative transfers, theory of accretion and jets & outflows.
Synchrotron Radiation and its Applications	PY 711	Learn about the basic of production of Synchrotron radiation, beam line instrumentation and experimental techniques to study atomic, molecular and cluster physics
Selected Topics in Atomic and Molecular Physics	PY 712	Learn about coherent spectroscopy, physics with trapped ions and atoms, and behaviour of atoms and molecules under intense fields.
Advanced Photonics	PY 713	Learn the basics of LASER, fibre and non-linear optics, and get exposed to nano-photonics and meta-materials.

Quantum Optics and Information	PY 714	Learn about quantum theory of radiation, light atom interaction, ultra-cold atoms, quantum degenerate gases, and elements of atom optics and quantum information.
High Power Lasers and Applications	PY 715	Learn about non-linear optical processes, Laser dynamics and pulse generation, ultra-short pulse generation, amplification & compression and their applications.
Laser-Matter Interactions and Applications to Advanced Material Processing	PY 716	Learn about laser matter interaction, surface characterization, measurement & diagnostic techniques, and applications to advanced material processing
Computational Plasma Physics: Introduction to Particle in Cell (PIC) Technique	PY 717	Make mathematical modelling of a particle in a cell and solve Maxwell's equations.
Nonlinear Plasma Theory	PY 718	Learn about non-linear waves, non-linear wave-wave interaction and wave-particle interaction.
Modeling and Simulations in Physics	PY 719	Learn about electronic structure theory and modelling & simulations using Monte Carlo and Cluster Molecular dynamics
Selected topics in Condensed Matter Theory	PY 720	Learn about the application of quantum mechanical and atomistic lattice dynamics and computer simulations to model, understand, and predict the properties of real materials.
Organic Semiconductor Devices	PY 721	Learn about the techniques of preparation of organic thin films and their characterization, molecular electronics, organic electronics, organic solar cells and organic gas sensors.
Single Crystal Growth and Devices	PY 722	Learn about the techniques of single crystal growth, their characterization and applications
Advanced Magnetism and Superconductivity	PY 723	Learn about magnetism, magnetic exchange interaction, spintronics and superconductivity.
Neutron as a Probe of Condensed Matter	PY 724	Learn about neutron scattering, crystal structure study using neutron diffraction technique, neutron reflectometry and dynamics in condensed matter.

Structure and Crystallography of Biomolecules	PY 725	Learn about the computational and experimental methods of determining 3D structures in protein and nucleic acid, macromoleculer crystallisation and characterization, diffraction data collection and data processing
Advanced Reactor Physics	PY 726	Learn about neutron transport theory, numerical methods for solution of the multi-group neutron diffusion equation, reactor dynamics and reactor noise and its applications
High Energy Density Physics: Theory	PY 727	Learn about hydrodynamic and shock wave, equation of state and radiation opacities, radiation hydrodynamic instabilities and inertial confinement fusion.
High Energy Density Physics: Experimental	PY 728	Learn about the physics of high energy density effects in matter, energy storage systems, energetic materials and applications, diagnostic techniques and data interpretation.
Nuclear Data Physics for Advanced Nuclear Applications	PY 729	Learn about nuclear physics data, representation of nuclear data, nuclear data processing, multi-grouping, concept of critical facility and exposure to error propagation and sensitivity studies.
Advanced Computational Methods for Steady State and Transient Behaviour of Neutron Transport	PY 730	Learn about solution of transport equation, neutron thermalization, treatment of resonances, solution of time dependent transport equation and solution of the fuel depletion equations.
Accelerator Driven Systems	PY 731	Learn about spallation neutron sources, sub-critical reactor, accelerator driven systems and waste transmutation

Course Structure:

II. Courses at IGCAR

Program Code : PHYS02	Programme Specific Outcome	Training in carring out fast reactor based research.
		Unique exposure to nuclear fuel cycle activities
		Material development for specific applications

Course Structure:

Sr. No.	Name of the Course	Course code
1	Mathematical Methods	PY1
2	Computational Methods	PY2
3	Introductory Reactor Physics and Engineering	PY3
4	Nuclear Physics and Nuclear Data	PY4
5	Engineering Drawing and Laboratory Practices and Experimental Methods	PY5
6	Reactor Materials	PY6
7	Radiation Detection and Measurements	PY7
8	Reactor Types and Advanced Reactor Concepts	PY8
9	Radiation Shielding Design and Protection	PY9
10	Reactor Dynamics and Safety Analysis	PY10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	PY11
12	Fluid Dynamics and Thermal Hydraulics	PY12
13	Advanced Computational Methods in Reactor Physics	PY13
14	Experimental and Operational Reactor Physics	PY14
15	Design Methods in Thermal and Fast Reactors and Computer codes	PY15
16	In Core of Fuel Management	PY16

Course Outcomes:

Name of the Course	Course code	Course Outcome
Mathematical Methods	PY1	Students learn vector spaces, Hilbert space, matrix methods, eigen value problems, differential and integral equations, complex variables.
Computational Methods	PY2	Since some complex equations cannot be solved analytically, numerical and computational methods are important. Students study the basics of computer architecture - hardware and software,
		Learn Various numerical methods
		Programming in Fortran and C
Introductory Reactor Physics and Engineering	PY3	Learn neutron physics, reactor physics including fast reactors; reactor kinetics and reactor control, all needed for working with nuclear reactors.
Nuclear Physics and Nuclear Data	PY4	Learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, nuclear models, nuclear data evaluation and processing which are Needed to work with nuclear reactors and for nuclear research.
Engineering Drawing and Laboratory Practices and Experimental Methods	PY5	Machine Drawings Projections, drafting, Autocad other material in this course are essential for engineers to produce accurate drawing for fabrication of small and large components for nuclear reactors and associated facilities.
Reactor Materials	PY6	Properties of nuclear fuels such as uranium, uranium oxide, plutonium, carbide and nitride fuels, MOX fuel, fuel fabrication, structural materials and clad materials, zirconium and alloys, moderators, Mechanical properties of materials, Radiation effects in materials, corrosion of metals and related topics makes this course a very important one for nuclear scientists and engineers.
		Ability to Solve unforeseen materials problems in operational reactors
		Ability to look for future candidate materials
Radiation Detection and Measurements	PY7	Required for radiation, safety workers and related scientists: Interaction of radiation with matter, radiation detectors including

		gas, semiconductor and scintillation detectors; ionization chambers; high resolution gamma spectroscopy, Monte Carlo simulations
Reactor Types and Advanced Reactor Concepts	PY8	Students will learn about different type of reactors such as Thermal reactors, fast reactors, High Temperature Reactor(HTR) and Advanced Heavy Water Reactor (AHWR). Metal fuelled FBR and Accelerator driven systems (ADS); Indian reactors APSARA, CIRUS, DHRUVA, PHWR, FTBR AND PFBR
Radiation Shielding Design and Protection	PY9	Students will study Radiation sources, its interaction with matter; summary of basic interaction mechanisms of alpha, beta, gamma/x -rays and neutrons with matter; radiation dosimetry; Interaction of radiation with biological matter; Radiation toxicity, Risk factors; radiation protection, shielding, and nuclear emergency management
Reactor Dynamics and Safety Analysis	PY10	Neutron kinetics and thermal effects. Feedback effects; Description of main reactor systems. Coolant system behaviour. Plant dynamics; safety systems; Reliability and Probabilistic Safety Analysis and related topics are taught in this course
Fuel Cycle Physics and Introduction to Fuel Cycle	PY11	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India. Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Issues related recycling – Effective fissile content of discharged fuel for next cycle; re-fabrication of fuel for the next cycle Activity and toxicity of discharged fuel
Fluid Dynamics and Thermal Hydraulics	PY12	Fluid continuum – Properties of fluids – Methods of describing fluid motion – Kinematics of fluid streamlines; Navier Stokes equations; Hydrostatics – Manometry; Fluids subjected to uniform linear acceleration and uniform rotation; Thermal hydraulics.

		Important specialisation for understanding behaviour of reactor coolants (liquid sodium and water) for safe reactor operation
Advanced Computational Methods in Reactor Physics	PY13	Students will learn Methods of solving neutron Diffusion equation; Finite element method- its advantages and disadvantages. Coarse mesh rebalancing. Methods of solving neutron transport equation; (a) PN method (b) Discrete ordinates method (c) Collision probabilities methods; Detailed burnup chain with all minor actinides. Solution of the burnup equations. Constant flux and constant power approximations.
Experimental and Operational Reactor Physics	PY14	In-depth exposure and develop expertise to experiential aspects of Reactor operations
		Dynamical methods to evaluate and monitor reactivity measurements
		Expertise to monitor delayed neutron counting and noble gas fission products to detect early stages of fuel failures.
		Exposure to operation aspects of various types of reactors
Design Methods in Thermal and Fast Reactors and Computer codes	PY15	Exposure to model and design of both thermal and fast reactors using neutron production, transport and reactions
		Expertise to use various design and validation codes for neutronics
In Core of Fuel Management	PY16	Develop expertise in various safety aspects of in-core fuel handling and management in different types of reactors
		Exposure to reactor specific fuel handling methods and controls
		Exposure to specialised computer codes for in-core fuel handling

III. Courses at RRCAT

Program Code : PHYS02	Programme Specific Outcome	Impart training to students to increase the knowledge base required for research work
		Enhance analytical and computational skill of the students required for carrying out research work
		Provide training to work with various scientific equipment including sophisticated lasers and radiation available from synchrotron sources Indus-1 and Indus -2

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	03PHYS02-001-C
2	Magnet Physics and Technology	03PHYS02-002-C
3	Laser Physics and Technology	03PHYS02-003-C
4	Electromagnetic Theory	03PHYS02-004-C
5	Accelerator Physics andBeam Diagnostics	03PHYS02-005-C
6	Reactor Physics, Radiation Physics, and Safety Issues	03PHYS02-006-C
7	Numerical and Mathematical Techniques and Scientific	03PHYS02-007-C
8	Materials Science and Technology- I	03PHYS02-008-C
9	Applications of Lasers in Nuclear Science, Industry	03PHYS02-009-C
10	Applications of Accelerators in Nuclear Science, Industry	03PHYS02-010-C
11	Vacuum Physics and Technology	03PHYS02-011-C
12	Quantum Mechanics	03PHYS02-012-C
13	Research Methodology	03PHYS02-013-C

(B) Elective Courses

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	03PHYS02-001-E
2	Magnet Physics and Technology	03PHYS02-002-E
3	Laser Physics and Technology	03PHYS02-003-E
4	Electromagnetic Theory	03PHYS02-004-E
5	Accelerator Physics andBeam Diagnostics	03PHYS02-005-E
6	Reactor Physics, Radiation Physics, and Safety Issues	03PHYS02-006-E
7	Numerical and Mathematical Techniques and Scientific	03PHYS02-007-E
8	Materials Science and Technology-I	03PHYS02-008-E
9	Applications of Lasers in Nuclear Science, Industry	03PHYS02-009-E
10	Applications of Accelerators in Nuclear Science, Industry	03PHYS02-010-E
11	Vacuum Physics and Technology	03PHYS02-011-E
12	Quantum Mechanics	03PHYS02-012-E

(C) Laboratory Courses

Sr. No.	Name of the Course	Course code
1	Laser and Applications	03PHYS02-001-L
2	Accelerators related applications	03PHYS02-002-L
3	Electronics	03PHYS02-003-L

(D) Reading Courses

Sr. No.	Name of the Course	Course code
1	Self-Reading	03PHYS02-001-R

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Engineering Mathematics	03PHYS02-001-C	This course reviews topics in Mathematics which are usually covered at the Master's level and are essential to understand the concepts of science and engineering
		This Course also deals with the advanced topics needed for carrying out research work in different areas of science and engineering
Magnet Physics and Technology	03PHYS02-002-C	Basic understanding of magnetism and its application.
		Analytical approach of magnet design mainly for accelerator application and field measurement technique.
		Fabrication technique and alignment of magnets.
Laser Physics and Technology	03PHYS02-003-C	This course introduces basic mechanism and principles of lasers, beam propagation, and optical resonators
		Introduction to physics and technology of various types of lasers
		This course introduces basic nonlinear optics
Electromagnetic Theory	03PHYS02-004-C	This course is meant for physicists and engineers. It reviews the M. Sc. Level and B. Tech level electromagnetic theory, and further strengthens some of the intricate concepts, and introduces new topics
		It emphasizes basic concepts needed to solve the electromagnetic boundary value problems, and prepares the students to develop better understanding of the computer codes used for that
		Students are expected to develop a better and rigorous understanding of generation of electromagnetic radiation, typically in synchrotron radiation source.
		Students learn about different types of electromagnetic waves – (i) plane waves, including its reflection and refraction at dielectric surface. (ii) Gaussian beams and Bessel beams, (iii) modes in waveguides and cavities, including its transport in microwave components and (iv) modes in optical fiber.

Accelerator Physics and Beam Diagnostics	03PHYS02-005-C	The course introduces basic concepts of accelerator physics and beam diagnostics.
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Reactor Physics, Radiation Physics, and Safety Issues	03PHYS02-006-C	Awareness about natural, man-made radiation, dose contribution from various practises, units and quantities, biological effects of radiation exposure and ICRP recommendations on radiation protection
		Awareness about the radiation hazards at work place, safe practises to be followed, exposure control measures, shielding philosophy and radiation detection.
		Understanding the radiation hazards at high energy electron and proton accelerators and laser facilities. Dose build up effects due to electromagnetic and hadronic cascade and its impact on radiation safety and tackling mechanisms
		Gaining fundamental concepts in reactor physics, interaction of various kind of radiation with matter.
Numerical and Mathematical Techniques and Scientific	03PHYS02-007-C	For rigorous and correct analysis of data (which are the outcome of research work), learning numerical and mathematical techniques is absolutely essential.
		This course teaches interpolation, extrapolation, error analysis etc which are integral parts of data analysis. The finite element method is a numerical method for solving problems of applied science and engineering, for example, structural analysis, heat transfer, fluid flow, mass transport etc
		Concept of scientific computing is necessary for numerically analyzing experimental and analytical results. For the same, programming languages (C and fortran) are taught.
		Different operating systems (windows, linux etc), which are taught, also help in understanding the working of computers, in turn, different aspects of scientific computing
Materials Science and Technology-I	03PHYS02-008-C	The course reviews the master's level solid state physics with certain advanced topics
		The advanced topics covered include: nonlinear properties of optical materials,

		electronic materials for novel applications like spintronics and introduction to symmetry and ferroelectric materials
		Students learn structures of various materials including alloys, ceramics, glasses, polymers, and composites
Applications of Lasers in Nuclear Science, Industry	03PHYS02-009-C	This course covers various applications of lasers in high resolution spectroscopy in metrology and medicine
		This courses exposes application of lasers in material processing
		This course introduces application of lasers in isotope separation
Applications of Accelerators in Nuclear Science, Industry	03PHYS02-010-C	This course aims to expose students to various applications of accelerators.
		Students become aware of applications in accelerator based radiotherapy and radiation processing
Vacuum Physics and Technology	03PHYS02-011-C	This course aims to introduce the basics of theory of vacuum
		Introduces various vacuum systems and components
		Students learn how to design a vacuum system
Quantum Mechanics	03PHYS02-012-C	This course reviews master's level quantum mechanics with more emphasis on problem solving and applications
		This course also covers advanced topics which will enhance understanding in many-electron systems and photo-atom interaction
Research Methodology	03PHYS02-013-C	Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

(B) Elective Courses

Name of the Course	Course code	Course Outcome
Modern Optics	03PHYS02-001-E	This course reviews the basic understanding of geometrical & wave optics with emphasis on topics of importance to lasers, laser-based measurements and laser-based systems.
		This course helps scholars to develop a sound understanding of optics required for designing and modelling lasers and laser-based systems.
Advanced Accelerator Physics	03PHYS02-002-E	This course discusses electron and ion sources, and the processes involved.
		This course discusses concepts related to proton and heavy ion linacs, transport of ion beams, and beam instabilities
		The course introduces advanced topics of free electron lasers, linear accelerator-based synchrotron radiation sources, laser plasma based accelerators and the concept of Accelerator Driven Systems.
Statistical Physics	03PHYS02-003-E	This course reviews master's level statistics focusing attention on quantum degenerate gases.
		This course helps scholars to develop deeper understanding of phase transition and concepts required to handle many-body systems of condensed matter and plasma physics
Plasma Physics and Technology	03PHYS02-004-E	This course aims to make students of basic plasma physics and the involved technology
		This course exposes students various aspects of plasma physics like waves in plasma, plasma production, plasma diagnostics, and plasma radiation
		This course introduces laser-plasma interaction at ultrahigh intensities
Materials Science & Tech. II	03PHYS02-005-E	To understand and interpret phase diagram for material synthesis.
		To learn about material synthesis by solid state and liquid phase route and methods of preparation of ceramics, thin film, nano-powder and single crystal
		To evaluate the direct & indirect band-gap, impurity & defect absorption, molecular vibrations by spectroscopic

		techniques like UV-vis-NIR spectroscopy, FTIR and Raman spectroscopy.
		To get acquainted with various spectroscopic instruments for materials like polarized light microscope, Scanning electron microscope, Transmission electron microscope and Scanning probe microscopes (AFM, STM).
Advanced Beam dynamics	03PHYS02-006-E	This course is meant for physicists, specializing in the field of particle accelerators. The selected topics on beam dynamics form the basis of design of modern particle accelerators.
		Students are expected to develop a clear understanding of how a charge particle beam evolves under the influence of applied electromagnetic field, including the self-force due to space charge
		Students learn about the physics underlying the phenomenon of emittance growth, and beam halo formation, which is a topic of current interest.
		The course prepares the students for using computational tools to address the design problems in the area of beam dynamics
Bio-photonics	03PHYS02-007-E	This course aims to introduce interaction of light with cells and tissues
		This course introduces optical imaging of tissues in turbid medium
		This course exposes the students to aspect of biomedical diagnosis and micromanipulation
Advance course on atom-photon interaction	03PHYS02-008-E	This course deals with interaction of light with matter at fully quantum and semi-classical levels
		This course exposes students to various perturbative and non-perturbative techniques to determine probabilities
		This course covers coherent dynamics of atoms in the interaction with light
		This course covers concepts of coherence of light and various quantum state of radiation field
Concepts in X-ray Physics	03PHYS02-009-E	The course deals with the basics of interaction between matter with x-rays
		The various x-ray based materials characterisation techniques like X-ray diffraction, X-ray absorption and

		photoelectron spectroscopy are dealt in details.
		This course is beyond the content matter of normal master level courses.
Physics of semiconductor Quantum structures	03PHYS02-010-E	The aim of this course is to introduce the students to various aspects of semiconductor nanostructures
		Students learn aspects of growing nanostructures
		Students learn various methods of characterising nanostructures

(C) Laboratory Courses

Name of the Course	Course code	Course Outcome
Laser and Applications	03PHYS02-001-L	Students get first-hand experience in handling various lasers and laser-based instrumentations
		Students learn various techniques to align and characterize lasers
Accelerators related applications	03PHYS02-002-L	Students get first-hand experience in handling various instruments needed for accelerator technology
Electronics	03PHYS02-003-L	Students get first-hand experience in handling various instruments required for electronics, image processing, and RF components
		Students are also expected to learn and handle GUI software and communication protocols

(D) Reading Courses

Name of the Course	Course code	Course Outcome
Self-Reading	03PHYS02-001-R	This course helps scholars to develop understanding in some of the key topics related to his/her research work

M.Sc. in ENGINEERING SCIENCES

(Program Code: ENGG03)

Course Structure:

I. Courses at BARC

Program Code : ENGG03	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Accelerator Physics and Technology	EN501
2	Engineering Mathematics	EN502-505
3	Health Physics and Rad & Indl Safety	EN506
4	Nuclear Fuel Cycle Technology	EN508
5	NPP & Advanced Reactor Concepts	EN509
6	Reactor Physics and Engineering	EN510

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Accelerator Physics and Technology	EN501	The course introduces basic concepts of accelerator physics, Vacuum and cryogenic systems
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Engineering Mathematics	EN502-505	Advanced knowledge in computational data analysis, data fitting and error analysis

		Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
Health Physics and Rad & Indl Safety	EN506	Learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Nuclear Fuel Cycle Technology	EN508	Familiarisation with font and back end of nuclear fuel cycle technology
		Knowledge of radioactive waste generation on nuclear fuel burning and its processing
NPP & Advanced Reactor Concepts	EN509	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts
		Familiarization with reactor physics design challenges
Reactor Physics and Engineering	EN510	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with nuclear reactors.

(A) MECHANICAL COURSES

(A1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Code design for PVP	EN610
2	Computational fluid Dynamics and Heat Transfer	EN611
3	Finite Element Method	EN621
4	Fracture Mechanics	EN622
5	Mechanics of Solids	EN624

(A2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Machine Design	EN711
4	Material Science in Nuclear Engineering	EN712
5	Multi-scale material modelling	EN715
6	Nuclear Emergencies	EN716
7	Reliability Engineering	EN718
8	Vibration	EN721

(A3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(A1) Core Engineering

Name of the Course	Course code	Course Outcome
Code design for PVP	EN610	Basis of ASME Sec.VIII and Sec.III eqns. for Pressure Vessel and Piping Design
		Nozzle openings, Vessel design under ext. pressure
		ANSI / ASME B31.1 and B31.3 piping code
		NDE Examination of welds, Acceptance standard
Computational fluid Dynamics and Heat Transfer	EN611	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer

Finite Element Method	EN621	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Fracture Mechanics	EN622	LEFM and EPFM, Material fracture props. determination
		PTS event of RPV and Master Curve Concept
		Computational Fracture Mechanics
		Fracture Mechanisms
Mechanics of Solids	EN624	Principles and Fundamental Equations of Elasticity
		Analysis of Stress and Strain, Thermal Stresses
		Introduction to Plasticity
		Theory of Plates and Shells

(A2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Programming Language C++
		Parallel Programming
		Scientific Visualization
		Artificial Neural Network
Fluid Power Technology	EN709	Basic principles of hydraulics and pneumatics, pressure control
		Fluid power pumps and compressors, Fluid experiments
		Directional and flow control valves, Fluid Logic & Control
		Advanced Hydraulic Control Circuits, Electronics and Instrumentation for Hydraulics
Machine Design	EN711	Basic Principles of Machine Design, Design and Drawing Practices
		Sealing Methods
		Special Dimensional Inspection Techniques
		Advanced Manufacturing Techniques
Material Science in Nuclear Engineering		Metallurgy of steels
		Nuclear Materials

	EN712	Advanced Polymeric materials and Composites
		Corrosion
Multi-scale material modelling	EN715	Atomistic models: Molecular dynamics, Monte Carlo methods
		Inter-atomic potentials, Mesoscopic methods
		Modeling at microscale
		Bridging the scale gaps between different simulation levels
Nuclear Emergencies	EN716	Radiation Shielding, Nuclear Waste Management
		Nuclear Accidents/emergencies, Effects of Hiroshima & Nagasaki bombing
		Medical decontamination with demonstration
		Monitoring of High radiation field area
Reliability Engineering	EN718	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Vibration	EN721	Single and Multi-degree-of-freedom Systems, Free vibration
		Response of Systems To Ground Motion: Earthquake motion
		Flow Induced Vibration
		Vibration Measurement and Signal Analysis

(A3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
MiniProject		To provide a hands-on experience of working in an

	EN593	ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem

(B) CHEMICAL ENGINEERING COURSES

(B1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Chemical Reaction Engineering	EN601
2	Advanced Mass Transfer	EN604
3	Code design for PVP	EN610
4	Computational Fluid Dynamics and Heat Transfer	EN611
5	Nuclear Chemical Engineering	EN628
6	Process Dynamics and Control	EN634
7	Process Modeling, Simulation and Optimization	EN635

(B2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Material Science in Nuclear Engineering	EN712
4	Membrane Technology	EN714

(B3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591

2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(B1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Chemical Reaction Engineering	EN601	Fundamentals of Non-ideal reactors & RTD studies
		Understanding Non-isothermal effects & dynamical behaviour
		Overview of Heterogeneous reactions
		Approaches in Advanced reaction engineering & reactor design
Advanced Mass Transfer	EN604	Understanding Mass transfer with and without chemical reactions
		Rate based approaches for design
		Selection and design of various contacting equipment
		Process intensification approaches
Code design for PVP	EN610	Overview of Theories for pressure vessel design
		ASME Sec. VIII Div. 1 and Div - II equations
		Pressure vessel design as per ASME
		Design of piping as per B31.1 piping code.
Computational Fluid Dynamics and Heat Transfer	EN611	Understanding Kinematics of fluid flow and governing equations
		Classification of Partial Differential Equations & their discretization
		Convective heat transfer for internal and external flows
		Numerical Solution of fluid flow and heat transfer equations
Nuclear Chemical Engineering	EN628	Overview of Recovery and processing of nuclear materials
		Uranium conversion and reconversion

		Isotope Separation
		Nuclear Waste Management
Process Dynamics and Control	EN634	Introduction to process control & control loop dynamics
		Fundamentals of state-space controls, state, measurement equations
		General solution of the state equation
		Multi-variable controls, de-coupling, relative gain array
Process Modeling, Simulation and Optimization	EN635	Formulation of Dynamic and steady state models
		Flow sheet Analysis & Plant Simulation
		General Approaches for Non-Linear Systems
		Plant optimisation by Genetic Algorithms and Neural Nets

(B2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Understanding Programming Language C++
		Finite difference, finite volume, finite element discretization, grid generation, artificial neural network
		Parallel Programming, Message Passing Interface and MPI communications
		Scientific Visualization methods
Fluid Power Technology	EN709	Basic principles of Hydraulics and pneumatics
		Properties of hydraulic fluids and pneumatic air
		Roto-dynamic pumps, pressure and flow control
		Approaches in Hydraulic Circuit Design
Material Science in Nuclear Engineering	EN712	Overview of Nuclear Materials & their classifications
		Structure and properties of nuclear materials
		Processing of Nuclear Materials

<table>
<tr><td></td><td></td><td>Material characterization techniques</td></tr>
<tr><td rowspan="4">Membrane Technology</td><td rowspan="4">EN714</td><td>Overview of Novel Membranes</td></tr>
<tr><td>Preparation and Characterization</td></tr>
<tr><td>Membrane Technologies</td></tr>
<tr><td>Applications of Membrane Technology</td></tr>
</table>

(B3) Non-Subject Assignments

<table>
<tr><th>Name of the Course</th><th>Course code</th><th>Course Outcome</th></tr>
<tr><td rowspan="2">VivaVoce–I& VivaVoce-II</td><td rowspan="2">EN591</td><td>Assessment of Fundamental Concepts in Nuclear Engineering</td></tr>
<tr><td>Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering</td></tr>
<tr><td>Practicals</td><td>EN592</td><td>Enhancing skills and reporting</td></tr>
<tr><td rowspan="4">MiniProject</td><td rowspan="4">EN593</td><td>Enhancing Skill Set for handling real life problems</td></tr>
<tr><td>Understanding and Documentation skills</td></tr>
<tr><td>Assessment of Fundamental Concepts in Nuclear Engineering</td></tr>
<tr><td>Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering</td></tr>
</table>

(C) METALLURGY

(C1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Corrosion	EN615

2	Extractive Metallurgy	EN620
3	Mechanical Metallurgy	EN623
4	Nuclear Materials	EN628
5	Nuclear Metallurgy	EN629
6	Physical Metallurgy	EN630
7	Process Control & Instrumentation	EN631

(C2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Digital Signal Processing & Image Processing	EN706
3	Image processing and Machine Vision	EN710
4	Materials Characterization	EN713
5	Multi scale Material Modeling	EN715
6	Nuclear Chemical Engineering	EN628
7	Nuclear Emergencies	EN716
8	Welding Science & Technology	EN723

(C3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(C1) Core Engineering

Name of the Course	Course code	Course Outcome
Corrosion	EN615	Understanding electrochemical theory of corrosion & corrosion basics
		General principles of corrosion control
		Forms of corrosion and its mitigation
		Corrosion problems in nuclear industry and its mitigation
Extractive Metallurgy	EN620	Thermodynamics and kinetics of metal extraction
		Advanced material processing techniques
		Process metallurgy of rare metals, special materials and alloys
		Process metallurgy of U, Th, Pu, Be, Zr, Hf, Nb, Ta & rare earths
Mechanical Metallurgy	EN623	Exposure to stress tensor, state of stress, principal stress, hydrostatic, deviatoric stress
		Dislocations and deformation behaviour
		Creep & creep law, deformation mechanism map
		Fracture mechanics and fatigue of metals
Nuclear Materials	EN628	Vacuum melting & solidification, controlling casting defects of U, Zr and Ti alloys
		Cold & hot working, dynamic recovery, recrystallization of fuel tube, texture microstructure control
		Powder metallurgy of oxide, mixed oxide, carbide, intermetallic nuclear fuel material
		Applications of powder metallurgy in applications relevant to DAE
Nuclear Metallurgy	EN629	Fabrication of different types of fuel for research and power reactors

		Health physics, radioactivity and safety aspects of Pu handling
		Effects of irradiation on nuclear fuel and structural materials, hydriding related problems in Zr alloys
		Post irradiation examination (PIE) of nuclear fuel and structural material
Physical Metallurgy	EN630	Understanding basics of crystallography, crystal defects during irradiation
		Thermodynamics, phase equilibria & phase transformation
		Diffusion mechanism, equations & solutions
		Recovery, Recrystalization and Grain Growth
Process Control & Instrumentation	EN631	Understanding basic principles of measurement
		Sensors, transducers & transmission methods for pressure, vacuum, flow, level
		Principles of Automatic Control Systems
		Fail safe principles, simple logic circuits, ladder circuits for control action

(C2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Exposure to programming languages: C and C++
		Application of finite difference, finite volume, finite element techniques, ANN etc. in DAE
		Introduction to parallel programming concepts
		Data storage & visualisation techniques and case studies
Digital Signal Processing & Image Processing	EN706	Introduction to digital signal processing system & applications
		Discrete Fourier transform, fast Fourier transform

		Image processing, image enhancement, image segmentation & analysis, morphological operations
Image processing and Machine Vision	EN710	Introduction to digital image model representation, image sensor, digitizer, computer, standard file format
		Image enhancement segmentation and analysis, restoration
		Morphological operations and image compression
		Machine vision & introduction to image understanding
Materials Characterization	EN713	Introduction to microscopy techniques: optical, SEM, TEM, AFM, STEM, EBSD, FIM
		XRD and applications, basics of SIMS, RBS
		Analytical TEM, chemical analysis in materials science
		Thermal expansion and conductivity, TGA/DTA/DSC, mechanical properties
Multi scale Material Modeling	EN715	Introduction to types of models and multiscale approaches
		Atomistic models – molecular dynamics
		Basics of Monte Carlo methods
		Analysis of simulation results, bridging scale gap between different simulation levels
Nuclear Chemical Engineering	EN628	Recovery & processing of U, Th, Zr, rare earths from from ores / intermediates
		Uranium Conversion/reconversion
		Isotope Separation
		Nuclear Waste Management
Nuclear Emergencies	EN716	Introduction to nuclear fuel cycle, transportation of radioactive material
		Radiological accidents / emergencies
		Effects of nuclear detonation, testing nuclear weapons
		Emergency Response methodology/ Philosophy

Welding Science & Technology	EN723	Overview of various welding processes - arc welding, beam welding, hybrid welding
		Cold Bonding/Solid State Bonding
		Welding metallurgy under high cooling rates
		Types of welding defects and its prevention

(C3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I & VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
Mini Project	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem

(D) CIVIL ENGINEERING

(D1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1
2	Civil Engg Design of Concrete & Steel Strct II	EN608.2
3	Design Basis Hazards & Geotechnical Engg	EN621
4	Earthquake Engineeing & Structural Dyanmics	EN609
5	Finite Element Method	EN626
6	Mechanics of Solids	EN624

(D2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Struct Dynamics & Earthquake Engg	EN724
2	Construction Materials, Management & Quality	EN614
3	Safety & Reliability of Civil Engineering	EN722
4	Project Management	EN717

(D3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(D1) Core Engineering

Name of the Course	Course code	Course Outcome
Civil Engg Design of Concrete & Steel Strct I	EN608.1	Various structures of nuclear facilities; safety, seismic, design and quality classifications of structures
		Design loads on structures and load combinations as per BIS, ACI and AERB standards
		Design of RC structures; fracture mechanics concept in RC design
		Shallow and deep foundation design; machine foundation design

Civil Engg Design of Concrete & Steel Strct II	EN608.2	Design of prestressed concrete structures
		Design of lined and unlined reactor containment structures using RCC-G/BPEL/BAEL and ASME codes
		Design of steel structures using BIS, AERB and AISC standards
		Design of underground and overhead water retaining structures; design of natural draft cooling tower
Design Basis Hazards & Geotechnical Engg	EN621	Siting of nuclear facilities; hazards due to internal and external events; design basis natural hazards, such as, seismic, flood, wind, snow and solar radiations
		Human-induced design basis hazards, such as, aircraft/missile impact, explosions/blast, and toxic gas release
		Soils and its classifications; laboratory and field tests on soils and rock; compaction of soils; bearing capacity of soils and rocks
		Stages of geotechnical investigations; soil and rock sampling; geophysical investigations; seismic refraction survey, cross-hole seismic test; ERT; liquefaction potential of sites
Earthquake Engineeing & Structural Dyanmics	EN609	Seismic waves and wave propagation; time history; response spectra; seismic instrumentation
		Dynamic loadings; dynamic response of SDOF and MDOF systems; dynamics of continuum system
		Response spectra and time history approaches for determining seismic structural

		response; SSI and FSI; structural response in frequency domain
		Seismic requalification of existing installations; retrofitting techniques
Finite Element Method	EN626	Basis of FEM; energy principles; shape function requirements; C0 and C1 continuity
		Derivation of stiffness matrix and load vector for bar, beam, 2D plane and 2D iso-parametric elements; evaluation of strain and stress
		Incompatible quadrilateral elements; Tetrahedron, and hexahedron elements; plate bending elements; shell elements; patch test; adoptive meshing; error analysis
		Non-linear problems; material and geometric non-linearity
Mechanics of Solids	EN624	Concepts of elasticity; Equilibrium equations; Solution of 1-D boundary value problem; tensors algebra
		Analysis of stress and strain; transformation using direction cosines; principal planes; octahedral plane; state of pure shear; strain deviator tensor
		Strain displacement relationship; Isotropy and Anisotropy; Strain energy; Plane stress and plane strain problems; solution for beam bending problem; solution in polar co-ordinates; thermal stresses
		Analysis of thin and thick plates; shear deformation theories; membrane theory of shells of revolution and translation; bending analysis of shells; application to cylindrical, spherical and conical shells; introduction to plasticity

(D2) Electives

Name of the Course	Course code	Course Outcome
Advanced Struct Dynamics & Earthquake Engg	EN724	Concept of performance based seismic design; seismic demand; capacity of structures; performance levels
		Concept of seismic and vibration control; passive control; semi-active control; active control; base isolation techniques
		Methods of testing; qualification of system by testing; seismic instrumentation; measurement of displacement, velocity, acceleration
		Fluid-structure interaction techniques; multibody dynamics
Construction Materials, Management & Quality	EN614	Construction materials, such as, concrete, reinforcement, structural steel, paints, water-proofing materials
		Design of formworks; slip forms; prestressing systems
		QA in civil design, materials, construction, O&M, and regulatory inspection
		Dewatering; rock excavation, construction safety and JHA; mode of tendering; contract clauses; dispute adjudication
Safety & Reliability of Civil Engineering	EN722	Statistics and probability; discrete and continuous random variables; probability distributions
		Concept of structural safety; limit states; MVFOSM; Hasofer Lind reliability index; Cornell reliability index; Monte Carlo simulation
		Probabilistic safety assessment; seismic fragility analysis; seismic risk; health assessment of existing concrete and steel structures; rehabilitation and retrofitting

		techniques; service life prediction
		Concept of industrial safety; fire hazard analysis; safety in handling machinery, equipment and tools; fitness and protection of personnel
Project Management	EN717	Type, cost and schedule of nuclear power projects; resources of project; project organization chart; delegation of power
		Scheduling in a project by PERT, CPM, precedence diagram method; project management software for planning, scheduling and monitoring
		Preparation of target plan, updating of progress, monitoring variance and reporting; physical and financial monitoring; capital budgeting and expenditure control
		Contingency plan; construction management; project management; SWOT analysis; problem solving techniques

(D3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
Mini Project	EN5A93	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg.

(E) ELECTRICAL ENGINEERING

(E1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design I	EN602
2	Computer Based System Design I	EN612
3	Electrical Systems for Nuclear Power Plants	EN618
4	Modern Control Systems Design and Simulation	EN625
5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(E2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design II	EN702
2	Artificial Intelligence and its Applications	EN703
3	Computer Based System Design II	EN704
4	Digital Signal Processing & Image Processing	EN706
5	Image Processing & Machine Vision	EN710
6	Signal Conditioning, Recovery and EMI Aspects	EN719
7	Software Engineering	EN720

(E3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(E1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design I	EN602	Materials and Electrical Properties, NDT, MFL
		Superconducting Properties
		Understanding Control Techniques of Electrical Motors and Electronics
		FEM and Applications
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Electrical Systems for Nuclear Power Plants	EN618	Recapitulation of Power System Design Analysis
		Basics of Switchyard Design Principles
		Understanding Protection Systems
		Exposure to Electrical Systems in NPP
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity

		Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(E2) Electives

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design II	EN702	Understanding Vector Control of PM Synchronous Motors
		Exposure to Design and Applications of Variable Reluctance Stepper Motors and Switched Reluctance
		Understanding Pulse Power Techniques
		High Voltage Systems
Artificial Intelligence and its Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies

		Understanding Reinforcement Learning and Dynamic Programming
Computer Based System Design II	EN704	Exposure to Data Communication Interfaces for Control Applications, Fieldbuses
		Understanding Real Time System Design Principles
		Understanding IPC mechanisms in RTOS
		Exposure to Safety System Design Regulations
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics

		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(E3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(F) ELECTRONICS ENGINEERING

(F1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electronic Circuit Design Techniques	EN603
2	Advanced Nuclear Instrumentation	EN605
3	Embedded & Computer Based Sys. Design	EN619
4	Modern Control Systems Design and Simulation	EN625

5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(F2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Digital Signal Processing & Image Processing	EN706
3	Embedded Electronics Software	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720
7	Artificial Intelligence & Applications	EN703

(F3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(F1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electronic Circuit Design Techniques	EN603	Introduction to VLSI Design Flow, HDL, Design and Simulation of HPD
		Understanding Semiconductor Detectors , MEMS Desin
		Introduction to RF Electronics

		Understanding Transmission Lines, Waveguides, RF Amplifiers,
Advanced Nuclear Instrumentation	EN605	Understanding Electronics in Spectroscope Design
		Nuclear Instruments, Alpha, Beta and Gamma Detectors, Scintillation Counters
		Introduction to Accelerator Instrumentation
		Understanding Reactor Neutronic Instruments and Signal Processing
Embedded & Computer Based Sys. Design	EN619	Overview of Microprocessors and Interfacing
		Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements
		Exposure to Computer Communication, Encoding and Technologies
		Understanding Software Developments for NPP/Accelerator C&I
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters

		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(F2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models

		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

(F3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(G)INSTRUMENTATION ENGINEERING

(G1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Applied Process Instrumentation	EN607
2	Computer Based System Design I	EN612
3	Modern Control Systems Design and Simulation	EN625
4	Reactor C&I and Human Machine Interface	EN636
5	Reactor Control Engineering and Instrumentation	EN637-8
6	Reliability Engineering	EN639

(G2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Computer Based System Design II	EN706
3	Digital Signal Processing & Image Processing	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720

(G3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(G1) Core Engineering

Name of the Course	Course code	Course Outcome
Applied Process Instrumentation	EN607	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation
		Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and

		Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Reactor C&I and Human Machine Interface	EN636	Overview of Reactor C&I & Power Supply Requirements for Instrumentation
		Understanding Control Room Design and Exposure to Codes & Guides
		Exposure to Relay & Control Logic Design, Critera for Relay, PLC & DCS Technologies
		C&I Cable Requirements
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(G2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

Computer Based System Design II	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Digital Signal Processing & Image Processing	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(G3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(H)COMPUTER SCIENCE AND ENGINEERING

(H1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Operating Systems	EN606
2	Computer Graphics & Visualisation	EN613
3	Distributed Computing	EN616
4	Networking & Information Security	EN627
5	Reactor Control Engineering	EN637
6	Software Engineering and Formal Methods	EN640

(H2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Data Base Management System & Web Technology	EN705
3	Digital Signal Processing & Image Processing	EN706
4	Embedded Electronics Software	EN707
5	Feedback Control System	EN708
6	Image Processing & Machine Vision	EN710

(H3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(H1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Operating Systems	EN606	Understanding IPC Calls
		Shell Programming
		Understanding Distributed File Systems
		Applications of System Calls
Computer Graphics & Visualisation	EN613	Understanding Geometric Transformations
		Applications of Geometric Projections
		Techniques for Hidden Surface Removals
		Applications of Scientific Visualisation
Distributed Computing	EN616	Understanding modern CPU Architectures
		Understanding Interconnect Techniques
		Understanding and Applications of HPC

		Understanding Grid Computing and Workflows
Networking & Information Security	EN627	Understanding Issues in the transport of data and Techniques
		Satellite Communications
		Understanding Network Security Concepts
		Advances in Cryptography and Cryptanalysis
Reactor Control Engineering	EN637	Understanding Physics behind Rector Control
		Understanding Point Kinetics Model and Reactor Periods
		Understanding Issues with Large Reactor Control and Modelling
		Understanding Control Requirements for PWR, PHWR, BWR and FBR
Software Engineering and Formal Methods	EN640	Understanding Techniques for modelling software
		Application of Model Checking and Theorem Proving
		Understanding Agile Programming
		Understanding Software Testing

(H2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Data Base Management System & Web Technology	EN705	Understanding SQL and Complex queries
		Understanding Clusters and Distributed Databases
		Understanding and Working with Web Technologies
		Modelling data and design of real data bases

Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Feedback Control System	EN708	State Space Representation and Applications
		Time Domain Analysis
		Appreciating need for Stability Analysis & Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications

(H3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life

Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

BACK TO MAIN

Course Structure:

II. Courses at IGCAR

Program Code: ENGG03	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors	NR
2	Engineering Mathematics	EM
3	Materials and Metallurgy	MM
4	Fast Reactor Physics and Shielding	RP
5	Reactor Engineering	RE
6	Health Physics and Radiological Safety	HP
7	Project Management	PM

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Nuclear Reactors	NR	Exposure to mechanical aspects of power plant engineering Details understanding of thermal and fast power reactors Introduction to sodium technology
Engineering Mathematics	EM	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering Introduction to numerical methods for solving ordinay and partial differential equations Probability and statistics Different types of transformations
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Reactor Engineering	RE	Basic understanding of core design of LMFBR Coolant circuits of LMFBR and special characteristics of sodium technology
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation Principles of radiation detection and Radiation Protection procedures Familiarization with principles of radiation detection and radiation Protection procedures
Project Management	PM	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(A) MECHANICAL ENGINEERING

(A1) CORE ENGINEERING

Sr. No.	**Name of the Course**	**Course code**
1	Code Design for Pressure Vessels and Piping	ME1
2	High Temperature Design and Inelastic Analysis	ME4
3	Computational Fluid Dynamics	ME6
4	Finite Element Method	ME8
5	Advanced Heat and Mass Transfer	ME10
6	Reliability Engineering	ME13
7	Manufacturing Technology	ME14

(A2) ELECTIVES

Sr. No.	**Name of the Course**	**Course code**
1	Machine Design	ME3
2	Structural Integrity Assessment Methods and NDE	
3	Vibration Engineering and condition Monitoring	
4	Seismic Design of Nuclear Reactors and Facilities	ME5
5	Plant Dynamics	

6	Experimental Mechanics	
7	Process Control and Instrumentation	ME15

(A3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-001-P
2	Seminar -1,2,3	02ENGG04-001-S

Course Outcomes:

(A1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for Pressure Vessels and Piping	ME1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping. In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered. It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
High Temperature Design and Inelastic Analysis	ME4	This course has direct relevance with the design of fast breeder reactor components & piping system. It covers mainly about the role of high-Temperature design concerning FBR programme, significant failure modes and associated design guidelines and advanced inelastic analysis methods. The high temperature design aspect is followed based on the RCC MRx RB procedure. Reliable design of components and piping system operating under high temperature operating conditions should address the additional damage associated with creep, fatigue and creep-fatigue interactions predominantly under thermo-mechanical loadings. There are many unresolved problems in the area of high-temperature

<table>
<tr><td></td><td></td><td>design such as visco-plasticity behaviour, ratcheting behaviour, high temperature crack initiation behaviour etc. These aspects are addressed in this course with the support of tutorials.</td></tr>
<tr><td>Computational Fluid Dynamics</td><td>ME6</td><td>Basics of Fluid Flow, Heat Transfer and Numerical Analysis
Numerical Solution of Complete Fluid Flow and Energy Equation</td></tr>
<tr><td rowspan="4">Finite Element Method</td><td rowspan="4">ME8</td><td>Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element</td></tr>
<tr><td>2D isoparametric formulation</td></tr>
<tr><td>Introduction to Nonlinear problems</td></tr>
<tr><td>Finite element applications for design</td></tr>
<tr><td>Advanced Heat and Mass Transfer</td><td>ME10</td><td>Advanced knowledge in heat and mass transfer
Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
Heat transfer in porous media and heat transfer with phase change
Radiation heat transfer</td></tr>
<tr><td rowspan="4">Reliability Engineering</td><td rowspan="4">ME13</td><td>Regression analysis, Functions of Random Variables</td></tr>
<tr><td>Probabilistic Fracture Mechanics</td></tr>
<tr><td>System Reliability Analysis</td></tr>
<tr><td>Reliability in Engineering Design</td></tr>
<tr><td rowspan="2">Manufacturing Technology</td><td rowspan="2">ME14</td><td>The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.</td></tr>
<tr><td>Participants are introduced to principles plastic deformation, processes like rolling, forging, extrusion etc in the case of metal forming module. Arc welding process,welding metallurgy, defects, inspection, quality control aspects are covered inwelding module. Extraction of Uranium and Zirconium from ore to final product form is coveed in the material processingmodule.</td></tr>
</table>

(A2) ELECTIVES

<table>
<tr><th>Name of the Course</th><th>Course code</th><th>Course Outcome</th></tr>
<tr><td>Machine Design</td><td rowspan="5">ME3</td><td>Basic concepts in vibrations analysis</td></tr>
<tr><td rowspan="3">Structural Integrity Assessment Methods and NDE</td><td>Basics of rotor dynamics and rotor balancing</td></tr>
<tr><td>Flow induced vibrations</td></tr>
<tr><td>Response of systems to earthquake</td></tr>
<tr><td>Vibration Engineering and condition Monitoring</td><td>Vibration measurements, instruments used and analysis of vibration signals</td></tr>
<tr><td>Seismic Design of Nuclear Reactors and Facilities</td><td rowspan="3">ME5</td><td>Introduction to earthquakes, design basis ground motion and IS 1893 spectra
Introduction of earthquake engineering and analysis for multi degree freedom systems</td></tr>
<tr><td>Plant Dynamics</td><td>Analysis and design of structures, equipments and piping</td></tr>
<tr><td>Experimental Mechanics</td><td>Indian Standard Criteria for earthquake resistant design</td></tr>
</table>

		Siesmin design snd requalifications of NPPs
Process Control and Instrumentation	ME15	Understanding the concepts of instrumentation and control for nuclear power plants
		Able to identify and define instrumentation and control needs of a process or machine
		Able to provide indicative choice of instruments in the design

(A3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-001-P	Training in formulating and execution of a research project.
Seminar -1,2,3	02ENGG04-001-S	training in presentation of research results orally and in writing.

(B) ELECTRONIC AND INSTRUMENTAL ENGINEERING

(B1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	EL2
2	Nuclear Instrumentation	EL3
3	Reliability Engineering	EL4
4	Software Engineering	EL5
5	Human Machine Interface for Reactor Control Instrumentation	EL8
6	Modern Control of Dynamic Systems	EL10

(B2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence and Digital Signal Processing	EL6
2	Process Instrumentation	EL7
3	Embedded and Computer based systems Design	EL9
4	Analytical Instrumentation	EL11

(B3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-002-P
2	Seminar -1,2,3	02ENGG04-002-S

Course Outcomes:

(B1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	EL2	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	EL3	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Reliability Engineering	EL4	Introduction to reliability engineering applied to C&I systems
		Basic concepts of reliability, statistics and fault tolerence
		Probabilistic Safety (Risk) Assessment methods in the NPPs
Software Engineering	EL5	Introduction to software engineering and standards
		Software quality assurance, verification and validation
		Software analysis, design and configuration management
Human Machine Interface for Reactor Control Instrumentation	EL8	The subject is aimed on advanced design in new trends and development philosophy in the area of human machine interface. The student should obtain an overview of technologies implemented for reactor programmes and acquire an insight of the technical background to apply the same in context of reactor applications.
		The course work is framed in order to give an Introduction to various PFBR systems and HMI models in Distributed Digital Control System and their application to process systems such as special supervision systems, component handling systems, Reactor Protection Systems & Reactor Regulating Systems and Incident monitoring & mitigation systems. Learn about PC based process control system, Supervisory Control and Data Acquisition Systems.
		This course includes Familiarisation of plant automation overview, Soft Console versus conventional control panels, Guidelines for design of HMI displays, Building HMI systems, designing plant databases, alarm management techniques,

		Security features, creating process mimics, Trending historical data, Methods of passing data to HMI package etc. The capabilities of commercially available Professional HMI packages will also be explored.
Modern Control of Dynamic Systems	EL10	Introduction to state variable description with examples
		Controllability, observability and control system design

(B2) ELECTIVES

Name of the Course	Course code	Course Outcome
Artificial Intelligence and Digital Signal Processing	EL6	Exposure to fundamentals of digital signal processing algorithms
		Exposure to practical DSP algorithms and its implementation on different platforms
		Exposure to system design using pre conditioning circuits, anti-aliasing filters and digital signal controllers
		Exposure to system design case studies like Condition Monitoring System for rotating equipments And radar signal processing
		After course completion the student will be able to handle practical engineering problems solvable by digital signal processing techniques
		It is a specialised course which will give an introduction to AI techniques.
		It will give a flavour to fuzzy logic, robotics, neural networks, genetic algorithm.
Process Instrumentation	EL7	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Embedded and Computer based systems Design	EL9	Understanding of VME bus and cPCI bus architecture.
		'C' programming with MISRA C compliant.
		Electronics design in analog and digital domain
		Learning of VLSI based design using EDA tools.
		Learning of VHDL based digital design.
		Electronics system design using TMR architecture, fault tolerant design
		Introduction of reliability analysis for electronics system.
Analytical Instrumentation	EL11	Introduction to the principles and applications of modern analytical instruments Sensitivity, precision, and limitations of analytical instruments

(B3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-002-P	Training in formulating and execution of a research project.
Seminar -1,2,3	02ENGG04-002-S	training in presentation of research results orally and in writing.

(C) CHEMICAL ENGINEERING

(C1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Nuclear Chemical Engineering	CE1
2	Chemical Engineering Thermodynamics	CE2
3	Transport Phenomena	CE3
4	Multi-Phase Flow Systems	CE4
5	Code Design for Pressure Vessels and Piping	CE5
6	Computational Fluid Dynamics and Heat Transfer	CE6
7	Advanced Chemical Reaction Engineering	CE7

(C2) SPECIALIZED COURSES

Sr. No.	Name of the Course	Course code
1	Process Analysis and Control	CE8
2	Advanced Mass Transfer	CE9

(C3) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Preparedness &Response to Nuclear Emergencies Artificial Intelligence Methods &Applications Membrane/ Separation Process and Technology	CEEL

(C4) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-003-P
2	Seminar -1,2,3	02ENGG04-003-S

Course Outcomes:

(C1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Nuclear Chemical Engineering	CE1	Introduction to nuclear chemical engineering for production, processing and management of nuclear materials
		Modelling and Simulation in Nuclear Chemical Engineering
Chemical Engineering Thermodynamics	CE2	Understanding the concepts of Thermodynamics , scope of Classical Thermodynamics, Phase Equilibrium, Chemical Reaction Equilibria.
Transport Phenomena	CE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyze transport problems
		Analyze transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyze transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Multi-Phase Flow Systems	CE4	Introduction to multiphase flow and its classification
		Modeling and Simulation in Nuclear Chemical Engineering
		Applications of two-phase flow in the design of steam generators
		The phenomena of fluidization and its industrial application
Code Design for Pressure Vessels and Piping	CE5	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design

		for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
Computational Fluid Dynamics and Heat Transfer	CE6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer
Advanced Chemical Reaction Engineering	CE7	Understanding of thermodynamics and kinetics of chemical reactions
		Design and analysis of chemical reactors
		Modelling of multiphase reactors

(C2) SPECIALIZATION

Name of the Course	Course code	Course Outcome
Process Analysis and Control	CE8	Understanding of dynamics of chemical process systems and nonlinear process dynamics
		Design of multivariable controllers
Advanced Mass Transfer	CE9	Introduction to theories of mass transfer and advanced mass transfer processes
		Selection and design of contacting equipment in nuclear chemical industries

(C3) ELECTIVES

Name of the Course	Course code	Course Outcome
Preparedness & Response to Nuclear Emergencies	CEEL	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Artificial Intelligence Methods & Applications		
Membrane/ Separation Process and Technology		

(C4) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-003-P	Training in formulating and execution of a research project.
Seminar -1,2,3	02ENGG04-003-S	training in presentation of research results orally and in writing.

(D) MATERIALS SCIENCE

(D1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	MS1
2	Computational Methods	MS2
3	Materials and Metallurgy	MS3
4	Reactor Physics and Fuel Design	MS4
5	Health Physics	MS5
6	Metallurgical Thermodynamics	MS6
7	Experimental Methods for Materials Research	MS7
8	Structural Materials for Nuclear Reactors	MS8
9	NDE Science and Technology	MS9
10	Physical Metallurgy	MS10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	MS11
12	Introduction to Materials Science and Engineering	MS12
13	Corrosion Science and Engineering	MS13
14	Mechanical Behavior of Engineering Materials	MS14
15	Manufacturing Technology	MS15

Course Outcomes:

(D1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Engineering Mathematics	MS1	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
		Introduction to numerical methods for solving ordinary and partial differential equations
		Probability and statistics
		Different types of transformations
Computational Methods	MS2	Introduction to programming languages such as C# and Matlab
		Exposure to numerical techniques for solving partial differential equations
		Neural network for predictive applications
		Basics of atomis modelling, molecular dynamics and introduction to Monte-carlo simulation
		Introduction to FEM and current trends in modelling and imulation

Materials and Metallurgy	MS3	To develop a basic understanding on the classification of materials
		Mechanical property based selection of materials for nuclear application and standards
		Various fabrication related issues in material including welding and corrosion
		Non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Reactor Physics and Fuel Design	MS4	Introduction to basic nuclear and neutron physics concepts
		Nuclear reactors and fuel design concepts
		Reactor kinetics
Health Physics	MS5	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Metallurgical Thermodynamics	MS6	Introduction to Classical thermodynamics: 1st and 2nd laws and their applications
		Thermodynamic properties of pure substances and mixtures Solution thermodynamics
		Phased equilibria in multicomponent systems and stability
		Chemical reactor equilibria Exposure to experimental methods for determining thermodynamic properties
Experimental Methods for Materials Research	MS7	Exposure to various experimental techniques for materials characterization, including X-ray techniques, electron microscopies, ion-beam techniques, electron spectroscopies nuclear spectroscopies, vibrational spectroscopy and resonance absorption spectroscopies
		Basic understanding of underlying physics
Structural Materials for Nuclear Reactors	MS8	Exposure to the three stage nuclear power programme
		Concept of selection of structural materials for different applications
		Materials for thermal reactors, fast breeder reactors and reprocessing applications
		Materials processing and fabrication of components
NDE Science and Technology	MS9	Introduction to various non-destructive evaluation techniques for safe and reliable operation of structures and components
		Surface, volumetric and Dynamic NDE
Physical Metallurgy	MS10	Basic understanding of crystal structure and microstructure
		Knowledge of origin, construction and classifications of metallurgical phase diagrams

		Understanding of different types of metallurgical phase transformations and underlying principles
		Introduction to microstructural characterization techniques and tools
Fuel Cycle Physics and Introduction to Fuel Cycle	MS11	Introduction of nuclear fuel cycles
		Introduction to exploration, recovery and enrichment and uranium and other nuclear fuel materials
		Different types of nuclear fuels and fuel fabrication
		Recycling the spent fuel, fission products and actinides
Introduction to Materials Science and Engineering	MS12	Introduction to basic structures, bonding and defects in solids and techniques for their characterization
		Physcial properties of materials
		Basics of phase diagram and phase transformations
		Techniques for synthesis of materials
Corrosion Science and Engineering	MS13	Basic understanding of corrosion process, monitoring and preventation
		Introduction to thermodynamics and kinetics of corrosion
		Forms of corrosion and corrosion in nuclear reactor and reprocessing plants
Mechanical Behavior of Engineering Materials	MS14	Introduction to engineering materials
		Elastic and plastic deformation in polycrystalline materials
		Strengthening mechanisms in polycrystalline structural materials
		Exposure to damage mechanisms such as creep, fatigue and also exposure to fracture mechanics
Manufacturing Technology	MS15	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles of plastic deformation, processes like rolling, forging, extrusion etc. in the case of metal forming module.
		Arc welding process, welding metallurgy, defects, inspection, quality control aspects are covered in welding module. Extraction of Uranium and Zirconium from ore to final product form is covered in the material processing module.

(E) FAST REACTOR ENGINEERING – I

(E1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(E2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for pressure vessel and piping	FRE1
2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2
3	Transport Phenomena	FRE3
4	Reliability Engineering	FRE4
5	Process Design and Control	FRE5
6	Vibration Engineering and Condition Monitoring	FRE6
7	Seismic Design of Nuclear Reactors and Facilities	FRE7
8	Emergency Preparedness and Disaster Management	FRE8

(E3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Dynamics and Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva Voce

Course Outcomes:

(E1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(E2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for pressure vessel and piping	FRE1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tube sheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.

Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2	Advanced knowledge in heat and mass transfer
		Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
		Heat transfer in porous media and heat transfer with phase change
		Radiation heat transfer
Transport Phenomena	FRE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyse transport problems
		Analyse transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyse transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Vibration Engineering and Condition Monitoring	FRE6	Basic concepts in vibrations analysis
		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	FRE7	Introduction to earthquakes, design basis ground motion and IS 1893 spectra
		Introduction of earthquake engineering and analysis for multi degree freedom systems
		Analysis and design of structures, equipment and piping
		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(E3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine
		Turbine troubles
Mechanical and Electrical Equipment	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(F) FAST REACTOR ENGINEERING – II

(F1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(F2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	FRE15
2	Nuclear Instrumentation	FRE16
3	Reliability Engineering	FRE4
4	Process Design and Control	FRE5
5	Embedded System Design & Human Machine Interface	FRE17
6	Process Instrumentation	FRE18
7	Emergency Preparedness and Disaster Management	FRE8

(F3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva-Voce

Course Outcomes:

(F1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(F2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	FRE15	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	FRE16	Students learn about basics of interaction of radiation with matter.
		Principle & Techniques to detect and measure ionizing radiation.
		Basics of radiation counting statistics
		Introduction to Neutron Flux Measurement in FBTR and PFBR.
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Embedded System Design & Human Machine Interface	FRE17	Introduction to Microprocessor Based Hardware Design
		Computer Communication and Networks
		Fault Tolerant and Distributed Architectures
		Programmable Logic Controller Design
		Overview of plant automation and Human Machine Interface (HMI)

Process Instrumentation	FRE18	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of various process variables
		Reliability principles, Fail safe design principles
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(F3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine Turbine troubles
Mechanical and Electrical Equipments	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To assess the understanding of the subject by the student and applying in problem solving.

BACK TO MAIN

Course Structure:

III. Courses at IPR

Program Code: ENGG03	Programme Specific Outcome	Learn about Plasma basics, its diagnostics and its applications.
		Learn Plasma and Fusion Technologies to build a device.
		Get detailed information on specific subject related to Fusion technology according to the stream of student i.e. Physics , mechanical etc.

T1. FUNDAMENTAL

Sr. No.	Name of the Course	Course code
1	Basic Plasma Physics	FC1
2	Experimental Plasma Physics	FC2
3	Tokamaks	FC3
4	Fusion Plasma Diagnostics	FC4
5	Measurement Techniques	FC5
6	Numerical Methods	FC6
7	Mathematical Methods	FC7
8	Vacuum, Cryogenics and Magnets	FC8

T2. CORE SUBJECTS

Sr. No.	Name of the Course	Course code
1	Fusion Neutronics	AS1
2	Plasma Facing Components: First Wall, Divertors, Blankets	AS2
3	Fusion Materials	AS3
4	RF, Current Drive and Neutral Beam Heating	AS4

T3. ELECTIVES

(A) PHYSICS

Sr. No.	Name of the Course	Course code
1	Magneto Hydro Dynamics	PH1
2	Kinetic Theory and Statistical Mechanics	PH2
3	Advanced Heat Transfer and Cryogenics	PH3/ME5
4	Tokamak Related Code	PH4

(B) MECHANICAL

Sr. No.	Name of the Course	Course code
1	Code Design for Internal and External Pressure Vessel	ME1
2	Finite Element and Volume Methods	ME2
3	Mechanics of Solid/Vibration/Remote Handling	ME3
4	Advanced Manufacturing Technologies	ME4
5	Advanced Heat Transfer and Cryogenics	ME5

(C) ELECTRICAL

Sr. No.	Name of the Course	Course code
1	Advanced Data Acquisition System	EE1
2	Advanced Tokamak controls	EE2
3	High Voltage, DC& AC/ Power Supplies	EE3
4	Signal Conditioning and EMI/EMC Aspects	EE4
5	Computer Based System Design	EE5
6	Digital Signal Processing and Image Processing	EE6

T4. MINI PROJECT (MP)

Sr. No.	Name of the Course	Course code
1	Mini Project	06ENGG03-001-MP

T5. PROJECT (P)

Sr. No.	Name of the Course	Course code
1	Project	06ENGG03-001-P

Course Outcomes:

T1. FUNDAMENTAL

Name of the Course	Course code	Course Outcome
Basic Plasma Physics	FC1	Course provides detailed information on,
		• Definition of plasma, description of collective behaviour in contrast to single particle behaviour.
		• Lorentz force equation, nonrelativistic motion of a charged particle in constant electric and magnetic field.
		• Fluid Description of Plasma, Waves in Plasma and MHD Description.
Experimental Plasma Physics	FC2	Course provides detailed information on,
		• Fundamental Gas Processes i.e. Maxwell-Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization,
		• Charged Particles in a Gas.
		• Self-sustaining Discharge i.e. Glow Discharge, Breakdown under Special Conditions, Arc Discharge.
		• Plasma Sheath and Diagnostics Experimental Plasma Devices.
Tokamaks	FC3	Course provides detailed information on,
		• Introduction to Thermonuclear Fusion reactions, Power Balance and Lawson Criteria, Tokamak as Fusion reactor,
		• Equilibrium and Transport i.e. Tokamak Equilibrium, Grad-Shafranov Equation, Safety Factor, q and Plasma Beta, Shafranov Shift and Plasma position control, Classical Transport,
		• Heating i.e. Ohmic Heating, Neutral Beam Heating, Wave Heating, Lower Hybrid Heating and Current Drive, Ion Cyclotron

		Resonance Heating, Electron Cyclotron Resonance Heating. • MHD Stability i.e. Ideal Kink modes, Ideal internal modes, Resistive tearing modes, Mirnov Oscillations, Saw-tooth oscillations, ELMs, Disruption scenarios. • Tokamak and Other Fusion Devices
Fusion Plasma Diagnostics	FC4	Course provides detailed information on, • Introduction to Tokomak diagnostics , Electrical diagnostics, Magnetic diagnostics • Measurements of plasma density and electron temperature i.e. Thomson scattering diagnostics, Reflectometery, Interferometry: ECE diagnostics. • Measurement of ion temperatures i.e. Charge exchange recombination spectroscopy (CXRS), X –ray crystal spectroscopy. • Measurements of Radiated power and Measurements of operational parameters i.e. Bolometers, Imaging Diagnostics and Beam emission spectroscopy.
Measurement Techniques	FC5	Course provides detailed information on, • Measurement system architecture, Computer based measurement systems, Errors in measurements, Measurement Units, Standard used in measurements. • Sensitivity, Resolution, Nonlinearity, Saturation, Dynamic Range, Offset, Drift, Electromagnetic Compatibility, Reliability. • Measurement of Electrical Parameters: Voltage, Current, Resistance, Capacitance, Impedance, Frequency, Phase shift, Power. • Sensors/Transducers and Their Applications to Physical Measurements , Introduction to Data Acquisition and Noise in Measurement System.
Numerical Methods	FC6	Course provides detailed information on, • Mathematical modeling, numerical methods and problem solving, Introduction to MATLAB programming, Error analysis methods, Case study. • Solutions of Linear Algebraic equations. • Numerical Differentiation and Integration • Roots, optimization and nonlinear sets of Equations. • Application of Ordinary Differential equations. • Application of Partial Differential equations.

		• Application of Curve fitting methods.
Mathematical Methods	FC7	Course provides detailed information on,
		• Vector analysis: vector identities, Use of Levi Civita and Kronecker delta functions for the derivation of vector identities, Notion of gradient, divergence and curl
		• Classification of matrices; Elementary operations; Determinant, rank and inverse of a matrix; Solution of linear equations; Eigenvalues and eigenvectors
		• Complex variables, function of a complex variable, continuity and differentiability, Cauchy-Riemann conditions, Analytic functions, Taylor and Laurent Series,
		• First and second order differential equations with constant and variable coefficients; Linear differential equations
Vacuum, Cryogenics and Magnets	FC8	Course provides detailed information on,
		• Fundamental of vacuum i.e. The vacuum and its applications, Gas laws, Pressure and mean free path, Flow regimes, Conductance, Throughput and pumping speed, Ultimate pressure and pump down time, Outgassing and permeation. Exposure to pumps and gauges.
		• Design of a vacuum system
		• Fundamental of cryogenics i.e. Cryogens properties, Heat loads in Cryogenic systems, Basic Thermodynamics and Cryogenic Processes, Material properties at low temperatures.
		• Design of cryogenics system i.e. Design aspects of Cryostat, Dewars and Cryolines. Fundamentals of Thermo-hydraulics and distribution network, Economics of Cryogens, Recovery of Helium and Thermal insulation.
		• Applications of Cryogenics Engineering in Fusion machines.
		• Fundamentals of Magnet system
		• Design and fabrication of magnet system

T2. CORE SUBJECTS

Name of the Course	Course code	Course Outcome
Fusion Neutronics	AS1	Course provides detailed information on, • Fusion Neutronics Principles, neutron production & detection techniques, nuclear interaction processes. • Particle transport phenomena in matter and Basics of fusion neutronics & blanket neutronics. • Principles of Neutron & Fusion product diagnostics, Radiation and licensing and Radiation damage & transmutation.
Plasma Facing Components: First Wall, Divertors, Blankets	AS2	Course provides detailed information on, • First Wall, Firstwall Concepts, Loads on Firswtall and Challenges for Firstwall. • Divertor Concepts , Loads on Divertor , Challenges for Divertor , Divertor Testing and Novel Divertor Concepts • Blanket Concept, Shield Blanket, Breeding Blanket, Liquid Metal (Pb Li) Technology, Fusion Fuel Cycle and Blanket Safety.
Fusion Materials	AS3	Course provides detailed information on, • Fundamentals of Material Science • Fusion Materials Requirements & Issues • Material Development and Joining Technologies • Material Characterization & Qualification
RF, Current Drive and Neutral Beam Heating	AS4	Course provides detailed information on, • Heating and current drive physics by neutral beam • Neutral beam injector system design and engineering • Introduction to RF heating • RF devices and Design tools i.e. ICRH, ECRH and LHCD.

T3. ELECTIVES

(A) PHYSICS

Name of the Course	Course code	Course Outcome
Magneto Hydro Dynamics	PH1	Course provides detailed information on, • Physical description of electrically conducting fluids .Derivation of basic MHD equations: Continuity, Equation of

		motion, Energy flow, Ohm’s law, Validity of MHD equations.
		• The low frequency dynamics of the electromagnetic field. Some properties of MHD: Ideal MHD equations, The Frozen Flux theorem, The effect of • resistivity, Similarity scaling, The Wöltjer invariants and helicity
		• Equilibrium general considerations, The Virial Theorem, Examples of simple equilibria: - pinch, Z-pinch, screw pinch, Poloidal , paramagnetic and diamagnetic states, Force-free fields, Toroidal equilibrium: the Grad-Shafranov equation, nonlinearity, Definition of q, beta, plasm a shape, etc.
Kinetic Theory and Statistical Mechanics	PH2	Course provides detailed information on,
		• Gas dynamic way of describing an uncharged fluid – heuristic
		• Recollect derivation of basic MHD equations – one fluid only (Continuity, Eqn of motion, Energy equation [thermodynamic closure], Electron equation of motion [Ohm's Law])
		• Introduce ideas of Phase Space (x,v) and distribution functions f(x,v,t)
		• Langmuir Oscillations and Waves – Vlasov-Poisson dispersion
		• Examples of GK formalism and obtained transport and Very cursory introduction to Onsager relationships
Advanced Heat Transfer and Cryogenics	PH3/ME5	Computational Fluid Dynamics
		Heat Transfer : Conduction
		Heat Transfer : Convection:
		Heat Transfer : Radiation:
		Cryogenics
		Gas Liquefaction and Refrigeration Systems
Tokamak Related Code	PH4	Course provides detailed information on,
		• Plasma core modelling i.e. Plasma equilibrium IPREQ , Plasma transport TSC , Plasma stability ERATO, PEST2 , ICRH heating TORIC , NBI heating NUBEAMS , Plasma start up model , Reactor system code , Eddy current analysis.
		• Edge-SOL studies i.e. 2D blob transport, Divertor study SOLPS (B2+ERINE) , 3D plasma study ERINE-3D

		• First principle simulations i.e. Low frequency (w/wc <<1) transport – what is Gyrokinetic method? , What are the transport processes neglected by gyrokinetic formalism?

(B) MECHANICAL

Name of the Course	Course code	Course Outcome
Code Design for Internal and External Pressure Vessel	ME1	Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and tori spherical end closures.
		Thick cylinder, sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div. – II equations for cylindrical / Spherical shell and conical, ellipsoidal and tori spherical end closures.
		Bending of circular plates and determination of stresses in simply supported and clamped Circular plate. Basis of ASME equation for flat closures.
		Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3.
Finite Element and Volume Methods	ME2	Introduction to FEM: Weighted residual method, Galerkin's methods, Weak form formulation , piecewise approximations. Basis of Finite Element Method, Variation principles, energy principles in structural mechanics, Element libraries
		Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements
		2D plane elements – 3 node triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
		Finite element applications for design: Finite element modelling and discretization criterion,

		h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.
Mechanics of Solid/Vibration/Remote Handling	ME3	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Laminar Boundary Layer and Forced Convective Heat
		Turbulent Flow and Heat Transfer
		Natural Convection
		Numerical Solution of Complete Fluid Flow and Energy Equation
Advanced Manufacturing Technologies	ME4	Advance manufacturing processes i.e. mechanical energy based processes , electrical energy based processes, chemical and electro-chemical energy based processes.
		Advanced materials joining and testing i.e. bolting , riveting , soldering , blazing ,adhesive bonding , diffusion bonding , mechanical joining, fusion welding, oxyacetylene welding , smaw , gtaw , gmaw , fcaw ,saw , esw, high energy beam welding.
		Responses of materials to welding i.e. microstructural changes , distortion , defects, undercuts ,overlaps , grain growth , blowholes , inclusions.
		Destructive and non-destructive tests for welds.
Advanced Heat Transfer and Cryogenics	ME5	Computational Fluid Dynamics
		Heat Transfer : Conduction
		Heat Transfer : Convection:
		Heat Transfer : Radiation:
		Cryogenics
		Gas Liquefaction and Refrigeration Systems
		Cryogenic Insulations
		Instrumentation in Cryogenics

(C) ELECTRICAL

Name of the Course	Course code	Course Outcome
Advanced Data Acquisition System	EE1	Course provides detailed information on,
		• Theory of Quantization , Advanced Data Acquisition Systems
		• Data Acquisition Interface , Analog Input/output
		• DAQ Clock and Trigger , Synchronization
		• SST-1 Data Acquisition System

Advanced Tokamak controls	EE2	Course provides detailed information on, • Fundamentals of Control System i.e. Terminology and basic structure of control system , Open loop and Closed loop systems, servomechanism, regulatory system, analogous systems, electrical analogy of physical systems, Physical Systems. • Different types of Control Systems • Introduction to Plasma Control • ITER Instrumentation & Control • SST-1 Operation &Control • Monitoring and Control of Auxiliary Systems
High Voltage, DC& AC/ Power Supplies	EE3	Course provides detailed information on, • Overview of Electrical systems in Fusion machines i.e. Basic introduction to electrical systems in Tokamak, Stellarator and Z-machine; Tokamak as a transformer, Electrical systems for plasma formation – Ohmic discharge, Arc discharge, RF discharge, MW discharge; Electrical systems for plasma confinement. • High Voltage Generation, High AC, DC and Impulse Voltages, High Voltage Components, Basic design features of High Voltage Power Transformer: Basic design of HV Transformer, Transformer insulation requirements, dielectric strength and voltage conditions, winding arrangements, surge behavior, behavior of liquid dielectric, electrode surface phenomena, gas evolution, processing techniques, construction of EHV transformer, short circuit behavior. • Linear and switching power supplies, DC to DC converters and their operating characteristics, Selection of Power Semiconductor Devices, Power supplies for pulsed gas discharge tubes, High current power supplies. Power supplies for heating and current drive, Requirement for arc fault protection, Protection by crowbar. • Power Electronics and design through modelling & simulation i.e. AC-DC Converters; Forced commutation;

		synchronous link converters, DC-AC converters, buck, boost, buck-boost, cuk, flyback configuration, resonant converters, PWM inverters; active filters. Machine modelling, DC machines, induction motor and synchronous machines.
Signal Conditioning and EMI/EMC Aspects	EE4	Course provides detailed information on, • Analog Signal Conditioning i.e. Principles of Analog Signal Conditioning, Signal Conditioning Configuration, Signal Conditioning Functions, Amplification, Transducer Excitation, Filtering, Isolation. • Signal Processing and Applications i.e. Review of signals and systems: Introduction, advantages and limitations of Analog and Digital Signal Processing, Advantages and Disadvantages of Digital Filters over Analog Filters. • EMI/EMC i.e. Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling Inductance Coupling, Shielding. • EMI Modelling i.e. Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns.
Computer Based System Design	EE5	Course provides detailed information on, • Personal computer architecture, memory organization, industrial PC, Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications. • Asynchronous and synchronous communication, • Local Area Networks, OSI 7 layer model and TCP/IP reference model, Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth, Networking hardware – cables, hub, switch, router etc. • Real-time Systems, their characteristics and applications, Real-time Operating Systems Concepts of Process and threads, Concurrency, Latency, context switching, scheduling policies.
Digital Signal Processing and Image Processing	EE6	Course provides detailed information on, • Basic elements of a digital signal processing system, Fourier series and Fourier transform, z transform Convolution, Correlation, Sampling

		theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.
		• Discrete Fourier Transform, Interpretation of DFT, Properties of DFT, DFT of real signals, Fast Fourier Transform Digital filters, DSP Applications.
		• Digital image model representation, Image sensor, Digitizer, Computer, Standard file format.
		• Image Enhancement i.e. Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Color image processing.
		• Image Segmentation and Analysis i.e. Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation, Boundary extraction and representation.
		• Morphological operations i.e. Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy based Methods, Image Compression Models, Error free compression, Lossy compression, Standards.

T4. MINI PROJECT (MP)

Name of the Course	Course code	Course Outcome
Mini Project	06ENGG01-001-MP	Student learns: • Literature Survey • Study of a small section of the major project based on either simulation or fabrication to realize the criticality and requirements to build a component for plasma application. • Practise for thesis writing

T5. PROJECT (P)

Name of the Course	Course code	Course Outcome
Project	06ENGG01-001-P	• Complete understanding about the criticality of a particular component to be built for plasma application.
		• Development of a component for a plasma application and get hands on experience.
		• Thesis report.

Ph.D. in APPLIED SYSTEMS ANALYSIS
(Program Code: APSA04)

Course Structure:

I. Courses at NISER

Program Code : APSA04	Programme Specific Outcome	Policy oriented research
		Multidisciplinary approach for Problem solving
		Interaction between natural science and Social Sciences

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Research Methods - I	H 601
2	Research Methods - II	H 602

(B) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Advanced Economic Theory	H 611
2	Econometric Theory and Applications	H 612
3	Issues in Public Finance	H613
4	Development Economics	H614
5	Environmental and Ecological Economics	H615
6	Poverty, inequality and Development	H616
7	Project Evaluation	H617
8	Indian Industrial Development	H618
9	New Institutional Economics	H619
10	International Trade and Finance	H620
11	Topics in experimental and behavioural approaches to economic development	H621
12	Environmental Economics and EIA	H 622
13	Humanities and the Institutional Space	H631
14	The Modern European Novel	H632

15	The idea of the nation in Indian English Fiction	H633
16	Black Intellectual traditions and the Narratives of Race in America	H634
17	Writings of the South Asian Diaspora	H 635
18	Translation and Culture: Issues and Perspectives	H 636
19	Organizational Behaviour	H 651
20	Leadership	H 652
21	Organizational Change and Development	H 653
22	Positive Psychology	H 654
23	Cross Cultural Psychology	H 655
24	Business Ethics	H 656
25	Classical Sociological Theory	H 671
26	Information and Society (Theory)	H 672
27	Sociology of Development	H 673
28	Contemporary Social Theory	H 674
29	Qualitative Research Methods	H 675
30	Quantitative Research Method I	H 676
31	Social Network Analysis I	H 677

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Research Methods - I	H 601	Understanding logic and empiricism
		Creating perspectives, theory building
		Legacy of science and scientific method
Research Methods - II	H 602	Understanding of Qualitative and quantitative research
		Imparting basic Research skills and ethical principles in research
		Inputs on data collection methods and techniques
		Inputs of Data Analysis and Report writing

(B) ELECTIVES

Name of the Course	Course code	Course Outcome
Advanced Economic Theory	H 611	Advanced knowledge of micro economic theory
		Advanced knowledge of macroeconomic theory
		Applications of the theories in various fields
Econometric Theory and Applications	H 612	Sample designing
		Regression using cross section data
		Regression using time series data
		Regression using panel data
Issues in Public Finance	H613	Budgeting
		Rule based and discretionary fiscal policy
		Public debt of Union and states
		Tax reforms
Development Economics	H614	Alternative approaches to development
		Different inequality measurement
		Different poverty measurements and controversies
		Basics of health economics and education
Environmental and Ecological Economics	H615	Environmental degradation and economic consequences
		Alternative approaches to control pollution
		Valuation methods
		Integrated environmental and economic accounting
Poverty, inequality and Development	H616	Debates on poverty measurements in India
		Measures of inequality
		Poverty and inequality in India
		Critiques of development policies to address poverty and inequality in India
Project Evaluation	H617	Welfare foundations of project evaluation
		Alternative approaches of project evaluation
		Case studies
Indian Industrial Development	H618	Review of Indian Industrial Policies since independence
		Policies for small scale industries
		Policies for foreign direct investment
New Institutional Economics	H619	Introduction to NIE
		Role of property rights, transaction costs in economic development.
		Role of norms and contracts in economic development
International Trade and Finance	H620	Evolution of IT theories
		International trading system
		Recent developments in international trade
		Recent status of international monetary system
Topics in experimental and behavioural approaches to economic development	H621	Basic concepts of behavioural economics
		Overview of experimental economics
		Application of behavioural and experimental economics

Environmental Economics and EIA	H 622	Broad aspects of environmental economics
		Environmental legislations in India
		Environmental Impact Assessment in India
Humanities and the Institutional Space	H631	To critically engage with the concept of the 'humanities.'
		To understand its place in the modern educational system.
		To examine the notion of 'value' with reference to disciplinary streams.
The Modern European Novel	H632	To survey modern European fiction.
		To examine the broader themes and contexts predicating the text.
		To build an understanding of the primary tropes inhabiting these narratives.
The idea of the nation in Indian English Fiction	H633	To gain substantial knowledge about the concepts of nation, nation-state, the Euro-centric as well as Indian notions of these ideas and the historical evolution of the same
		To be familiar with various literary texts coming within the purview of "Indian English fiction" and the numerous ways in which they grapple with the idea of nation
Black Intellectual traditions and the Narratives of Race in America	H634	To understand the intellectual evolution of race theory in America.
		To cross reference color hierarchies across geographies.
		To evaluate concepts such as citizenship, community and justice in relation to African American literary narratives.
Writings of the South Asian Diaspora	H 635	To be familiar with the history, significance, and related concepts about 'diapsora'
		To know the role of the colonial project in the creation of displacement and diaspora
		To be familiar with some of the prominent south Asian diasporic writers and their writings
		To be familiar with some of the major concerns in south Asian diasporic writings
Translation and Culture: Issues and Perspectives	H 636	To know about the importance of literary translation and be familiar with various translation theories and the ways in which they approach translation
		To understand and appreciate the difficulties of cross-cultural translation
		To have some familiarity with issues of adaptation (such as literary text to film)
Organizational Behaviour	H 651	Acquire knowledge and thorough understanding of the historical background and growth of OB
		Understand the dynamics of individual human behavior and group behavior at the workplace.

		Identify and analyze how individuals, groups and organization systems interact to influence organizational effectiveness and efficiency.
Leadership	H 652	understood the different attributes of effective leadership in terms of traits and styles.
		Compare and contrast different leadership theories and their relevance within a context.
		Sources of power and its influence on leader-member relationship in a diverse and interdependent group.
Organizational Change and Development	H 653	Define the different concepts of Organizational Change and Organizational Development
		Explain different change models, the need for change.
		Learn about different OD models, diagnosis, intervention and evaluation.
		Discuss OD process and human resource within the framework of organization's culture.
Positive Psychology	H 654	Understand the basic assumptions, principles and concepts of Positive Psychology
		Study positive phenomena in real life as to how it applies to relationships and teams.
		To identify and describe research methods predominantly used in positive psychology research.
		Critically evaluate theory and research
Cross Cultural Psychology	H 655	Have a strong knowledge base in the concepts and theories of cross-cultural psychology
		Acquire an overview of methods used in cross-cultural research, critically evaluate cross-cultural research and review the generalizability of such research findings.
		Identify the ways in which cultural dimensions influence human cognition and behavior
Business Ethics	H 656	Understand and evaluate various ethical frameworks of business decision making
		Analyze the relationship between macroeconomic policy, good economics and corporate social responsibility.
		Understand stakeholder relations and challenges to ethical business in a globalized world.
Classical Sociological Theory	H 671	Application of Sociological theories
		Understanding the fundamental concepts and perspectives
		Conceptualisation of social systems/structures/functions
Information and Society (Theory)	H 672	Demonstrate an understanding of the impact of information & information technology on society & change process.

		Identify key issues involved in the development of the Information Society.
		Articulate personal perspectives and show a critical awareness of the positive and negative issues of the information society.
		Use the internet and social media to develop communication skills and share information.
Sociology of Development	H 673	Understanding various notions of development
		Broadened perspectives on various models of development
		Understanding development indicators and contemporary issues in Development
Contemporary Social Theory	H 674	Able to demonstrate an understanding and knowledge of a range of sociological theorists and their contributions to the field.
		Able to assemble ideas about sociological theory into a coherent argument, applying the tools of critical analysis.
		Evaluate the theories encountered and assess their relevance to contemporary problems.
		Analyze the differences between theories according to different social realities.
Qualitative Research Methods	H 675	Able to understand the nuances of qualitative research approaches
		Skills for qualitative research tools
		Making sense of qualitative data and analysis
		Competence for report writing
Quantitative Research Method I	H 676	Able to collect, organize, design, and draw inferences from data with respect to a question using appropriate statistical methodology and problem solving skill.
		Able to read, interpret, and critically analyze journal articles directed at Ph.D. students.
		Arrange a sample survey for his/her own research purposes.
		Undertake univariate and bivariate statistical tests as appropriate.
Social Network Analysis I	H 677	Able to collect, organize, design, and draw inferences from data with respect to a question using appropriate statistical methodology and problem solving skill.
		Able to read, interpret, and critically analyze journal articles directed at Ph.D. students.
		Arrange a sample survey for his/her own research purposes.
		Undertake univariate and bivariate statistical tests as appropriate.

BACK TO MAIN

Ph.D. in CHEMICAL SCIENCES
(Program Code: CHEM04)

Course Structure:

II. Courses at IGCAR

Program Code : CHEM04	Programme Specific Outcome	Theoretical work for understanding solvent – metal ion interactions.
		Matrix isolation spectroscopy to understand conformers and weak molecular attractions
		Solvent development for reprocessing of nuclear fuels.
		Novel sensor materials development and characterization for sensor applications
		Materials development for matrices for nuclear waste immobilization

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Mathematical and Computational Methods, Numerical Analysis and Computer Programming	CH1
2	Chemical Thermodynamics	CH2
3	Electrochemistry	CH3
4	Introduction to Materials Science and Engineering	CH4
5	Analytical Chemistry for Nuclear Fuel Cycle	CH5
6	Chemical Instrumentation and Laboratory Techniques	CH6
7	Health Physics and Radiation Sciences	CH7
8	Introductory Reactor Physics and Fuel Design	CH8
9	Chemistry of Fuel Cycle - I	CH9
10	Chemistry of Fuel Cycle - II	CH10
11	Materials for Nuclear Reactors and Fuel Cycle Processing Systems	CH11
12	Nuclear and Radiochemistry	CH12
13	Corrosion Science and Engineering	CH13
14	Quantum Chemistry & Group Theory	CH-14
15	Molecular Spectroscopy	CH-15
16	Lasers and Application	CH-16
17	Nanomaterials and Advanced Chemical Sensors	CH-17
18	Course on Research Methodology	CH-RM

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Mathematics and Computational methods	CH-1	Practical applications of mathematical and computational methods are taught; besides these, computational software packages are introduced. The course basically prepares students to apply these aspects in their research areas for solving problems.
Chemical Thermodynamics	CH-2	This course helps students to understand various processes employed in chemical industries. Experimental methods to determine thermodynamic properties and phase diagram investigations are unique to this course. Estimation of thermodynamic properties and thermodynamic modelling study helps for a career in research and industry.
Electrochemistry and Corrosion Science	CH-3	Fundamentals and practical applications of electrochemistry are discussed. Advanced electrochemical techniques, pyrochemical process are taught. Aqueous corrosion and engineering help students to take up career in research and industry.
Introduction to Materials Science and Engineering	CH-4	Various characterisation techniques are taught. Material synthesis methods e.g. sol-gel are discussed extensively. Students handle various characterisation tools e.g. XRD, and Thin-film deposition followed by characterisation.
Analytical Chemistry for Nuclear Fuel Cycle	CH-5	Handling and learning about various sophisticated analytical techniques and instrumentation. Students are exposed to latest analytical techniques. Methodology for development of analytical technqiues for various materials is discussed. This Course prepare students for both research and industry.
Chemical Instrumentation and Laboratory Techniques	CH-6	This course helps students to have flair for setting-up of facility and analytical instruments.

Health Physics and Radiation Sciences	CH-7	Specialised course for students to work on radiation and associated safety aspects. Basics of interaction of radiation with matter. Introduces theory of various nuclear radiation detectors and their practical applications Introduces Biological Effects, Radiation Protection and Regulation procedure, Emergency Preparedness and Management
Chemistry of Fuel Cycle-I	CH-9	This course gives basic introduction to nuclear materials and thermodynamic properties of fuel at higher temperature. Many theories and concepts taught will be directly applied to nuclear plants.
Chemistry of Fuel Cycle-II: Actinide chemistry and separation science	CH-10	This course gives basic introduction to nuclear reactors and fuels. Many theories and concepts of re-use of nuclear fuel, need for nuclear energy are dealt extensively.
Materials for Nuclear Reactors and Fuel Cycle Processing Systems	CH-11	Brief overview of nuclear reactors in India and across the world. Details of nuclear materials are dealt extensively.
Nuclear and Radiochemistry	CH-12	Advanced course in nuclear chemistry. Helps students to understand and appreciate various fundamental aspects of radioactivity. Practicals help students to develop expertise in handling radioactive materials. Students measure half-life of radioactive nuclides. The fundamentals and applications taught helps in preparing students for various out-reach programs.
Corrosion Science and Engineering	CH-13	Fundamentals and practical applications of corrosion science and engineering help students to take up career in research. Also prepares students for a career in industry.
Quantum Chemistry & Group Theory	CH-14	Train students to gain expertise in theoretical chemistry. Students are trained to handle modelling software packages. Students apply these for metal-

		complexation, weak intermolecular interactions, thermodynamic calculations.
Molecular Spectroscopy	CH-15	Train students to gain expertise in theoretical chemistry. Besides applied experimental spectroscopy is taught which helps candidate in research career and subsequent job prospects. Special techniques such as matrix isolation spectroscopy, laser-Raman techniques are taught with experimental demonstration.
Lasers and Application	CH-16	(a) Both fundamentals and general applications of Lasers are taught. (b) Students handle lasers in the practical for technological applications. (c) Students handle lasers for various analytical chemistry applications.
Nanomaterials and Advanced Chemical Sensors	CH-17	The fundamental knowledge gained in this course had helped to (a) understanding and development of materials (b) tailor made materials for preparation of chemical sensors (c) indigenous sensors (d) special sensors (for e.g. in-sodium) which have to be developed - which will not be supplied by commercial sources.
Course on Research Methodology	CH-RM	Ethics in research, plagiarism, manuscript writing, Data analysis, presentation of results are dealt extensively. Ensure students are ready for taking up research work.

Course Structure:

III. Courses at NISER

Program Code : CHEM04	Programme Specific Outcome	Ability to pursue a career in chemical research
		Human resource with knowledge base in theoretical and experimental chemistry
		Ability to work on societal problems involving chemistry
		Ability to apply the basic concepts and principles of chemistry in solving real life problems

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Physical Methods in Chemistry I	C606
2	Physical Methods in Chemistry II	C601
3	Coordination Chemistry	C604
4	Chemical Binding	C605
5	Advanced Organic Chemistry	C665

(B) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Chemical Rate Processes	C602
2	Chemistry of Heterocycles and Natural Products	C603
3	Molecular Modeling	C651
4	Classics in Molecules	C653
5	Solid State Chemistry	C652
6	Crystallography	C654
7	Principles of Drug action	C655
8	Advanced Bio-inorganic Chemistry	C656
9	Nuclear Magnetic Resonance	C657
10	Advanced Functional Materials	C658

11	Supramolecular Chemistry	C659
12	Chemistry of Nanomaterials	C660
13	Polymer Chemistry	C662
14	Molecular Reaction Dynamics	C663
15	Theory of Molecular Spectroscopy	C664
16	Catalysis: Reaction Mechanisms and Applications	C666
17	Advanced Main group Chemistry	C667
18	Advanced Fluorescence Spectroscopy	C668
19	Biomacromolecules	C669
20	Advanced Heterocyclic Chemistry	C670
21	Statistical Mechanics	C671
22	Photochemistry	C751
23	Pharmaceutical Chemistry	C752
24	Group Theory and Molecular Spectroscopy	C753

(C) LIST OF RESEARCH PROJECT COURSES

Sr. No.	Course Name	Course No
1	Minor Organic Chemistry Project-I	C754
2	Minor Organic Chemistry Project-II	C755
3	Minor Inorganic Chemistry Project-I	C756
4	Minor Inorganic Chemistry Project-II	C757
5	Minor Physical Chemistry Project-I	C758
6	Minor Physical Chemistry Project-II	C759

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Physical Methods in Chemistry I	C606	Understand the basics of absorption and fluorescence spectroscopy.
		Theoretical prediction of absorption maximum of some organic molecules.
		Identifying and distinguishing various type of electronic transition using solvent perturbation techniques.
		Understanding the concept of micro polarity and the importance of this parameter in spectroscopy
		Understanding some important photoprocessess such as electron transfer and energy transfer and their applications in energy related applications.

		Applications of fluorescence spectroscopy in detecting various analytes (Sensing applications)
Physical Methods in Chemistry II	C601	Understanding the concepts of energy minimization, frequency calculations and transition state optimization.
		Practical experience in applications of quantum chemical calculations
Coordination Chemistry	C604	Understand the fundamentals of Group Theory and apply it to molecular spectroscopy
		Understand the link between molecular spectroscopy, symmetry and information content of molecular spectra.
		Understanding the formation of molecular orbitals.
		Calculate/predict energy levels and spectral features using symmetry as a simplification tool
		Use symmetry arguments to possibly solve molecular Problems.
Chemical Binding	C605	Understand the quantum mechanics of molecules
		Construct molecular orbitals for polyatomic molecules
		Apply symmetry and molecular orbital theory to derive molecular terms
		Understand the theory Hartree-Fock (HF), DFT, and semi-empirical methods
Advanced Organic Chemistry	C665	Understanding of important organic transformations with advanced mechanisms.
		Learning the recent advances in organic chemistry
		Enhanced ability to connect the learned topics with current research problem and envisage new research projects.

(B) ELECTIVES

Name of the Course	Course code	Course Outcome
Chemical Rate Processes	C602	Understanding of important organic transformations with advanced mechanisms.
		Learning the recent advances in organic chemistry
		Enhanced ability to connect the learned topics with current research problem and envisage new research projects.
		Understanding of important organic transformations with advanced mechanisms.

Chemistry of Heterocycles and Natural Products	C603	Understanding nomenclature, structure and reactivity of aromatic and non-aromatic heterocycles.
		Understanding the design and application of various organic reactions for the synthesis of natural products.
		Understanding the classification, structure and synthesis of biomolecules
Molecular Modeling	C651	Construct potential energy surfaces and force-fields for molecules
		Perform HF, DFT, and semi-empirical calculations on molecules
		Perform chemical dynamics simulations for simple reactions
		Apply molecular dynamics and Monte-Carlo simulations on large sized molecules
Classics in Molecules	C653	To learn discovery of organic molecules and their impact on the world such as Urea, Glucose, & Penicillin
		To understand the basic organic chemistry for learning chemical biology
		To learn the small organic molecules that interaction with molecular targets
		To find the nature of drugs and their function in biological changes
Solid State Chemistry	C652	Describe the principles concerning solid state structures
		Describe specific crystal structures by applying basic crystallographic concepts
		Describe the experimental use of the diffraction phenomenon
		Use powder diffraction data for characterising cubic substances
		Analyse thermograms and phase diagrams in known systems
Crystallography	C654	Define concepts such as lattice, point and space groups
		Be familiar with Bragg's Law and explain its the relation to crystal structure
		Identify and describe different diffraction methods
		Interpret and assign X-ray and electron diffraction patterns
		use crystallographic data for a validated phase analysis
Principles of Drug action	C655	To learn pharmacokinetics and pharmacology
		To understand absorption, distribution, metabolism, and excretion of drugs

		To learn various stages of drug discovery process such as clinical trails
		To find the modern drug discovery and development processes including the identification of molecular targets, High-throughput screening (HTS)
Advanced Bio-inorganic Chemistry	C656	Apply the basic principles in inorganic and general chemistry to interdisciplinary topics in the field of bioinorganic chemistry.
		Describe the main roles of metal ions in biological processes, and identify the chemical properties that are required to each particular function.
		Describe the role of metal ions in enzymes involved in acid-base reactions.
		Describe the role of metal ions that are involved in electron-transfer reactions in biological systems.
		Describe how oxygen is transported in different species and identify the metal centers involved in this task.
		Describe the different metal-activation sites in enzymes that are involved in the activation of oxygen.
		Identify the main toxicological mechanisms of metals and the biological defenses against the toxic effects.
		List some medical applications of inorganic compounds.
Nuclear Magnetic Resonance	C657	Theoretical understanding of the basic working principle of NMR spectroscopy.
		Building in-depth knowledge of the routinely performed experimental steps.
		Analysis of pulse sequence of few key one- and two-dimensional experiments to understand how certain spectra are generated.
		Understanding the theory behind common problems encountered during routine operation of an NMR spectrometer.
Advanced Functional Materials	C658	Introduction to materials in modern technology
		Learn about semiconductor and dielectric materials.
		Exploring the role of magnetic materials in inter-disciplinary sciences
		Use of polymer materials and nano-composites in chemistry and day-today life.
Supramolecular Chemistry	C659	Learn various noncovalent interactions.
		Design the synthesis of novel macrocycles

		Understand the stabilization of anions, cations and neutral substrates.
		To evaluate the binding and stability constants
Chemistry of Nanomaterials	C660	Key concepts of Bottom-up and Top down approaches
		Understanding the mechanism of formation of 0-D, 1-D, 2-D, 3-D
		nanostructured materials.
		Understanding the structure-property relationship of carbon nanomaterials and
		self-assembled monolayers.
		Application of nanomaterials for energy applications and biological applications.
Polymer Chemistry	C662	Different types of polymers
		Concepts of polymers
		Applications of polymers
		Challenges involved in making bio-degradable polymers
Molecular Reaction Dynamics	C663	Apply transition state theory and RRKM theory to compute rate constants
		Understand the theory of classical and quantum scattering phenomena
		Learn, how to follow the dynamics of chemical reactions experimentally and theoretically
Theory of Molecular Spectroscopy	C664	Separate the molecular motion into translations, rotations, and vibrations components
		Transform between internal and normal mode coordinates
		Understand the rovibronic spectroscopy of molecules
		Understand multiphoton processes and their application in modern spectroscopy
Catalysis: Reaction Mechanisms and Applications	C666	Understanding the principles of catalysis.
		Key concepts of various elementary steps which are important in catalytic cycle.
		Understanding the development of various catalysts in many important catalytic reactions.
		Implications and applications of catalysis in industry and academia.
Advanced Main group Chemistry	C667	Understanding the structure and bonding aspects of metal-metal single or multiple bond of main group elements
		Soluble main group metal hydrides: synthesis and their reactivity studies.
		Group 13 and Group 14 low valent metallacylces: synthesis and reactivity studies

		Application of Main group compounds in homogeneous catalysis.
Advanced Fluorescence Spectroscopy	C668	Describes basic principles and application of fluorescence spectroscopy.
		To learn, how fluorescence spectroscopy is used for frequency and time domain studies of important chemical process.
		To learn to use fluorescence spectroscopy in biological related molecules.
		It also introduces fluorescence imaging**.**
Biomacromolecules	C669	Basic understanding of biomolecules with respect to their structure
		Structure and function relation of biologically important molecules
		In-depth understanding of various biological processes such as DNA replication, protein synthesis
Advanced Heterocyclic Chemistry	C670	Basic understanding of biomolecules with respect to their structure
		Structure and function relation of biologically important molecules
		In-depth understanding of various biological processes such as DNA replication, protein synthesis
		Basic understanding of biomolecules with respect to their structure
Statistical Mechanics	C671	Understanding the concepts of ensembles, energy partition and probability distribution
		Learning of classical and quantum statistical mechanics
		Application of statistical mechanics to study the thermodynamic properties of simple gases and solids.
Photochemistry	C751	Understanding the photoinduced reactions in chemical and biological systems.
		Understanding the photo-physical processes
		Basic principles and application of fluorescence spectroscopy
		Use the knowledge of photochemistry in materials applications
Pharmaceutical Chemistry	C752	To learn pharmacokinetics and pharmacology
		To understand pharmacores and their interactions in molecular targets
		To interpret AMDE principle of drugs (absorption, distribution, metabolism, and excretion)
		To understand drug discovery processes

Group Theory and Molecular Spectroscopy	C753	Understand the fundamentals of Group Theory and apply it to molecular spectroscopy
		Understand the link between molecular spectroscopy, symmetry and information content of molecular spectra.
		Understanding the formation of molecular orbitals.
		Calculate/predict energy levels and spectral features using symmetry as a simplification tool
		Use symmetry arguments to possibly solve molecular Problems.
		Understand the basics of light-matter interaction.
		Understand the fundamentals of rotational, vibrational and electronic spectroscopy. Calculation of some useful parameters from spectral data.

(C) RESEARCH PROJECT COURSES:

Name of the Course	Course Code	Course Outcome
Minor Organic Chemistry Project I	C754	Understanding review of literature in a specified research field
		To learn characterization of organic molecules such as spectral and analytical data
		To set up experiments for known compounds
Minor Organic Chemistry Project II	C755	Independent ability to set up a chemical reaction
		Understanding the reaction progress and monitoring
		Isolation and characterization of organic compounds
Minor Inorganic Chemistry Project I	C756	Understanding review of literature in a specified research field
		Find out the research problem
		To learn the synthesis of known compounds
Minor Inorganic Chemistry Project II	C757	To learn the characterization of compounds
		Ability to write a report
		Ability to design future plans
Minor Physical Chemistry Project I	C758	Understanding review of literature in a specified research field
		To learn several spectroscopic techniques
		Learning basic laboratory techniques
Minor Physical Chemistry Project II	C759	Ability to study in detail about selected research problem
		Ability to find new alternative approaches to a research problem
		Ability to design future plans

Ph.D. in ENGINEERING SCIENCES (Program Code: ENGG04)

BACK TO MAIN

Course Structure:

I. Courses at BARC

Program Code : ENGG04	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	**Name of the Course**	**Course code**
1	Accelerator Physics and Technology	EN501
2	Engineering Mathematics	EN502-505
3	Health Physics and Rad & Indl Safety	EN506
4	Nuclear Fuel Cycle Technology	EN508
5	NPP & Advanced Reactor Concepts	EN509
6	Reactor Physics and Engineering	EN510

Course Outcomes:

FOUNDATION COURSES

Name of the Course	**Course code**	**Course Outcome**
Accelerator Physics and Technology	EN501	The course introduces basic concepts of accelerator physics, Vacuum and cryogenic systems
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Engineering Mathematics	EN502-505	Advanced knowledge in computational data analysis, data fitting and error analysis

		Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
Health Physics and Rad & Indl Safety	EN506	Learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Nuclear Fuel Cycle Technology	EN508	Familiarisation with font and back end of nuclear fuel cycle technology
		Knowledge of radioactive waste generation on nuclear fuel burning and its processing
NPP & Advanced Reactor Concepts	EN509	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts
		Familiarization with reactor physics design challenges
Reactor Physics and Engineering	EN510	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with nuclear reactors.

(A) MECHANICAL COURSES

(A1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Code design for PVP	EN610
2	Computational fluid Dynamics and Heat Transfer	EN611
3	Finite Element Method	EN621
4	Fracture Mechanics	EN622
5	Mechanics of Solids	EN624

(A2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Machine Design	EN711
4	Material Science in Nuclear Engineering	EN712
5	Multi-scale material modelling	EN715
6	Nuclear Emergencies	EN716
7	Reliability Engineering	EN718
8	Vibration	EN721

(A3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(A1) Core Engineering

Name of the Course	Course code	Course Outcome
Code design for PVP	EN610	Basis of ASME Sec.VIII and Sec.III eqns. for Pressure Vessel and Piping Design
		Nozzle openings, Vessel design under ext. pressure
		ANSI / ASME B31.1 and B31.3 piping code
		NDE Examination of welds, Acceptance standard
Computational fluid Dynamics and Heat Transfer	EN611	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer

Finite Element Method	EN621	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Fracture Mechanics	EN622	LEFM and EPFM, Material fracture props. determination
		PTS event of RPV and Master Curve Concept
		Computational Fracture Mechanics
		Fracture Mechanisms
Mechanics of Solids	EN624	Principles and Fundamental Equations of Elasticity
		Analysis of Stress and Strain, Thermal Stresses
		Introduction to Plasticity
		Theory of Plates and Shells

(A2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Programming Language C++
		Parallel Programming
		Scientific Visualization
		Artificial Neural Network
Fluid Power Technology	EN709	Basic principles of hydraulics and pneumatics, pressure control
		Fluid power pumps and compressors, Fluid experiments
		Directional and flow control valves, Fluid Logic & Control
		Advanced Hydraulic Control Circuits, Electronics and Instrumentation for Hydraulics
Machine Design	EN711	Basic Principles of Machine Design, Design and Drawing Practices
		Sealing Methods
		Special Dimensional Inspection Techniques
		Advanced Manufacturing Techniques
Material Science in Nuclear Engineering		Metallurgy of steels
		Nuclear Materials

	EN712	Advanced Polymeric materials and Composites
		Corrosion
Multi-scale material modelling	EN715	Atomistic models: Molecular dynamics, Monte Carlo methods
		Inter-atomic potentials, Mesoscopic methods
		Modeling at microscale
		Bridging the scale gaps between different simulation levels
Nuclear Emergencies	EN716	Radiation Shielding, Nuclear Waste Management
		Nuclear Accidents/emergencies, Effects of Hiroshima & Nagasaki bombing
		Medical decontamination with demonstration
		Monitoring of High radiation field area
Reliability Engineering	EN718	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Vibration	EN721	Single and Multi-degree-of-freedom Systems, Free vibration
		Response of Systems To Ground Motion: Earthquake motion
		Flow Induced Vibration
		Vibration Measurement and Signal Analysis

(A3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
MiniProject		To provide a hands-on experience of working in an

	EN593	ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Learning oral and written communication of research results.

(B) CHEMICAL ENGINEERING COURSES

(B1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Chemical Reaction Engineering	EN601
2	Advanced Mass Transfer	EN604
3	Code design for PVP	EN610
4	Computational Fluid Dynamics and Heat Transfer	EN611
5	Nuclear Chemical Engineering	EN628
6	Process Dynamics and Control	EN634
7	Process Modeling, Simulation and Optimization	EN635

(B2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Material Science in Nuclear Engineering	EN712
4	Membrane Technology	EN714

(B3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591

2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(B1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Chemical Reaction Engineering	EN601	Fundamentals of Non-ideal reactors & RTD studies
		Understanding Non-isothermal effects & dynamical behaviour
		Overview of Heterogeneous reactions
		Approaches in Advanced reaction engineering & reactor design
Advanced Mass Transfer	EN604	Understanding Mass transfer with and without chemical reactions
		Rate based approaches for design
		Selection and design of various contacting equipment
		Process intensification approaches
Code design for PVP	EN610	Overview of Theories for pressure vessel design
		ASME Sec. VIII Div. 1 and Div - II equations
		Pressure vessel design as per ASME
		Design of piping as per B31.1 piping code.
Computational Fluid Dynamics and Heat Transfer	EN611	Understanding Kinematics of fluid flow and governing equations
		Classification of Partial Differential Equations & their discretization
		Convective heat transfer for internal and external flows
		Numerical Solution of fluid flow and heat transfer equations
Nuclear Chemical Engineering	EN628	Overview of Recovery and processing of nuclear materials
		Uranium conversion and reconversion

		Isotope Separation
		Nuclear Waste Management
Process Dynamics and Control	EN634	Introduction to process control & control loop dynamics
		Fundamentals of state-space controls, state, measurement equations
		General solution of the state equation
		Multi-variable controls, de-coupling, relative gain array
Process Modeling, Simulation and Optimization	EN635	Formulation of Dynamic and steady state models
		Flow sheet Analysis & Plant Simulation
		General Approaches for Non-Linear Systems
		Plant optimisation by Genetic Algorithms and Neural Nets

(B2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Understanding Programming Language C++
		Finite difference, finite volume, finite element discretization, grid generation, artificial neural network
		Parallel Programming, Message Passing Interface and MPI communications
		Scientific Visualization methods
Fluid Power Technology	EN709	Basic principles of Hydraulics and pneumatics
		Properties of hydraulic fluids and pneumatic air
		Roto-dynamic pumps, pressure and flow control
		Approaches in Hydraulic Circuit Design
Material Science in Nuclear Engineering	EN712	Overview of Nuclear Materials & their classifications
		Structure and properties of nuclear materials
		Processing of Nuclear Materials

		Material characterization techniques
Membrane Technology	EN714	Overview of Novel Membranes
		Preparation and Characterization
		Membrane Technologies
		Applications of Membrane Technology

(B3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering

(C) METALLURGY

(C1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Corrosion	EN615

2	Extractive Metallurgy	EN620
3	Mechanical Metallurgy	EN623
4	Nuclear Materials	EN628
5	Nuclear Metallurgy	EN629
6	Physical Metallurgy	EN630
7	Process Control & Instrumentation	EN631

(C2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Digital Signal Processing & Image Processing	EN706
3	Image processing and Machine Vision	EN710
4	Materials Characterization	EN713
5	Multi scale Material Modeling	EN715
6	Nuclear Chemical Engineering	EN628
7	Nuclear Emergencies	EN716
8	Welding Science & Technology	EN723

(C3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(C1) Core Engineering

Name of the Course	Course code	Course Outcome
Corrosion	EN615	Understanding electrochemical theory of corrosion & corrosion basics
		General principles of corrosion control
		Forms of corrosion and its mitigation
		Corrosion problems in nuclear industry and its mitigation
Extractive Metallurgy	EN620	Thermodynamics and kinetics of metal extraction
		Advanced material processing techniques
		Process metallurgy of rare metals, special materials and alloys
		Process metallurgy of U, Th, Pu, Be, Zr, Hf, Nb, Ta & rare earths
Mechanical Metallurgy	EN623	Exposure to stress tensor, state of stress, principal stress, hydrostatic, deviatoric stress
		Dislocations and deformation behaviour
		Creep & creep law, deformation mechanism map
		Fracture mechanics and fatigue of metals
Nuclear Materials	EN628	Vacuum melting & solidification, controlling casting defects of U, Zr and Ti alloys
		Cold & hot working, dynamic recovery, recrystallization of fuel tube, texture microstructure control
		Powder metallurgy of oxide, mixed oxide, carbide, intermetallic nuclear fuel material
		Applications of powder metallurgy in applications relevant to DAE
Nuclear Metallurgy	EN629	Fabrication of different types of fuel for research and power reactors

		Health physics, radioactivity and safety aspects of Pu handling
		Effects of irradiation on nuclear fuel and structural materials, hydriding related problems in Zr alloys
		Post irradiation examination (PIE) of nuclear fuel and structural material
Physical Metallurgy	EN630	Understanding basics of crystallography, crystal defects during irradiation
		Thermodynamics, phase equilibria & phase transformation
		Diffusion mechanism, equations & solutions
		Recovery, Recrystalization and Grain Growth
Process Control & Instrumentation	EN631	Understanding basic principles of measurement
		Sensors, transducers & transmission methods for pressure, vacuum, flow, level
		Principles of Automatic Control Systems
		Fail safe principles, simple logic circuits, ladder circuits for control action

(C2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Exposure to programming languages: C and C++
		Application of finite difference, finite volume, finite element techniques, ANN etc. in DAE
		Introduction to parallel programming concepts
		Data storage & visualisation techniques and case studies
Digital Signal Processing & Image Processing	EN706	Introduction to digital signal processing system & applications
		Discrete Fourier transform, fast Fourier transform

		Image processing, image enhancement, image segmentation & analysis, morphological operations
Image processing and Machine Vision	EN710	Introduction to digital image model representation, image sensor, digitizer, computer, standard file format
		Image enhancement segmentation and analysis, restoration
		Morphological operations and image compression
		Machine vision & introduction to image understanding
Materials Characterization	EN713	Introduction to microscopy techniques: optical, SEM, TEM, AFM, STEM, EBSD, FIM
		XRD and applications, basics of SIMS, RBS
		Analytical TEM, chemical analysis in materials science
		Thermal expansion and conductivity, TGA/DTA/DSC, mechanical properties
Multi scale Material Modeling	EN715	Introduction to types of models and multiscale approaches
		Atomistic models – molecular dynamics
		Basics of Monte Carlo methods
		Analysis of simulation results, bridging scale gap between different simulation levels
Nuclear Chemical Engineering	EN628	Recovery & processing of U, Th, Zr, rare earths from from ores / intermediates
		Uranium Conversion/reconversion
		Isotope Separation
		Nuclear Waste Management
Nuclear Emergencies	EN716	Introduction to nuclear fuel cycle, transportation of radioactive material
		Radiological accidents / emergencies
		Effects of nuclear detonation, testing nuclear weapons
		Emergency Response methodology/ Philosophy

Welding Science & Technology	EN723	Overview of various welding processes - arc welding, beam welding, hybrid welding
		Cold Bonding/Solid State Bonding
		Welding metallurgy under high cooling rates
		Types of welding defects and its prevention

(C3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I & VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
Mini Project	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Learning oral and written communication of research results.

(D) CIVIL ENGINEERING

(D1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1

2	Civil Engg Design of Concrete & Steel Strct II	EN608.2
3	Design Basis Hazards & Geotechnical Engg	EN621
4	Earthquake Engineeing & Structural Dyanmics	EN609
5	Finite Element Method	EN626
6	Mechanics of Solids	EN624

(D2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Struct Dynamics & Earthquake Engg	EN724
2	Construction Materials, Management & Quality	EN614
3	Safety & Reliability of Civil Engineering	EN722
4	Project Management	EN717

(D3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(D1) Core Engineering

Name of the Course	Course code	Course Outcome
Civil Engg Design of Concrete & Steel Strct I	EN608.1	Various structures of nuclear facilities; safety, seismic, design and quality classifications of structures
		Design loads on structures and load combinations as per BIS, ACI and AERB standards
		Design of RC structures; fracture mechanics concept in RC design

		Shallow and deep foundation design; machine foundation design
Civil Engg Design of Concrete & Steel Strct II	EN608.2	Design of prestressed concrete structures
		Design of lined and unlined reactor containment structures using RCC-G/BPEL/BAEL and ASME codes
		Design of steel structures using BIS, AERB and AISC standards
		Design of underground and overhead water retaining structures; design of natural draft cooling tower
Design Basis Hazards & Geotechnical Engg	EN621	Siting of nuclear facilities; hazards due to internal and external events; design basis natural hazards, such as, seismic, flood, wind, snow and solar radiations
		Human-induced design basis hazards, such as, aircraft/missile impact, explosions/blast, and toxic gas release
		Soils and its classifications; laboratory and field tests on soils and rock; compaction of soils; bearing capacity of soils and rocks
		Stages of geotechnical investigations; soil and rock sampling; geophysical investigations; seismic refraction survey, cross-hole seismic test; ERT; liquefaction potential of sites
Earthquake Engineeing & Structural Dyanmics	EN609	Seismic waves and wave propagation; time history; response spectra; seismic instrumentation
		Dynamic loadings; dynamic response of SDOF and MDOF systems; dynamics of continuum system
		Response spectra and time history approaches for determining seismic structural

		response; SSI and FSI; structural response in frequency domain
		Seismic requalification of existing installations; retrofitting techniques
Finite Element Method	EN626	Basis of FEM; energy principles; shape function requirements; C0 and C1 continuity
		Derivation of stiffness matrix and load vector for bar, beam, 2D plane and 2D iso-parametric elements; evaluation of strain and stress
		Incompatible quadrilateral elements; Tetrahedron, and hexahedron elements; plate bending elements; shell elements; patch test; adoptive meshing; error analysis
		Non-linear problems; material and geometric non-linearity
Mechanics of Solids	EN624	Concepts of elasticity; Equilibrium equations; Solution of 1-D boundary value problem; tensors algebra
		Analysis of stress and strain; transformation using direction cosines; principal planes; octahedral plane; state of pure shear; strain deviator tensor
		Strain displacement relationship; Isotropy and Anisotropy; Strain energy; Plane stress and plane strain problems; solution for beam bending problem; solution in polar co-ordinates; thermal stresses
		Analysis of thin and thick plates; shear deformation theories; membrane theory of shells of revolution and translation; bending analysis of shells; application to cylindrical, spherical and conical shells; introduction to plasticity

(D2) Electives

Name of the Course	Course code	Course Outcome
Advanced Struct Dynamics & Earthquake Engg	EN724	Concept of performance based seismic design; seismic demand; capacity of structures; performance levels
		Concept of seismic and vibration control; passive control; semi-active control; active control; base isolation techniques
		Methods of testing; qualification of system by testing; seismic instrumentation; measurement of displacement, velocity, acceleration
		Fluid-structure interaction techniques; multibody dynamics
Construction Materials, Management & Quality	EN614	Construction materials, such as, concrete, reinforcement, structural steel, paints, water-proofing materials
		Design of formworks; slip forms; prestressing systems
		QA in civil design, materials, construction, O&M, and regulatory inspection
		Dewatering; rock excavation, construction safety and JHA; mode of tendering; contract clauses; dispute adjudication
Safety & Reliability of Civil Engineering	EN722	Statistics and probability; discrete and continuous random variables; probability distributions
		Concept of structural safety; limit states; MVFOSM; Hasofer Lind reliability index; Cornell reliability index; Monte Carlo simulation
		Probabilistic safety assessment; seismic fragility analysis; seismic risk; health assessment of existing concrete and steel structures; rehabilitation and retrofitting

		techniques; service life prediction
		Concept of industrial safety; fire hazard analysis; safety in handling machinery, equipment and tools; fitness and protection of personnel
Project Management	EN717	Type, cost and schedule of nuclear power projects; resources of project; project organization chart; delegation of power
		Scheduling in a project by PERT, CPM, precedence diagram method; project management software for planning, scheduling and monitoring
		Preparation of target plan, updating of progress, monitoring variance and reporting; physical and financial monitoring; capital budgeting and expenditure control
		Contingency plan; construction management; project management; SWOT analysis; problem solving techniques

(D3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
Mini Project	EN5A93	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg.

(E) ELECTRICAL ENGINEERING

(E1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design I	EN602
2	Computer Based System Design I	EN612
3	Electrical Systems for Nuclear Power Plants	EN618
4	Modern Control Systems Design and Simulation	EN625
5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(E2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design II	EN702
2	Artificial Intelligence and its Applications	EN703
3	Computer Based System Design II	EN704
4	Digital Signal Processing & Image Processing	EN706
5	Image Processing & Machine Vision	EN710
6	Signal Conditioning, Recovery and EMI Aspects	EN719
7	Software Engineering	EN720

(E3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(E1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design I	EN602	Materials and Electrical Properties, NDT, MFL
		Superconducting Properties
		Understanding Control Techniques of Electrical Motors and Electronics
		FEM and Applications
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Electrical Systems for Nuclear Power Plants	EN618	Recapitulation of Power System Design Analysis
		Basics of Switchyard Design Principles
		Understanding Protection Systems
		Exposure to Electrical Systems in NPP
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity

		Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(E2) Electives

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design II	EN702	Understanding Vector Control of PM Synchronous Motors
		Exposure to Design and Applications of Variable Reluctance Stepper Motors and Switched Reluctance
		Understanding Pulse Power Techniques
		High Voltage Systems
Artificial Intelligence and its Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies

		Understanding Reinforcement Learning and Dynamic Programming
Computer Based System Design II	EN704	Exposure to Data Communication Interfaces for Control Applications, Fieldbuses
		Understanding Real Time System Design Principles
		Understanding IPC mechanisms in RTOS
		Exposure to Safety System Design Regulations
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics

		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(E3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(F) ELECTRONICS ENGINEERING

(F1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electronic Circuit Design Techniques	EN603
2	Advanced Nuclear Instrumentation	EN605
3	Embedded & Computer Based Sys. Design	EN619
4	Modern Control Systems Design and Simulation	EN625

5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(F2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Digital Signal Processing & Image Processing	EN706
3	Embedded Electronics Software	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720
7	Artificial Intelligence & Applications	EN703

(F3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(F1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electronic Circuit Design Techniques	EN603	Introduction to VLSI Design Flow, HDL, Design and Simulation of HPD
		Understanding Semiconductor Detectors , MEMS Desin
		Introduction to RF Electronics
		Understanding Transmission Lines, Waveguides, RF Amplifiers,

Advanced Nuclear Instrumentation	EN605	Understanding Electronics in Spectroscope Design
		Nuclear Instruments, Alpha, Beta and Gamma Detectors, Scintillation Counters
		Introduction to Accelerator Instrumentation
		Understanding Reactor Neutronic Instruments and Signal Processing
Embedded & Computer Based Sys. Design	EN619	Overview of Microprocessors and Interfacing
		Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements
		Exposure to Computer Communication, Encoding and Technologies
		Understanding Software Developments for NPP/Accelerator C&I
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP

Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(F2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS

Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

(F3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(G)INSTRUMENTATION ENGINEERING

(G1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Applied Process Instrumentation	EN607
2	Computer Based System Design I	EN612
3	Modern Control Systems Design and Simulation	EN625
4	Reactor C&I and Human Machine Interface	EN636
5	Reactor Control Engineering and Instrumentation	EN637-8
6	Reliability Engineering	EN639

(G2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Computer Based System Design II	EN706
3	Digital Signal Processing & Image Processing	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720

(G3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(G1) Core Engineering

Name of the Course	Course code	Course Outcome
Applied Process Instrumentation	EN607	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation
		Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and

		Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Reactor C&I and Human Machine Interface	EN636	Overview of Reactor C&I & Power Supply Requirements for Instrumentation
		Understanding Control Room Design and Exposure to Codes & Guides
		Exposure to Relay & Control Logic Design, Critera for Relay, PLC & DCS Technologies
		C&I Cable Requirements
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(G2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

Computer Based System Design II	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Digital Signal Processing & Image Processing	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(G3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(H)COMPUTER SCIENCE AND ENGINEERING

(H1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Operating Systems	EN606
2	Computer Graphics & Visualisation	EN613
3	Distributed Computing	EN616
4	Networking & Information Security	EN627
5	Reactor Control Engineering	EN637
6	Software Engineering and Formal Methods	EN640

(H2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Data Base Management System & Web Technology	EN705
3	Digital Signal Processing & Image Processing	EN706
4	Embedded Electronics Software	EN707
5	Feedback Control System	EN708
6	Image Processing & Machine Vision	EN710

(H3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(H1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Operating Systems	EN606	Understanding IPC Calls
		Shell Programming
		Understanding Distributed File Systems
		Applications of System Calls
Computer Graphics & Visualisation	EN613	Understanding Geometric Transformations
		Applications of Geometric Projections
		Techniques for Hidden Surface Removals
		Applications of Scientific Visualisation
Distributed Computing	EN616	Understanding modern CPU Architectures
		Understanding Interconnect Techniques
		Understanding and Applications of HPC

		Understanding Grid Computing and Workflows
Networking & Information Security	EN627	Understanding Issues in the transport of data and Techniques
		Satellite Communications
		Understanding Network Security Concepts
		Advances in Cryptography and Cryptanalysis
Reactor Control Engineering	EN637	Understanding Physics behind Rector Control
		Understanding Point Kinetics Model and Reactor Periods
		Understanding Issues with Large Reactor Control and Modelling
		Understanding Control Requirements for PWR, PHWR, BWR and FBR
Software Engineering and Formal Methods	EN640	Understanding Techniques for modelling software
		Application of Model Checking and Theorem Proving
		Understanding Agile Programming
		Understanding Software Testing

(H2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Data Base Management System & Web Technology	EN705	Understanding SQL and Complex queries
		Understanding Clusters and Distributed Databases
		Understanding and Working with Web Technologies
		Modelling data and design of real data bases

Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Feedback Control System	EN708	State Space Representation and Applications
		Time Domain Analysis
		Appreciating need for Stability Analysis & Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications

(H3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Training in formulation and execution of research project.
		Training in written and oral presentation skills.

BACK TO MAIN

Course Structure:

II. Courses at IGCAR

Program Code: ENGG04	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	**Name of the Course**	**Course code**
1	Nuclear Reactors	NR
2	Engineering Mathematics	EM
3	Materials and Metallurgy	MM
4	Fast Reactor Physics and Shielding	RP
5	Reactor Engineering	RE
6	Health Physics and Radiological Safety	HP
7	Project Management	PM

Course Outcomes:

FOUNDATION COURSES

Name of the Course	**Course code**	**Course Outcome**
Nuclear Reactors	NR	Exposure to mechanical aspects of power plant engineering Details understanding of thermal and fast power reactors Introduction to sodium technology
Engineering Mathematics	EM	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering Introduction to numerical methods for solving ordinay and partial differential equations Probability and statistics Different types of transformations
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Reactor Engineering	RE	Basic understanding of core design of LMFBR Coolant circuits of LMFBR and special characteristics of sodium technology
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation Principles of radiation detection and Radiation Protection procedures Familiarization with principles of radiation detection and radiation Protection procedures
Project Management	PM	Training in Planning and execution of a research project

(A) MECHANICAL ENGINEERING

(A1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for Pressure Vessels and Piping	ME1
2	High Temperature Design and Inelastic Analysis	ME4
3	Computational Fluid Dynamics	ME6
4	Finite Element Method	ME8
5	Advanced Heat and Mass Transfer	ME10
6	Reliability Engineering	ME13
7	Manufacturing Technology	ME14

(A2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Machine Design	ME3
2	Structural Integrity Assessment Methods and NDE	
3	Vibration Engineering and condition Monitoring	
4	Seismic Design of Nuclear Reactors and Facilities	ME5
5	Plant Dynamics	

6	Experimental Mechanics	
7	Process Control and Instrumentation	ME15

(A3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-001-P
2	Seminar -1,2,3	02ENGG04-001-S

Course Outcomes:

(A1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for Pressure Vessels and Piping	ME1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles.
		The course also include introduction to tubesheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered. It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
High Temperature Design and Inelastic Analysis	ME4	This course has direct relevance with the design of fast breeder reactor components & piping system. It covers mainly about the role of high-Temperature design concerning FBR programme, significant failure modes and associated design guidelines and advanced inelastic analysis methods. The high temperature design aspect is followed based on the RCC MRx RB procedure. Reliable design of components and piping system operating under high temperature operating conditions should address the additional damage associated with creep, fatigue and creep-fatigue interactions predominantly under thermo-mechanical loadings. There are many unresolved problems in the area of high-temperature

		design such as visco-plasticity behaviour, ratcheting behaviour, high temperature crack initiation behaviour etc. These aspects are addressed in this course with the support of tutorials.
Computational Fluid Dynamics	ME6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis Numerical Solution of Complete Fluid Flow and Energy Equation
Finite Element Method	ME8	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Advanced Heat and Mass Transfer	ME10	Advanced knowledge in heat and mass transfer Laminar boundary layer and forced convective heat, turbulent flow and heat transfer Heat transfer in porous media and heat transfer with phase change Radiation heat transfer
Reliability Engineering	ME13	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Manufacturing Technology	ME14	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles plastic deformation, processes like rolling, forging, extrusion etc in the case of metal forming module. Arc welding process,welding metallurgy, defects, inspection, quality control aspects are covered inwelding module. Extraction of Uranium and Zirconium from ore to final product form is coveed in the material processingmodule.

(A2) ELECTIVES

Name of the Course	Course code	Course Outcome
Machine Design	ME3	Basic concepts in vibrations analysis
Structural Integrity Assessment Methods and NDE		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
Vibration Engineering and condition Monitoring		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	ME5	Introduction to earthquakes, design basis ground motion and IS 1893 spectra Introduction of earthquake engineering and analysis for multi degree freedom systems
Plant Dynamics		Analysis and design of structures, equipments and piping
Experimental Mechanics		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Process Control and Instrumentation	ME15	Understanding the concepts of instrumentation and control for nuclear power plants
		Able to identify and define instrumentation and control needs of a process or machine
		Able to provide indicative choice of instruments in the design

(A3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-001-P	Training in formulation and execution of research project.
Seminar -1,2,3	02ENGG04-001-S	Training in presentation of research results.

(B) ELECTRONIC AND INSTRUMENTAL ENGINEERING

(B1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	EL2
2	Nuclear Instrumentation	EL3
3	Reliability Engineering	EL4
4	Software Engineering	EL5
5	Human Machine Interface for Reactor Control Instrumentation	EL8
6	Modern Control of Dynamic Systems	EL10

(B2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence and Digital Signal Processing	EL6
2	Process Instrumentation	EL7
3	Embedded and Computer based systems Design	EL9
4	Analytical Instrumentation	EL11

(B3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-002-P
2	Seminar -1,2,3	02ENGG04-002-S

Course Outcomes:

(B1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	EL2	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	EL3	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Reliability Engineering	EL4	Introduction to reliability engineering applied to C&I systems
		Basic concepts of reliability, statistics and fault tolerence
		Probabilistic Safety (Risk) Assessment methods in the NPPs
Software Engineering	EL5	Introduction to software engineering and standards
		Software quality assurance, verification and validation
		Software analysis, design and configuration management
Human Machine Interface for Reactor Control Instrumentation	EL8	The subject is aimed on advanced design in new trends and development philosophy in the area of human machine interface. The student should obtain an overview of technologies implemented for reactor programmes and acquire an insight of the technical background to apply the same in context of reactor applications.
		The course work is framed in order to give an Introduction to various PFBR systems and HMI models in Distributed Digital Control System and their application to process systems such as special supervision systems, component handling systems, Reactor Protection Systems & Reactor Regulating Systems and Incident monitoring & mitigation systems. Learn about PC based process control system, Supervisory Control and Data Acquisition Systems.
		This course includes Familiarisation of plant automation overview, Soft Console versus conventional control panels, Guidelines for design of HMI displays, Building HMI systems, designing plant databases, alarm management techniques,

		Security features, creating process mimics, Trending historical data, Methods of passing data to HMI package etc. The capabilities of commercially available Professional HMI packages will also be explored.
Modern Control of Dynamic Systems	EL10	Introduction to state variable description with examples
		Controllability, observability and control system design

(B2) ELECTIVES

Name of the Course	Course code	Course Outcome
Artificial Intelligence and Digital Signal Processing	EL6	Exposure to fundamentals of digital signal processing algorithms
		Exposure to practical DSP algorithms and its implementation on different platforms
		Exposure to system design using pre conditioning circuits, anti-aliasing filters and digital signal controllers
		Exposure to system design case studies like Condition Monitoring System for rotating equipments And radar signal processing
		After course completion the student will be able to handle practical engineering problems solvable by digital signal processing techniques
		It is a specialised course which will give an introduction to AI techniques.
		It will give a flavour to fuzzy logic, robotics, neural networks, genetic algorithm.
Process Instrumentation	EL7	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Embedded and Computer based systems Design	EL9	Understanding of VME bus and cPCI bus architecture.
		'C' programming with MISRA C compliant.
		Electronics design in analog and digital domain
		Learning of VLSI based design using EDA tools.
		Learning of VHDL based digital design.
		Electronics system design using TMR architecture, fault tolerant design
		Introduction of reliability analysis for electronics system.
Analytical Instrumentation	EL11	Introduction to the principles and applications of modern analytical instruments Sensitivity, precision, and limitations of analytical instruments

(B3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-002-P	Training in formulation and execution of research project.
Seminar -1,2,3	02ENGG04-002-S	Training in presentation of research results.

(C) CHEMICAL ENGINEERING

(C1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Nuclear Chemical Engineering	CE1
2	Chemical Engineering Thermodynamics	CE2
3	Transport Phenomena	CE3
4	Multi-Phase Flow Systems	CE4
5	Code Design for Pressure Vessels and Piping	CE5
6	Computational Fluid Dynamics and Heat Transfer	CE6
7	Advanced Chemical Reaction Engineering	CE7

(C2) SPECIALIZED COURSES

Sr. No.	Name of the Course	Course code
1	Process Analysis and Control	CE8
2	Advanced Mass Transfer	CE9

(C3) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Preparedness &Response to Nuclear Emergencies	CEEL
	Artificial Intelligence Methods &Applications	
	Membrane/ Separation Process and Technology	

(C4) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-003-P
2	Seminar -1,2,3	02ENGG04-003-S

Course Outcomes:

(C1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Nuclear Chemical Engineering	CE1	Introduction to nuclear chemical engineering for production, processing and management of nuclear materials
		Modelling and Simulation in Nuclear Chemical Engineering
Chemical Engineering Thermodynamics	CE2	Understanding the concepts of Thermodynamics , scope of Classical Thermodynamics, Phase Equilibrium, Chemical Reaction Equilibria.
Transport Phenomena	CE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyze transport problems
		Analyze transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyze transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Multi-Phase Flow Systems	CE4	Introduction to multiphase flow and its classification
		Modeling and Simulation in Nuclear Chemical Engineering
		Applications of two-phase flow in the design of steam generators
		The phenomena of fluidization and its industrial application
Code Design for Pressure Vessels and Piping	CE5	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design

		for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
Computational Fluid Dynamics and Heat Transfer	CE6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer
Advanced Chemical Reaction Engineering	CE7	Understanding of thermodynamics and kinetics of chemical reactions
		Design and analysis of chemical reactors
		Modelling of multiphase reactors

(C2) SPECIALIZATION

Name of the Course	Course code	Course Outcome
Process Analysis and Control	CE8	Understanding of dynamics of chemical process systems and nonlinear process dynamics
		Design of multivariable controllers
Advanced Mass Transfer	CE9	Introduction to theories of mass transfer and advanced mass transfer processes
		Selection and design of contacting equipment in nuclear chemical industries

(C3) ELECTIVES

Name of the Course	Course code	Course Outcome
Preparedness & Response to Nuclear Emergencies	CEEL	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Artificial Intelligence Methods & Applications		
Membrane/ Separation Process and Technology		

(C4) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-003-P	Training in formulation and execution of research project.
Seminar -1,2,3	02ENGG04-003-S	Training in presentation of research results.

(D) MATERIALS SCIENCE

(D1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	MS1
2	Computational Methods	MS2
3	Materials and Metallurgy	MS3
4	Reactor Physics and Fuel Design	MS4
5	Health Physics	MS5
6	Metallurgical Thermodynamics	MS6
7	Experimental Methods for Materials Research	MS7
8	Structural Materials for Nuclear Reactors	MS8
9	NDE Science and Technology	MS9
10	Physical Metallurgy	MS10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	MS11
12	Introduction to Materials Science and Engineering	MS12
13	Corrosion Science and Engineering	MS13
14	Mechanical Behavior of Engineering Materials	MS14
15	Manufacturing Technology	MS15

Course Outcomes:

(D1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Engineering Mathematics	MS1	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
		Introduction to numerical methods for solving ordinary and partial differential equations
		Probability and statistics
		Different types of transformations
Computational Methods	MS2	Introduction to programming languages such as C# and Matlab
		Exposure to numerical techniques for solving partial differential equations
		Neural network for predictive applications
		Basics of atomis modelling, molecular dynamics and introduction to Monte-carlo simulation
		Introduction to FEM and current trends in modelling and imulation

Materials and Metallurgy	MS3	To develop a basic understanding on the classification of materials
		Mechanical property based selection of materials for nuclear application and standards
		Various fabrication related issues in material including welding and corrosion
		Non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Reactor Physics and Fuel Design	MS4	Introduction to basic nuclear and neutron physics concepts
		Nuclear reactors and fuel design concepts
		Reactor kinetics
Health Physics	MS5	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Metallurgical Thermodynamics	MS6	Introduction to Classical thermodynamics: 1st and 2nd laws and their applications
		Thermodynamic properties of pure substances and mixtures Solution thermodynamics
		Phased equilibria in multicomponent systems and stability
		Chemical reactor equilibria Exposure to experimental methods for determining thermodynamic properties
Experimental Methods for Materials Research	MS7	Exposure to various experimental techniques for materials characterization, including X-ray techniques, electron microscopies, ion-beam techniques, electron spectroscopies nuclear spectroscopies, vibrational spectroscopy and resonance absorption spectroscopies
		Basic understanding of underlying physics
Structural Materials for Nuclear Reactors	MS8	Exposure to the three stage nuclear power programme
		Concept of selection of structural materials for different applications
		Materials for thermal reactors, fast breeder reactors and reprocessing applications
		Materials processing and fabrication of components
NDE Science and Technology	MS9	Introduction to various non-destructive evaluation techniques for safe and reliable operation of structures and components
		Surface, volumetric and Dynamic NDE
Physical Metallurgy	MS10	Basic understanding of crystal structure and microstructure
		Knowledge of origin, construction and classifications of metallurgical phase diagrams

		Understanding of different types of metallurgical phase transformations and underlying principles
		Introduction to microstructural characterization techniques and tools
Fuel Cycle Physics and Introduction to Fuel Cycle	MS11	Introduction of nuclear fuel cycles
		Introduction to exploration, recovery and enrichment and uranium and other nuclear fuel materials
		Different types of nuclear fuels and fuel fabrication
		Recycling the spent fuel, fission products and actinides
Introduction to Materials Science and Engineering	MS12	Introduction to basic structures, bonding and defects in solids and techniques for their characterization
		Physcial properties of materials
		Basics of phase diagram and phase transformations
		Techniques for synthesis of materials
Corrosion Science and Engineering	MS13	Basic understanding of corrosion process, monitoring and preventation
		Introduction to thermodynamics and kinetics of corrosion
		Forms of corrosion and corrosion in nuclear reactor and reprocessing plants
Mechanical Behavior of Engineering Materials	MS14	Introduction to engineering materials
		Elastic and plastic deformation in polycrystalline materials
		Strengthening mechanisms in polycrystalline structural materials
		Exposure to damage mechanisms such as creep, fatigue and also exposure to fracture mechanics
Manufacturing Technology	MS15	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles of plastic deformation, processes like rolling, forging, extrusion etc. in the case of metal forming module.
		Arc welding process, welding metallurgy, defects, inspection, quality control aspects are covered in welding module. Extraction of Uranium and Zirconium from ore to final product form is covered in the material processing module.

(E) FAST REACTOR ENGINEERING – I

(E1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(E2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for pressure vessel and piping	FRE1
2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2
3	Transport Phenomena	FRE3
4	Reliability Engineering	FRE4
5	Process Design and Control	FRE5
6	Vibration Engineering and Condition Monitoring	FRE6
7	Seismic Design of Nuclear Reactors and Facilities	FRE7
8	Emergency Preparedness and Disaster Management	FRE8

(E3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Dynamics and Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva Voce

Course Outcomes:

(E1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(E2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for pressure vessel and piping	FRE1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tube sheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.

Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2	Advanced knowledge in heat and mass transfer
		Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
		Heat transfer in porous media and heat transfer with phase change
		Radiation heat transfer
Transport Phenomena	FRE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyse transport problems
		Analyse transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyse transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Vibration Engineering and Condition Monitoring	FRE6	Basic concepts in vibrations analysis
		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	FRE7	Introduction to earthquakes, design basis ground motion and IS 1893 spectra
		Introduction of earthquake engineering and analysis for multi degree freedom systems
		Analysis and design of structures, equipment and piping
		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(E3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine
		Turbine troubles
Mechanical and Electrical Equipment	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical’s	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	assessment of the understanding of the subject by the student and its application in problem solving.

(F) FAST REACTOR ENGINEERING – II

(F1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(F2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	FRE15
2	Nuclear Instrumentation	FRE16
3	Reliability Engineering	FRE4
4	Process Design and Control	FRE5
5	Embedded System Design & Human Machine Interface	FRE17
6	Process Instrumentation	FRE18
7	Emergency Preparedness and Disaster Management	FRE8

(F3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva-Voce

Course Outcomes:

(F1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(F2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	FRE15	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	FRE16	Students learn about basics of interaction of radiation with matter.
		Principle & Techniques to detect and measure ionizing radiation.
		Basics of radiation counting statistics
		Introduction to Neutron Flux Measurement in FBTR and PFBR.
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Embedded System Design & Human Machine Interface	FRE17	Introduction to Microprocessor Based Hardware Design
		Computer Communication and Networks
		Fault Tolerant and Distributed Architectures
		Programmable Logic Controller Design
		Overview of plant automation and Human Machine Interface (HMI)

Process Instrumentation	FRE18	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of various process variables
		Reliability principles, Fail safe design principles
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(F3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine Turbine troubles
Mechanical and Electrical Equipments	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	assessment of the understanding of the subject by the student and its application in problem solving.

BACK TO MAIN

Course Structure:

III. Courses at VECC

Program Code : ENGG04	Programme Specific Outcome	Impart knowledge in Experimental and Theoretical Nuclear Physics(and Allied Areas), Material Sciences, Theoretical Physics and High EnergyPhysics.
		Develop human resource for faculty position in physics and applied physicsin academic institutions and National Laboratories.
		Learning to work in mega-science projects through National and International collaborations.

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Mathematical Physics	04ENGG04-001-C
2	Quantum Mechanics	04ENGG04-002-C
3	Classical Mechanics	04ENGG04-003-C
4	Statistical Mechanics	04ENGG04-004-C
5	Classical Electrodynamics	04ENGG04-005-C
6	Research Methodology	04ENGG04-006-C
	Computational Methods and Programming	
7	Experimental techniques and methods	04ENGG04-007-C
8	Basic Field Theory	04ENGG04-008-C
9	Basic Accelerator physics	04ENGG04-009-C
10	Basic Condensed Matter Physics	04ENGG04-0010-C
11	Basic Nuclear physics	04ENGG04-011-C
12	Laboratory experiments	04ENGG04-012-C
13	Advanced Nuclear Structure	04ENGG04-013-C
14	Advanced nuclear reaction	04ENGG04-014-C
15	Advanced Accelerator physics	04ENGG04-015-C
16	Advanced High Energy Physics	04ENGG04-016-C
17	Advanced Materials Science – I	04ENGG04-017-C

18	Advanced Material Science II	04ENGG04-018-C
19	Advanced High Energy Physics (Experiment)	04ENGG04-001-E
20	Project	04ENGG04-001-P

Course Outcomes:

(A) Core Courses

Name of the Course	**Course code**	**Course Outcome**
Mathematical Physics	04ENGG04-001-C	Understanding the underlying mathematical structure of Quantum Physics
		Using the techniques of complex analysis to solve realistic physical problems
		Model the Regression Learning Models
		Understanding the Geometric ideas behind modern physics
QUANTUM MECHANICS	04ENGG04-002-C	Learn approximation methods used in quantum mechanics
		Basic understanding in Collision theory
		Exposure to relativistic quantum mechanics
		Learn Lagrangian formulation
Classical Mechanics	04ENGG04-003-C	Introduction of Lagrangian formulation
		Introduction of Hamiltonian formulation
		Connection of classical mechanics with quantum mechanics
Statistical Mechanics	04ENGG04-004-C	Detailed understanding of the different distribution functions, statistical techniques and their application to different physical systems
		Understanding of different statistical methods, thermodynamic connection and their application to different physical problems related to condensed matter physics and nuclear physics
		Learnt advance topics of equilibrium and non-equilibrium statistical mechanics (ex: phase transition kinetics, transport theory) which are extensively used in state-of-the art research problems.
Classical Electrodynamics	04ENGG04-005-C	Impart knowledge on classical field theory
		Learn the basic science of electricity and magnetism

		Develop skill in applications of electromagnetic theory invarious practical problems
		Develop mathematical skill to solve partial differential equations.
Research Methodology	04ENGG04-006-C	This is an essential course to pursue research work for PhD in Physical Sciences and Engineering Sciences
		Impart knowledge and skills to analyse data and prepare scientific manuscript.
		Learn about Ethical aspects in research
Computational Methods and Programming		Applications of the machine learning and programming in understanding the numerical approach to solve a scientific project which can hardly be solved analytically
		Use of the numerical methods for simulating detection techniques and performances a priori and check the feasibility
		Implement the machine learning and numerical approach to understand the human learning aspects.
		Implementation of numerical techniques in the analysis of experimental data and understand them in the framework of numerical modelling with associated physics.
		Machine learning and numerical methods have an important role in illustrating and predicting in the field of Bioinformatics, Linguistics, Data mining and Big data analysis both in the social and scientific paradigm
Experimental techniques and methods	04ENGG04-007-C	Imparts knowledge on laboratory safety, vacuum techniques, cryogenics and workshop practices
		Provides understanding on different material characterization techniques viz. electron microscopy, XRD, optical, electrical and magnetic measurements
		Learns about different detectors and techniques used in nuclear and high energy physics.

Basic Field Theory	04ENGG04-008-C	This course is designed to provide an elementary idea about the Lorentz invariance and Relativistic kinematics.
		Basic concepts about the classical field theory and symmetries and conservation laws are provided.
Basic Accelerator physics	04ENGG04-009-C	The Basic Accelerator Physics course focuses on the key concepts of particle accelerators and their applications. The objective of the course is to emphasize the knowledge of beam dynamics in Linear and circular accelerator including the effect of space charge. Exposure regarding various types of accelerators is given.
Basic Condensed Matter Physics	04ENGG04-0010-C	In the basic materials science courses the covered areas are mainly crystal structure and crystallography, defects in solids, electronic structure of solids. Also the magnetism, superconductivity, superfluidity and dielectric properties of solids have been taught.
Basic Nuclear physics	04ENGG04-011-C	Learning basic properties of nuclei like mass, charge, shape etc.
		Learning nuclear models related to nuclear collective dynamics and fission decay
		Learning microscopic many-body thoery for nucleus
Laboratory experiments	04ENGG04-012-C	Gives hands on experience and understanding on topics discussed in the experimental techniques and methods course
		Provides practical understanding on the operation and use of a different types of instrument and facility
		Get basic training for planning a goal oriented real life experiment
		Learn to prepare scientific reports
Advanced Nuclear Structure	04ENGG04-013-C	Different model calculations of nuclear structure physics
		Different modes of excitations in nuclei and associated observables
		Specific knowledge of gamma ray spectroscopy and its application to nuclear structure

		Methods of lifetime and moment measurements in nuclei
		Total absorption spectroscopy and beta-delayed neutron emission measurements and their practical application.
		A detailed and overall theoretical understanding on the ground and excited state properties in nuclei along with a detailed knowledge on the experimental know-how in the measurement of different nuclear structure quantities. Students are expected to connect the experimental observables and the deduced quantities with the theoretical parameters related to nuclear structure.
Advanced nuclear reaction	04ENGG04-014-C	Advanced nuclear reaction course is designed to develop basic understanding of nature around us which includes formation of stars to discovery of new elements using accelerator based research. It includes following modules
		Study of fusion –fission dynamics, deep - inelastic reactions, multi fragmentation etc.
		Nuclear Astro physics and Equation of State for dense nuclear matter
Advanced Accelerator physics	04ENGG04-015-C	The Advance Accelerator Physics course focuses on the key concepts of modern particle accelerators and their applications. The objective of the course is to emphasize the knowledge of beam dynamics in Linear and circular accelerator including the effect of space charge. Various advanced accelerator projects has also been discussed.
		It covers Advance accelerators: Free electron laser, Plasma accelerators, Spallation neutron sources, Rare ion beam facilities. Accelerators driven subcritical systems.
		It covers Storage rings and synchrotron radiation**:** Radiation from moving charges, Radiation power and angular distribution, Quantum fluctuation, Beam lifetime, beam cooling.

		It covers Beam with space charge: Envelope oscillations, modes and instabilities, Sources of emittance growth, Wake fields and image charge effects.
Advanced High Energy Physics	04ENGG04-016-C	This course is designed to provide an elementary idea about the Standard Model of particle physics with particular emphasis on Quantum Chromodynamics. Basic concepts about the structure of hadrons as well as relativistic heavy ion collisions are also provided
Advanced Materials Science – I	04ENGG04-017-C	Understand formation of defects due to particle irradiation in materials Understand effect of radiation damage on physical and mechanical properties of materials Correlate defects and property changes due to irradiation in materials Emulate neutron damage with ion irradiation in structural materials.
Advanced Material Science II	04ENGG04-018-C	In this course mainly properties of advance functional materials, e.g., multi-functional materials, nano-particle system and advanced oxide materials have been covered. Defect characterization in oxides by positron annihilation techniques and Mossbauer spectroscopy in oxides have also been covered
Advanced High Energy Physics (Experiment)	04ENGG04-001-E	Advanced EHEP course is tuned to train the students with following objectives (a) experimental techniques and methodologies used specifically in EHEP (b) detailed courses on research topics being followed in experimental high energy heavy ion collision research like, collectivity, correlation, particle production mechanism, heavy flavour production The students after completion of course can handle EHEP data to extract physics information after various levels of corrections and error analysis. They are also trained to handle particle detectors for HEP applications Students have a detailed overview on particle production mechanism both in hard and soft sector

		Students, after completion of course know about production of heavy flavours (open and hidden charm)
		Students can handle Monte-Carlo models for particle production
Project	04ENGG04-001-P	Exposure to a particular experimental or theoretical work
		Literature survey and develop expertise in problem identification
		Data collection and subsequent analysis of data , presentation of data
		Develop documentation and presentation skills

BACK TO MAIN

Course Structure:

IV. Courses at IPR

Program Code: ENGG04	Programme Specific Outcome	Learn about Plasma basics, its diagnostics and its applications.
		Learn Plasma and Fusion Technologies to build a device.
		Get detailed information on specific subject related to Fusion technology according to the stream of student i.e. Physics , mechanical etc.

T1. FUNDAMENTAL

Sr. No.	Name of the Course	Course code
1	Basic Plasma Physics	FC1
2	Experimental Plasma Physics	FC2
3	Tokamaks	FC3
4	Fusion Plasma Diagnostics	FC4
5	Measurement Techniques	FC5
6	Numerical Methods	FC6
7	Mathematical Methods	FC7
8	Vacuum, Cryogenics and Magnets	FC8

T2. CORE SUBJECTS

Sr. No.	Name of the Course	Course code
1	Fusion Neutronics	AS1
2	Plasma Facing Components: First Wall, Divertors, Blankets	AS2
3	Fusion Materials	AS3
4	RF, Current Drive and Neutral Beam Heating	AS4

T3. ELECTIVES

(A) PHYSICS

Sr. No.	Name of the Course	Course code
1	Magneto Hydro Dynamics	PH1
2	Kinetic Theory and Statistical Mechanics	PH2
3	Advanced Heat Transfer and Cryogenics	PH3/ME5
4	Tokamak Related Code	PH4

(B) MECHANICAL

Sr. No.	Name of the Course	Course code
1	Code Design for Internal and External Pressure Vessel	ME1
2	Finite Element and Volume Methods	ME2
3	Mechanics of Solid/Vibration/Remote Handling	ME3
4	Advanced Manufacturing Technologies	ME4
5	Advanced Heat Transfer and Cryogenics	ME5

(C) ELECTRICAL

Sr. No.	Name of the Course	Course code
1	Advanced Data Acquisition System	EE1
2	Advanced Tokamak controls	EE2
3	High Voltage, DC& AC/ Power Supplies	EE3
4	Signal Conditioning and EMI/EMC Aspects	EE4
5	Computer Based System Design	EE5
6	Digital Signal Processing and Image Processing	EE6

T4. MINI PROJECT (MP)

Sr. No.	Name of the Course	Course code
1	Mini Project	06ENGG04-001-MP

T5. PROJECT (P)

Sr. No.	Name of the Course	Course code
1	Project	06ENGG04-001-P

Course Outcomes:

T1. FUNDAMENTAL

Name of the Course	Course code	Course Outcome
Basic Plasma Physics	FC1	Course provides detailed information on,
		• Definition of plasma, description of collective behaviour in contrast to single particle behaviour.
		• Lorentz force equation, nonrelativistic motion of a charged particle in constant electric and magnetic field.
		• Fluid Description of Plasma, Waves in Plasma and MHD Description.
Experimental Plasma Physics	FC2	Course provides detailed information on,
		• Fundamental Gas Processes i.e. Maxwell-Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization,
		• Charged Particles in a Gas.
		• Self-sustaining Discharge i.e. Glow Discharge, Breakdown under Special Conditions, Arc Discharge.
		• Plasma Sheath and Diagnostics Experimental Plasma Devices.
Tokamaks	FC3	Course provides detailed information on,
		• Introduction to Thermonuclear Fusion reactions, Power Balance and Lawson Criteria, Tokamak as Fusion reactor,
		• Equilibrium and Transport i.e. Tokamak Equilibrium, Grad-Shafranov Equation, Safety Factor, q and Plasma Beta, Shafranov Shift and Plasma position control, Classical Transport,
		• Heating i.e. Ohmic Heating, Neutral Beam Heating, Wave Heating, Lower Hybrid Heating and Current Drive, Ion Cyclotron

		Resonance Heating, Electron Cyclotron Resonance Heating.
		• MHD Stability i.e. Ideal Kink modes, Ideal internal modes, Resistive tearing modes, Mirnov Oscillations, Saw-tooth oscillations, ELMs, Disruption scenarios.
		• Tokamak and Other Fusion Devices
Fusion Plasma Diagnostics	FC4	Course provides detailed information on,
		• Introduction to Tokomak diagnostics , Electrical diagnostics, Magnetic diagnostics
		• Measurements of plasma density and electron temperature i.e. Thomson scattering diagnostics, Reflectometery, Interferometry: ECE diagnostics.
		• Measurement of ion temperatures i.e. Charge exchange recombination spectroscopy (CXRS), X –ray crystal spectroscopy.
		• Measurements of Radiated power and Measurements of operational parameters i.e. Bolometers, Imaging Diagnostics and Beam emission spectroscopy.
Measurement Techniques	FC5	Course provides detailed information on,
		• Measurement system architecture, Computer based measurement systems, Errors in measurements, Measurement Units, Standard used in measurements.
		• Sensitivity, Resolution, Nonlinearity, Saturation, Dynamic Range, Offset, Drift, Electromagnetic Compatibility, Reliability.
		• Measurement of Electrical Parameters: Voltage, Current, Resistance, Capacitance, Impedance, Frequency, Phase shift, Power.
		• Sensors/Transducers and Their Applications to Physical Measurements , Introduction to Data Acquisition and Noise in Measurement System.
Numerical Methods	FC6	Course provides detailed information on,
		• Mathematical modeling, numerical methods and problem solving, Introduction to MATLAB programming, Error analysis methods, Case study.
		• Solutions of Linear Algebraic equations.
		• Numerical Differentiation and Integration
		• Roots, optimization and nonlinear sets of Equations.
		• Application of Ordinary Differential equations.
		• Application of Partial Differential equations.

		• Application of Curve fitting methods.
Mathematical Methods	FC7	Course provides detailed information on,
		• Vector analysis: vector identities, Use of Levi Civita and Kronecker delta functions for the derivation of vector identities, Notion of gradient, divergence and curl
		• Classification of matrices; Elementary operations; Determinant, rank and inverse of a matrix; Solution of linear equations; Eigenvalues and eigenvectors
		• Complex variables, function of a complex variable, continuity and differentiability, Cauchy-Riemann conditions, Analytic functions, Taylor and Laurent Series,
		• First and second order differential equations with constant and variable coefficients; Linear differential equations
Vacuum, Cryogenics and Magnets	FC8	Course provides detailed information on,
		• Fundamental of vacuum i.e. The vacuum and its applications, Gas laws, Pressure and mean free path, Flow regimes, Conductance, Throughput and pumping speed, Ultimate pressure and pump down time, Outgassing and permeation. Exposure to pumps and gauges.
		• Design of a vacuum system
		• Fundamental of cryogenics i.e. Cryogens properties, Heat loads in Cryogenic systems, Basic Thermodynamics and Cryogenic Processes, Material properties at low temperatures.
		• Design of cryogenics system i.e. Design aspects of Cryostat, Dewars and Cryolines. Fundamentals of Thermo-hydraulics and distribution network, Economics of Cryogens, Recovery of Helium and Thermal insulation.
		• Applications of Cryogenics Engineering in Fusion machines.
		• Fundamentals of Magnet system
		• Design and fabrication of magnet system

T2. CORE SUBJECTS

Name of the Course	Course code	Course Outcome
Fusion Neutronics	AS1	Course provides detailed information on, • Fusion Neutronics Principles, neutron production & detection techniques, nuclear interaction processes. • Particle transport phenomena in matter and Basics of fusion neutronics & blanket neutronics. • Principles of Neutron & Fusion product diagnostics, Radiation and licensing and Radiation damage & transmutation.
Plasma Facing Components: First Wall, Divertors, Blankets	AS2	Course provides detailed information on, • First Wall, Firstwall Concepts, Loads on Firswtall and Challenges for Firstwall. • Divertor Concepts , Loads on Divertor , Challenges for Divertor , Divertor Testing and Novel Divertor Concepts • Blanket Concept, Shield Blanket, Breeding Blanket, Liquid Metal (Pb Li) Technology, Fusion Fuel Cycle and Blanket Safety.
Fusion Materials	AS3	Course provides detailed information on, • Fundamentals of Material Science • Fusion Materials Requirements & Issues • Material Development and Joining Technologies • Material Characterization & Qualification
RF, Current Drive and Neutral Beam Heating	AS4	Course provides detailed information on, • Heating and current drive physics by neutral beam • Neutral beam injector system design and engineering • Introduction to RF heating • RF devices and Design tools i.e. ICRH, ECRH and LHCD.

T3. ELECTIVES

(A) PHYSICS

Name of the Course	Course code	Course Outcome
Magneto Hydro Dynamics	PH1	Course provides detailed information on, • Physical description of electrically conducting fluids .Derivation of basic MHD equations: Continuity, Equation of

		motion, Energy flow, Ohm's law, Validity of MHD equations.
		• The low frequency dynamics of the electromagnetic field. Some properties of MHD: Ideal MHD equations, The Frozen Flux theorem, The effect of • resistivity, Similarity scaling, The Wöltjer invariants and helicity
		• Equilibrium general considerations, The Virial Theorem, Examples of simple equilibria: - pinch, Z-pinch, screw pinch, Poloidal , paramagnetic and diamagnetic states, Force-free fields, Toroidal equilibrium: the Grad-Shafranov equation, nonlinearity, Definition of q, beta, plasm a shape, etc.
Kinetic Theory and Statistical Mechanics	PH2	Course provides detailed information on,
		• Gas dynamic way of describing an uncharged fluid – heuristic
		• Recollect derivation of basic MHD equations – one fluid only (Continuity, Eqn of motion, Energy equation [thermodynamic closure], Electron equation of motion [Ohm's Law])
		• Introduce ideas of Phase Space (x,v) and distribution functions f(x,v,t)
		• Langmuir Oscillations and Waves – Vlasov-Poisson dispersion
		• Examples of GK formalism and obtained transport and Very cursory introduction to Onsager relationships
Advanced Heat Transfer and Cryogenics	PH3/ME5	Computational Fluid Dynamics
		Heat Transfer : Conduction
		Heat Transfer : Convection:
		Heat Transfer : Radiation:
		Cryogenics
		Gas Liquefaction and Refrigeration Systems
Tokamak Related Code	PH4	Course provides detailed information on,
		• Plasma core modelling i.e. Plasma equilibrium IPREQ , Plasma transport TSC , Plasma stability ERATO, PEST2 , ICRH heating TORIC , NBI heating NUBEAMS , Plasma start up model , Reactor system code , Eddy current analysis.
		• Edge-SOL studies i.e. 2D blob transport, Divertor study SOLPS (B2+ERINE) , 3D plasma study ERINE-3D

		• First principle simulations i.e. Low frequency (w/wc <<1) transport – what is Gyrokinetic method? , What are the transport processes neglected by gyrokinetic formalism?

(B) MECHANICAL

Name of the Course	Course code	Course Outcome
Code Design for Internal and External Pressure Vessel	ME1	Membrane theory for thin shells, stresses in cylindrical, spherical and conical Shells. General theory of Membrane stresses in vessel under internal pressure and its application to ellipsoidal, and tori spherical end closures.
		Thick cylinder, sphere and derivation of Lame's equations. Derivation of ASME Sec. VIII Div. 1 and Div. – II equations for cylindrical / Spherical shell and conical, ellipsoidal and tori spherical end closures.
		Bending of circular plates and determination of stresses in simply supported and clamped Circular plate. Basis of ASME equation for flat closures.
		Piping thickness as per ANSI / ASME B31.1 and B31.3 piping code. Flexibility factor and stress intensification factor. Design of piping system as per B31.1 piping code. Design of piping for hazardous fluid as per B31.3.
Finite Element and Volume Methods	ME2	Introduction to FEM: Weighted residual method, Galerkin's methods, Weak form formulation , piecewise approximations. Basis of Finite Element Method, Variation principles, energy principles in structural mechanics, Element libraries
		Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements
		2D plane elements – 3 node triangular element: Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axi-symmetric elements; Evaluation of strain/stress.
		Finite element applications for design: Finite element modelling and discretization criterion,

		h & p refinement, sources of potential error in the finite element solution of design problems, order of convergence, patch test, adaptive meshing, error analysis, stress categorization as per ASME.
Mechanics of Solid/Vibration/Remote Handling	ME3	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Laminar Boundary Layer and Forced Convective Heat
		Turbulent Flow and Heat Transfer
		Natural Convection
		Numerical Solution of Complete Fluid Flow and Energy Equation
Advanced Manufacturing Technologies	ME4	Advance manufacturing processes i.e. mechanical energy based processes , electrical energy based processes, chemical and electro-chemical energy based processes.
		Advanced materials joining and testing i.e. bolting , riveting , soldering , blazing ,adhesive bonding , diffusion bonding , mechanical joining, fusion welding, oxyacetylene welding , smaw , gtaw , gmaw , fcaw ,saw , esw, high energy beam welding.
		Responses of materials to welding i.e. microstructural changes , distortion , defects, undercuts ,overlaps , grain growth , blowholes , inclusions.
		Destructive and non-destructive tests for welds.
Advanced Heat Transfer and Cryogenics	ME5	Computational Fluid Dynamics
		Heat Transfer : Conduction
		Heat Transfer : Convection:
		Heat Transfer : Radiation:
		Cryogenics
		Gas Liquefaction and Refrigeration Systems
		Cryogenic Insulations
		Instrumentation in Cryogenics

(C) ELECTRICAL

Name of the Course	Course code	Course Outcome
Advanced Data Acquisition System	EE1	Course provides detailed information on,
		• Theory of Quantization , Advanced Data Acquisition Systems
		• Data Acquisition Interface , Analog Input/output
		• DAQ Clock and Trigger , Synchronization
		• SST-1 Data Acquisition System

Advanced Tokamak controls	EE2	Course provides detailed information on, • Fundamentals of Control System i.e. Terminology and basic structure of control system , Open loop and Closed loop systems, servomechanism, regulatory system, analogous systems, electrical analogy of physical systems, Physical Systems. • Different types of Control Systems • Introduction to Plasma Control • ITER Instrumentation & Control • SST-1 Operation &Control • Monitoring and Control of Auxiliary Systems
High Voltage, DC& AC/ Power Supplies	EE3	Course provides detailed information on, • Overview of Electrical systems in Fusion machines i.e. Basic introduction to electrical systems in Tokamak, Stellarator and Z-machine; Tokamak as a transformer, Electrical systems for plasma formation – Ohmic discharge, Arc discharge, RF discharge, MW discharge; Electrical systems for plasma confinement. • High Voltage Generation, High AC, DC and Impulse Voltages, High Voltage Components, Basic design features of High Voltage Power Transformer: Basic design of HV Transformer, Transformer insulation requirements, dielectric strength and voltage conditions, winding arrangements, surge behavior, behavior of liquid dielectric, electrode surface phenomena, gas evolution, processing techniques, construction of EHV transformer, short circuit behavior. • Linear and switching power supplies, DC to DC converters and their operating characteristics, Selection of Power Semiconductor Devices, Power supplies for pulsed gas discharge tubes, High current power supplies. Power supplies for heating and current drive, Requirement for arc fault protection, Protection by crowbar. • Power Electronics and design through modelling & simulation i.e. AC-DC Converters; Forced commutation;

		synchronous link converters, DC-AC converters, buck, boost, buck-boost, cuk, flyback configuration, resonant converters, PWM inverters; active filters. Machine modelling, DC machines, induction motor and synchronous machines.
Signal Conditioning and EMI/EMC Aspects	EE4	Course provides detailed information on, • Analog Signal Conditioning i.e. Principles of Analog Signal Conditioning, Signal Conditioning Configuration, Signal Conditioning Functions, Amplification, Transducer Excitation, Filtering, Isolation. • Signal Processing and Applications i.e. Review of signals and systems: Introduction, advantages and limitations of Analog and Digital Signal Processing, Advantages and Disadvantages of Digital Filters over Analog Filters. • EMI/EMC i.e. Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling Inductance Coupling, Shielding. • EMI Modelling i.e. Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns.
Computer Based System Design	EE5	Course provides detailed information on, • Personal computer architecture, memory organization, industrial PC, Standard bus: Overview of PCI and VME bus, mechanical, electrical and functional specifications. • Asynchronous and synchronous communication, • Local Area Networks, OSI 7 layer model and TCP/IP reference model, Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth, Networking hardware – cables, hub, switch, router etc. • Real-time Systems, their characteristics and applications, Real-time Operating Systems Concepts of Process and threads, Concurrency, Latency, context switching, scheduling policies.
Digital Signal Processing and Image Processing	EE6	Course provides detailed information on, • Basic elements of a digital signal processing system, Fourier series and Fourier transform, z transform Convolution, Correlation, Sampling

		theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.
		• Discrete Fourier Transform, Interpretation of DFT, Properties of DFT, DFT of real signals, Fast Fourier Transform Digital filters, DSP Applications.
		• Digital image model representation, Image sensor, Digitizer, Computer, Standard file format.
		• Image Enhancement i.e. Spatial domain methods, Frequency domain methods, 2-D Fourier Transform, Filtering, Image smoothing & sharpening, Histogram Modification, Color image processing.
		• Image Segmentation and Analysis i.e. Detection of discontinuities, Edge linking and boundary detection, Thresholding, Segmentation, Boundary extraction and representation.
		• Morphological operations i.e. Image Restoration-PSF, Deconvolution, Restoration using inverse filtering, Wiener filtering & maximum entropy based Methods, Image Compression Models, Error free compression, Lossy compression, Standards.

T4. MINI PROJECT (MP)

Name of the Course	Course code	Course Outcome
Mini Project	06ENGG01-001-MP	**Student learns ,**
		• Literature Survey
		• Study of a small section of the major project based on either simulation or fabrication to realize the criticality and requirements to build a component for plasma application.
		• Practise for thesis writing

T5. PROJECT (P)

Name of the Course	Course code	Course Outcome
Project	06ENGG01-001-P	• Complete understanding about the criticality of a particular component to be built for plasma application.
		• Development of a component for a plasma application and get hands on experience.
		• Thesis report.

BACK TO MAIN

Ph.D. in LIFE SCIENCES (Program Code: LIFE04)

Course Structure:

II. Courses at SINP

Program Code : LIFE04	Programme Specific Outcome	To introduce multi-disciplinary aspects of life science research in the first year to the students from different backgrounds (Life/Physical Sciences)
		To introduce various techniques used in life Science research
		To develop the skill of scientific writing and presentation.
		To develop the ability to carry out independent scientific research

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	PRINCIPLES OF BIOCHEMISTRY	PBC
2	PRINCIPLES OF PHYSICAL CHEMISTRY	PPC
3	STRUCTURAL AND COMPUTATIONAL BIOLOGY	SCB
4	ADVANCED LABORATORY PRACTICES	ALP
5	RESEARCH METHODOLOGY	RM
6	OPTIONAL COURSE1	OPT1
7	OPTIONAL COURSE2	OPT2
8	OPTIONAL COURSE3	OPT3
9	PROJECT	PRO

Course Outcomes:

Name of the Course	Course code	Course Outcome
PRINCIPLES OF BIOCHEMISTRY	PBC	Familiarization of the students from various backgrounds with biomolecules and metabolism.
		Introductory knowledge about different cellular processes and sub-cellular structures
PRINCIPLES OF PHYSICAL CHEMISTRY	PPC	Basic knowledge about chemical and physical perspective of life sciences
		Introductory knowledge about spectroscopy, nanomaterials and radioactivity
STRUCTURAL AND COMPUTATIONAL BIOLOGY	SCB	Understanding of structural and functional aspects of biomolecules
		Knowledge of computer programming for life science research
		Ability to do statistical analysis of biological data
ADVANCED LABORATORY PRACTICES	ALP	Introductory knowledge about various cell and molecular biological, biochemical and biophysical techniques
RESEARCH METHODOLOGY	RM	Idea about doctoral research, ethics of scientific research, scientific writing and presentation.
OPTIONAL COURSE1	OPT1	Advanced level knowledge about techniques like spectroscopy, imaging, mass spectrometry and crystallography
OPTIONAL COURSE2	OPT2	In depth understanding of various aspects cell biology
OPTIONAL COURSE3	OPT3	Knowledge about some topics in modern biology related to drug discovery, nanobiomaterials, membrane biophysics
PROJECT	PRO	Preparedness to do independent doctoral research

III. Courses at ACTREC-TMC

Program Code : LIFE04	Programme Specific Outcome	Basic understanding in cancer biology.
		Develop the ability of students to critically read and analyse the literature
		Develop analytical thinking in students with an emphasis on developing experimental design.
		Allow deeper study in specialized topics in cancer biology

(A) Research Methodology

Sr. No.	Name of the Research Methodology	Course code
1	The flow and structure of a paragraph – case study. Grammar, common unscientific terms used in writing, the common pitfalls seen - direct translation of words from mother tongue to English	RM1
2	Literature review - where to get material, the quality and quantity of content. Establishing a background for a research project	RM2
3	Laboratory notebook maintenance - Do's and don'ts, Good research practice, ethics, plagiarism	RM3
4	The art and science behind manuscript writing and successful research proposal Ideas, their formulations, what are aims and objectives, What constitutes results and discussions	RM4
5	The fine art of power point presentation	RM5
6	Preparing figures for manuscripts and grants	RM6

(B) Core courses

Sr. No.	Name of the Course	Course code
1	Cell Biology & Cancer Biology	09LIFE04-001-C
2	Cell Proliferation and Cell death	09LIFE04-002-C
3	Oncogenes and Tumor Suppressors	09LIFE04-003-C
4	Metastasis and Angiogenesis	09LIFE04-004-C
5	Cancer Epigenetics and Genetics	09LIFE04-005-C
6	Carcinogenesis	09LIFE04-006-C
7	Tumor Immunology	09LIFE04-007-C
8	Structural Biology and Biophysics	09LIFE04-008-C

(C) Elective courses

Sr. No.	Name of the Elective Course	Course code
1	Biostatistics (*Compulsory)*	09LIFE04-001-E
2	Animal Models in Cancer Research	09LIFE04-002-E
3	Cancer Therapeutics	09LIFE04-003-E
4	Carcinogenesis, Chemoprevention and DNA Repair	09LIFE04-004-E
5	Deregulation of Cell Growth in Cancer	09LIFE04-005-E
6	Structural Bioinformatics, Biophysics & Structural Biology	09LIFE04-006-E
7	Tumor Immunology	09LIFE04-007-E
8	Metastasis	09LIFE04-008-E

Course Outcomes:

(A) Research Methodology

Name of the Research Methodology	**Course code**	**Course Outcome**
The flow and structure of a paragraph – case study. Grammar, common unscientific terms used in writing, the common pitfalls seen - direct translation of words from mother tongue to English	RM1	The student is taught the importance of accurate writing and how that helps convey information to the reader.
		Basic rules of grammar are addressed.
Literature review - where to get material, the quality and quantity of content. Establishing a background for a research project	RM2	The students learn how to review the literature
		The students learn how to read the relevant literature to establish the basis for their hypothesis.
Laboratory notebook maintenance - Do's and don'ts, Good research practice, ethics, plagiarism	RM3	The students learn the basics of record keeping in the laboratory.
		How to ensure that the results observed are meaningful.
		How to analyse their data
		The students are lectured on the importance of doing ethical experiments and not plagiarising information from other sources.
The art and science behind manuscript writing and successful research proposal Ideas, their formulations, what are aims and objectives, What constitutes results and discussions The fine art of power point presentation Preparing figures for manuscripts and grants	RM4	These three lectures focus on: 1. How to design a research proposal 2. How to write a research proposal 3. How to write a research paper 4. How to prepare figures for proposals and papers. Does and don’ts of figure preparation.
	RM5	
	RM6	

(B) Core courses

Name of the Course	**Course code**	**Course Outcome**
Cell Biology & Cancer Biology	09LIFE04-001-C	Over-view on what is cancer and its causes, differences between normal and cancer cells, detailed understanding of cell organelles, intracellular protein transport.
		Understanding of normal stem cells and cancer stem cells, biomarkers to identify cancer stem cells.

		Reprogramming and pluri-potency. Demonstrations and lectures on advanced microscopy and in vivo - cell imaging using luminescence and microPET-CT
Cell Proliferation and Cell death	09LIFE04-002-C	A detailed analysis of the pathways underlying cell cycle progression and cell death. Study on animal models for understanding phenotype of cyclin and cyclin dependent kinases.
		Understanding the mechanisms of cell death and methods to detect apoptosis.
		Understanding differences between apoptosis, necrosis and autophagy. How cancer metabolism is distinct from normal cells and how this can be exploited therapeutically.
Oncogenes and Tumor Suppressors	09LIFE04-003-C	Understanding the mechanism of action of oncogenes and tumor suppressor genes and their function.
		Understand the difference between mouse and human telomeres and how this affects tumor progression in both species.
Metastasis and Angiogenesis	09LIFE04-004-C	Mechanisms underlying cell adhesion and migration and how these are altered in tumors.
		Mechanisms underlying metastatic progression. Understanding how a tumor deals with nutrient and oxygen deprivation.
		Understanding how hypoxia contributes to angiogenesis and vasculogenesis. Various models to study angiogenesis.
Cancer Epigenetics and Genetics	09LIFE04-005-C	Epigenetic mechanisms that affect tumor growth.
		Cancer as an inherited genetic disease. Understanding chromatin structure, histon varients and their modifications in cancer.
		Understanding DNA methylation and gene-regulation.
		Detailed methodology to study chromatin-biology.
		Advanced knowledge on application of proteomics, Next Generation Sequencing and Genomics

Carcinogenesis	09LIFE04-006-C	Understanding Mechanisms of carcinogenesis. DNA repair and its role in inhibiting tumor progression.
		Understanding carcinogen metabolism and activation of cellular oncogenes and their contribution to carcinogenesis.
		Understanding role of tumor viruses and micro-organisms contributing to carcinogenesis.
Tumor Immunology	09LIFE04-007-C	Basics of tumor immunology. Differences between adaptive and innate immunity.
		Cell types contributing to tumor immunity and their role in cancer immuno therapy. Applications of monoclonal antibodies, vaccines in cancer diagnosis and therapy.
		Advanced technologies to study immune biomarkers on cells, immuno deficient mouse models to study tumor development and immune responses.
Structural Biology and Biophysics	09LIFE04-008-C	Basics of spectroscopy. Principles of protein-protein interactions and protein folding.
		Understanding mechanism of action of enzymes and assays to study their function.

(C)Elective courses

Name of the Elective Course	Course code	Course Outcome
BIOSTATISTICS *(COMPULSORY)*	09LIFE04-001-E	Probability distribution (normal, Poisson, t, F, Chi-square)
		Sample size determination and justification of power estimates in a research protocol - observational studies, clinical trials (superiority, non-inferiority / equivalence), animal studies
		Hypothesis testing: analysis of categorical or continuous data
		Biostatistics pertaining to survival analysis
ANIMAL MODELS IN CANCER RESEARCH	09LIFE04-002-E	Anatomy and biology of small animals used in cancer research.
		Transgenic and knockout technology to generate animal models

		Animal models for carcinogenesis, chemoprevention and drug screening and testing.
		Using imaging to study tumor progression in animal models.
CANCER THERAPEUTICS	09LIFE04-003-E	Modules of cancer therapy – chemo, radio and targeted therapy.
		Mechanisms of resistance to chemo and radio therapeutics.
		Drug design, development and screening
		Immunotherapy and gene therapy including RNAi
CARCINOGENESIS, CHEMOPREVENTION AND DNA REPAIR	09LIFE04-004-E	Determination of carcinogen exposure and dosage
		Short term and long term assays for carcinogenesis
		The role of DNA damage, viruses and epigenetics in carcinogenesis
		Basics of chemoprevention.
DEREGULATION OF CELL GROWTH IN CANCER	09LIFE04-005-E	Detailed analysis of the molecular mechanisms underlying Rb and p53 function.
		Mechanisms underlying tumor progression upon activation of Ras, PI3K, Myc and wnt signalling.
		Checkpoint pathways and cancer
		Senescence and cancer
STRUCTURAL BIOINFORMATICS, BIOPHYSICS & STRUCTURAL BIOLOGY	09LIFE04-006-E	Spectroscopic Techniques: Absorption Spectroscopy and Fluorescence Spectroscopy Spectropolarimetry: Circular Dichroism
		Biophysical methods: Protein conformation, interactions and oligomeric properties
		X-ray Crystallography (lecture and hands-on)
		NMR Spectroscopy
		Structural Bioinformatics: Molecular Modeling (homology, threading, ab initio); small molecule/peptide design; MDS: Different tools available for these in silico studies
		Molecular Docking (protein-protein, protein-ligand/small molecules)
		Drug Designing-challenges, in-silico design-advantages, steps and tools (QSAR, 3D-QSAR etc) Application:

		How drug design leads to clinical trials with example.
		Hands-on training in Bioinformatics
TUMOR IMMUNOLOGY	09LIFE04-007-E	Basic concepts of innate and adaptive immunity and their role in tumor immunity
		Immunodiagnosis and immunotherapy of Cancer. Role of monoclonal antibodies, vaccines and cell-based therapies
		Understanding of the tumor microenvironment, cells soluble factors contributing to immunosuppressive networks
		Animal models that have immune defects used to transplant human tumors and study their application for drug development and immunotherapies
		Understanding how Flow Cytometer works. Principle and applications followed by demonstration
METASTASIS	09LIFE04-008-E	Molecular basis underlying detachment, intravasation and invasion in tumor cells.
		Survival in the bloodstream, invasion and metastatic colonization.
		Pathways contributing to the spread of metastatic disease including EMT, Hippo, Notch Wnt and CSC pathways.
		Targeted therapy and immunotherapy in metastasis and models and imaging in metastasis.

BACK TO MAIN

IV. Courses at IMSc

Program Code : LIFE04	Programme Specific Outcome	To understand biological data and the means by which they are acquired
		To communicate and collaborate with biologists
		To understand and apply quantitative techniques from mathematics, physics and data science to biological phenomena
		To comprehend, express and present scientific data
		To understand and interpret model calculations

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Biology-1	10-LIFE04-001-C
2	Protein Structure	10-LIFE04-002-C
3	Mathematics and statistics for biologists	10-LIFE04-003-C
4	Physical Methods for Biologists	10-LIFE04-004-C
5	Biology-2	10-LIFE04-005-C
6	Biological sequence analysis	10-LIFE04-006-C
7	Systems Biology	10-LIFE04-007-C

(B) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Biophysics of Macromolecular Structures	10-LIFE04-001-E
2	Simulation Techniques in Biology	10-LIFE04-002-E
3	Population Biology, Ecology and Evolution	10-LIFE04-003-E
4	Computational Neuroscience	10-LIFE04-004-E
5	Modeling of Infectious Diseases	10-LIFE04-005-E

Course Outcomes:

(A) Core Courses

Name of the Core Courses	Course code	Course Outcome
Biology-1	10-LIFE04-001-C	Learn basics of genetics, biochemistry, molecular biology and cell biology
		Learn about foundational experiments contributing to key developments in molecular biology over the last century
		Learn basics of developmental biology and molecular evolution
		Learn about biological systems where computational modelling has already made an impact
Protein Structure	10-LIFE04-002-C	Learn basics of biochemistry and protein structure (including globular, membrane proteins)
		Learn computational tools required to understand and address structural aspects of proteins
Mathematics and statistics for biologists	10-LIFE04-003-C	Learn to frame and solve simple problems in dynamics using differential equations, and understand some classic applications
		Learn basic concepts and applications of linear algebra
		Learn essentials of probability theory and statistics and applications to biological problems
		Have a basic competence in numerical methods, machine learning methods and tools, and related topics
Physical Methods for Biologists	10-LIFE04-004-C	Learn how to make biophysical estimates
		Learn about the random walk and diffusion, Ficks law and how to make related estimates
		Learn to make statistical mechanics calculations in biology, involving cooperativity, entropy and self-assembly
		Learn about biological polymers and their properties and perform force extension calculations
		Understand biological fluids, Reynolds number and the Stokes limit
Biology-2	10-LIFE04-005-C	Learn basics of DNA packaging, Chromatin structure and Epigenetics

		Learn basics of neuroscience, ecology and evolution
		Learn basic experimental techniques in biology
		Learn basics of intercellular communication, physiology, epidemiology and immunology
Biological sequence analysis	10-LIFE04-006-C	Have a basic understanding of computer science algorithms, especially related to strings and pattern-matching
		Understanding of sequence alignment algorithms, generative models, hidden Markov models
		Basic understanding of phylogenetics and related principles and algorithms
		Basics of next-generation-sequencing methods and analysis, including essential algorithms
		Ability to frame and implement algorithms for real-world bioinformatic tasks
Systems Biology	10-LIFE04-007-C	Understand the role of networks across different scales in biology
		Mathematically model the dynamics of simple networks of interacting biological entities
		Understand the basic physical mechanisms explaining how spatial patterns can emerge spontaneously
		Learn the functional role of waves in biology for transport, communication and coordination

(B) Elective Courses

Name of the Elective Courses	Course code	Course Outcome
Biophysics of Macromolecular Structures	10-LIFE04-001-E	Understand the basics of biological macromolecular structure and functions
		Understand different biophysical approaches for probing the biological macromolecular structures and the environment in which they function.
Simulation Techniques in Biology	10-LIFE04-002-E	Learn basic statistical mechanics tools for simulation methodologies probing different length and time scales
		Apply simulation technologies to understand protein structure and function in-silico

Population Biology, Ecology and Evolution	10-LIFE04-003-E	To understand the time evolution of single species population using different types of mathematical models
		Learn basic aspects of game theory to understand how cooperation can emerge
		To model trophic (predator-prey) interactions in multiple species communities
		To understand basic aspects of the mathematical theory of evolution through natural selection
Computational Neuroscience	10-LIFE04-004-E	Understand how information is processed by the nervous system
		Learn how neurons communicate with each other and with sensory, as well as, effector organs
		Derive the Hodgkin-Huxley model of action potential transmission along a nerve
		Able to simulate in computers the electrical activity in neurons and small neuronal networks
Modeling of Infectious Diseases	10-LIFE04-005-E	Understand disease, disease spread and modeling approaches
		Learn the basics of epidemiology and epidemiological methods
		Derive and solve ordinary dufferential equation based models of disease spreading
		Understand basic concepts of immunology

BACK TO MAIN

V. Courses at NISER

Program Code : LIFE04	Programme Specific Outcome	Training in carrying out research in advanced molecular biology.
		Development of man power for advanced research in bio techniques.
		Building human resource for research in bio informatics and computational biology.

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	BIOINFORMATICS AND COMPUTATIONAL BIOLOGY	B601
2	BIOTECHNIQUES	B602
3	ADVANCED MOLECULAR BIOLOGY	B701

(B) Elective Courses

Sr. No.	Name of the Elective	Course code
1	ADVANCED CELL BIOLOGY	B601
2	GENETIC ENGINEERING	B602
3	ADVANCED BIOCHEMISTRY	B701
4	ADVANCED MICROBIOLOGY	B654
5	ENZYMOLOGY	B655
6	ADVANCED NEUROBIOLOGY	B656
7	CHEMICAL BIOLOGY	B657
8	VIROLOGY	B658
9	PLANT PHYSIOLOGY	B659
10	DEVELOPMENTAL BIOLOGY	B660
11	ADVANCED IMMUNOLOGY	B751
12	INFECTIOUS DISEASE BIOLOGY	B752

13	CANCER BIOLOGY	B753
14	ADVANCED GENETICS	B754
15	IMMUNE REGULATION AND INFECTION	B755
16	MACROMOLECULAR CRYSTALLOGRAPHY	B756
17	QUANTITATIVE BIOLOGY	B757
18	ION CHANNELS	B758
19	CONCEPTS IN MECHANOBIOLOGY	B759
20	MOLECULAR ERRORS IN DISEASE	B760
21	PLANT DEVELOPMENTAL BIOLOGY	B761

(C) Project Assignments

Sr. No.	Name of the Project Assignments	Course code
1	RESEARCH PROJECT ASSIGNMENT 1	B699
2	RESEARCH PROJECT ASSIGNMENT 2	B799

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
BIOINFORMATICS AND COMPUTATIONAL BIOLOGY	B601	Application of bioinformatics knowledge in understanding relationships at sequence, structure and network-level.
		Demonstration of popularly used bioinformatics tools for research work
		Help understand the patterns of life and rhythms
BIOTECHNIQUES	B602	Basic principle behind the biophysical, and biochemical experiments. Troubleshoot the experiments, interpretation of results, plotting of graphs, design the experiments.

ADVANCED MOLECULAR BIOLOGY	B701	Understand the recent advancements in molecular biology, structure-function analysis and regulation. Reading research articles, designing experiment and data analysis.

(B) Elective courses

Name of the Elective	**Course code**	**Course Outcome**
ADVANCED CELL BIOLOGY	B601	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell structure
		Evolution of cell organelles, importance in health and disease.
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
GENETIC ENGINEERING	B602	Understanding the basic principles of Recombinant DNA technology
		Knowledge of various tools and techniques used in genetic engineering
		Applications in the generation of transgenic models
ADVANCED BIOCHEMISTRY	B701	Understanding the mechanism of protein folding
		In depth knowledge about Post translational modifications of proteins
		Mechanisms and implications of protein turn over in cells
ADVANCED MICROBIOLOGY	B654	Develop understanding of bacterial responses to various stimuli
		Gain insights into bacterial biofilm formation and quorum sensing mechanisms
ENZYMOLOGY	B655	Build comprehension on nature and functioning of enzymes.
		Make students understand kinetics of enzyme mediated reactions and enzyme inhibition kinetics
		Develop basic understanding on enzyme engineering

ADVANCED NEUROBIOLOGY	B656	Develop understanding about the central nervous system-controlled process and their mechanism of regulation.
		In-depth understanding of the neural circuits and behavior.
		Understand and analyze the recent updates in the field and significance.
CHEMICAL BIOLOGY	B657	Introducing the concept of chemical biology
		Application of chemistry to advance the study of biological systems
		Understanding biology to do new chemistry?
		How is chemical biology used to advance science and human health?
		Understanding chemical structures of bio-molecules
		Comparative understanding of biosynthesis and laboratory synthesis
		Understanding energetics of biochemical pathways and processes
		Be competent in reading and interpreting primary literature in the areas of chemical biology
VIROLOGY	B658	At completion of the course, student is expected to comprehend structural organization, and different biological processes of viruses
		Develop basic knowledge of biology and pathological manifestation of few important human and animal viral pathogens
		Develop comprehension of tools and approaches to study viral biology.
PLANT PHYSIOLOGY	B659	Entrain the students with different hormone physiology and its interaction.
		Learning light physiology, transformation and photosynthesis.
DEVELOPMENTAL BIOLOGY	B660	Understanding the principles governing development of an organism from conception to birth.
		Key concepts in maintenance of growth of an organism and aging.
		Implications in Evolution, Health and disease.
ADVANCED IMMUNOLOGY	B751	Understating the current concepts of immunological processes associated to infection immunity, tumor immunity, autoimmunity and other immuno-

		regulatory states of altered host immune system.
INFECTIOUS DISEASE BIOLOGY	B752	Develop understanding infection process, infection epidemiology, host-pathogen interactions and evolution of pathogens
CANCER BIOLOGY	B753	Understanding basic molecular and cellular mechanisms of carcinogenesis.
		Integrating knowledge to understand therapeutic approaches.
		Stimulate research interest.
ADVANCED GENETICS	B754	Integrating knowledge of Basic genetics, molecular biology and genomics to understand advances in the field of Genetics.
		Stimulate research interest.
IMMUNE REGULATION AND INFECTION	B755	Comprehensive understanding on Immune regulation, immune deviation in bacterial, viral and parasitic infections
		Insights in to Translational aspects of Immunology such as vaccines, immunomodulatory agents in infectious as well as autoimmune diseases
MACROMOLECULAR CRYSTALLOGRAPHY	B756	Understand theory behind the X-ray diffraction to structure determination. Data collection strategy, processing, interpretation of data statistics, structure solution methods, refinement methods, interpretation of electron density map.
QUANTITATIVE BIOLOGY	B757	Introducing the concepts of mathematics in biology
		Understanding the quantitative aspects of biology
		How is statistics and mathematics required and applied in the field of biology
		Understanding how mathematical models of biology are developed
		Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of quantitative biology
		Understanding quantitative biology to do new and more insightful biology
ION CHANNELS	B758	Understanding the principles governing ion channel functions
		Biochemcial, biophysical, genetical basis of ion channel and its response
		Key concepts in maintenance of ion

		channel structure, function and ionic homeostasis of the cell
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
CONCEPTS IN MECHANOBIOLOGY	B759	Comprehend the concept that cells are complex micron-sized machines/ nano-machines.
		Understanding of the mechanical behavior of cell and tissues and the biological responses of these biological systems to mechanical stimuli.
		Gain knowledge on how cells generate and sustain mechanical forces within their environment, as part of their normal physiology.
		Ability to visualize that cells are active materials that can detect mechanical stimulation by the activation of mechanosensitive signaling pathways, and respond to physical cues through cytoskeletal re-organization and force generation
		Competence in reading and interpretation of primary literature in the area of mechanobiology and address research questions relating to cell processes using mechanobiological approaches.
		Enable students of disciplines other than biology to understand how principles of mechanics and engineering
MOLECULAR ERRORS IN DISEASE	B760	Understanding the concepts of molecular pathogenesis.
		Basic understanding of the common pathologies of organ systems.
		Understanding of the recent advances in molecular explanation for such pathologies.
PLANT DEVELOPMENTAL BIOLOGY	B761	Learning molecular genetics approaches to understand plant development.
		Understanding the interaction of biotic and abiotic component is major focus.
		Designing experimental strategies understanding plant development.

Ph.D. in MATHEMATICAL SCIENCES (Program Code: MATH04)

Course Structure:

I. Courses at HRI

Program Code : MATH04	Programme Specific Outcome	The training in the programme will make the student to think abstractly.
		At the end of the program, the student will have the knowledge of problem solving methods and will be able to find new research problems in the subject.

SEMISTER I

Sr. No.	Name of the Course	Course code
1	Algebra I	08MATH04-001-C
2	Analysis I	08MATH04-002-C
3	Topology I	08MATH04-003-C
4	Seminar Course I	08MATH04-001-S

SEMISTER II

Sr. No.	Name of the Course	Course code
1	Algebra II	08MATH04-004-C
2	Analysis II	08MATH04-005-C
3	Topology II	08MATH04-006-C
4	Differential manifolds	08MATH04-007-C
5	Seminar Course II	08MATH04-002-S

SEMISTER III
(Based on the interest, a student can take a project in one of the following Topics)

Sr. No.	Name of the Course	Course code
1	Algebraic number theory	08MATH04-008-C
2	Local fields	08MATH04-009-C

3	Fourier analysis	08MATH04-010-C
4	Harmonic analysis	08MATH04-011-C
5	Introduction to number theory	08MATH04-012-C
6	Analytic number theory	08MATH04-013-C
7	Lie algebras	08MATH04-014-C
8	Representations of finite groups	08MATH04-015-C
9	Commutative algebra	08MATH04-016-C
10	Algebraic varieties	08MATH04-017-C
11	Other elective courses	08MATH04-001-E

Course Outcomes:

SEMISTER I

Name of the Course	**Course code**	**Course Outcome**
Algebra I	08MATH04-001-C	At the end of this course, the student should have a good grasp (beyond the competence that is expected of a typical master's level student) of the fundamentals of the topics in Algebra that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both routine and not-so-routine.
Analysis I	08MATH04-002-C	At the end of this course, the student should have a good grasp (beyond the competence that is expected of a typical master's level student) of the fundamentals of the topics in Analysis that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both routine and not-so-routine.
Topology I	08MATH04-003-C	At the end of this course, the student should have a good grasp (beyond the competence that is expected of a typical master's level student) of the fundamentals of the topics in Topology that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both routine and not-so-routine.
Seminar Course I	08MATH04-001-S	At the end of this course, the student should be in a position to choose a research topic to work on for a Ph. D thesis

SEMISTER II

Name of the Course	Course code	Course Outcome
Algebra II	08MATH04-004-C	At the end of this course, the student should have a good grasp of the advanced topics of the fundamentals in advanced topics in Algebra that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both not-so-routine and read research papers.
Analysis II	08MATH04-005-C	At the end of this course, the student should have a good grasp of the advanced topics of the fundamentals in advanced topics in Analysis that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both not-so-routine and read research papers.
Topology II	08MATH04-006-C	At the end of this course, the student should have a good grasp of the advanced topics of the fundamentals in advanced topics in Topology that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both not-so-routine and read research papers.
Differential manifolds	08MATH04-007-C	At the end of this course, the student should have a good grasp (beyond the competence that is expected of a typical master's level student) of the fundamentals of the topics in Differential manifolds that are listed. The student should be able to apply the abstract theory to concrete situations of interest and solve problems both routine and not-so-routine.
Seminar Course II	08MATH04-002-S	At the end of this course, the student should have progressed in choosing a research problem for Ph. D thesis.

SEMISTER III

Name of the Course	Course code	Course Outcome
Algebraic number theory	08MATH04-008-C	At the end of this course, the student should have learned and developed the fundamentals of Algebraic Number Theory which he/she will need for pursuing research work in this area.
Local fields	08MATH04-009-C	At the end of this course, the student should have learned and developed the fundamentals of Local fields which are needed for pursuing research work in this subject.

Fourier analysis	08MATH04-010-C	At the end of this course, the student should have learned and developed the fundamentals of Fourier Analysis which are needed for pursuing research work in this topic.
Harmonic analysis	08MATH04-011-C	At the end of this course, the student should have learned and developed the fundamentals of Harmonic Analysis which are needed for pursuing research work in this subject.
Introduction to number theory	08MATH04-012-C	At the end of this course, the student should have learned and developed the fundamentals of Introduction to Number Theory which are needed for pursuing research work in this subject.
Analytic number theory	08MATH04-013-C	At the end of this course, the student should have learned and developed the fundamentals of Analytic Number Theory which are needed for pursuing research work in this topic.
Lie algebras	08MATH04-014-C	At the end of this course, the student should have learned and developed the fundamentals of Lie algebras which are needed for pursuing research work in this subject.
Representations of finite groups	08MATH04-015-C	At the end of this course, the student should have learned and developed the fundamentals of Representations of finite groups which are needed for pursuing research work in this topic.
Commutative algebra	08MATH04-016-C	At the end of this course, the student should have learned and developed the fundamentals of Commutative algebra which are needed for a Ph.D thesis work in this topic.
Algebraic varieties	08MATH04-017-C	At the end of this course, the student should have learned and developed the fundamentals of Algebraic varieties which needed for pursuing research work in this topic.
Other elective courses	08MATH04-001-E	At the end of this course, the student should have learned and developed the fundamentals of (a chosen Topic) which he/she needs for a Ph.D thesis work.

BACK TO MAIN

Course Structure:

II. Courses at IMSc

Program Code : MATH04	Programme Specific Outcome	Original research in chosen specialized area
		Knowledge of literature in chosen area and related areas
		Ability to apply concepts and techniques in problem solving
		Ability to communicate clearly both orally and in writing
		Ability to critically evaluate current research

Core Subjects

Sr. No.	Name of the Course	Course code
1	Algebra I	10MATH04-001-C
2	Algebra II	10MATH04-002-C
3	Analysis I	10MATH04-003-C
4	Analysis II	10MATH04-004-C
5	Topology I	10MATH04-005-C
6	Topology II	10MATH04-006-C
7	Complex Analysis	10MATH04-007-C
8	Credit Seminar	10MATH04-008-C
9	Research Methodology	10MATH04-009-C

Electives

Sr. No.	Name of the Course	Course code
1	TOPICS IN ANALYTIC NUMBER THEORY	10MATH04-001-E
2	TOPICS IN ALGEBRAIC NUMBER THEORY	10MATH04-002-E
3	TOPICS IN COMMUTATIVE ALGEBRA	10MATH04-003-E
4	TOPICS IN MODULAR FORMS	10MATH04-004-E
5	TOPICS IN ELLIPTIC CURVES	10MATH04-005-E
6	TOPICS IN ALGEBRAIC CURVES	10MATH04-006-E
7	TOPICS IN DIOPHANTINE GEOMETRY	10MATH04-007-E

8	TOPICS IN TRANSCENDENTAL NUMBER THEORY	10MATH04-008-E
9	TOPICS IN ALGEBRAIC GROUPS	10MATH04-009-E
10	TOPICS IN INFINITE DIMENSIONAL LIE ALGEBRAS	10MATH04-010-E
11	TOPICS IN FUNCTIONAL ANALYSIS	10MATH04-011-E
12	TOPICS IN NON-COMMUTATIVE GEOMETRY	10MATH04-012-E
13	TOPICS IN LIE GROUPS	10MATH04-013-E
14	TOPICS IN ALGEBRAIC GEOMETRY	10MATH04-014-E
15	TOPICS IN DIFFERENTIAL GEOMETRY	10MATH04-015-E
16	TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS	10MATH04-016-E
17	TOPICS IN MATHEMATICAL PHYSICS	10MATH04-017-E
18	TOPICS IN ALGEBRA	10MATH04-018-E
19	TOPICS IN OPERATOR ALGEBRAS	10MATH04-019-E
20	TOPICS IN REPRESENTATION THEORY	10MATH04-020-E
21	TOPICS IN ALGEBRAIC COMBINATORICS	10MATH04-021-E
22	TOPICS IN TOPOLOGY	10MATH04-022-E
23	TOPICS IN SYMPLECTIC GEOMETRY	10MATH04-023-E
24	PROGRAMMING FOR MATHEMATICIANS	10MATH04-024-E

Course Outcomes:

Core subjects

Name of the Course	Course code	Course Outcome
Algebra I	10MATH04-001-C	Understanding of basic group theory in the language of group actions
		Ability to apply linear algebra, in particular, canonical forms and spectral theory
		Understanding of basic category theory and tensor products

Algebra II	10MATH04-002-C	Understanding the fundamentals of Galois theory
		Familiarity with semi simplicity and its applications
		Good understanding of the representation theory of finite groups
		Knowledge of basic commutative algebra
Analysis I	10MATH04-003-C	Knowledge of measure theory
		Understanding of L^p spaces
		Familiarity with product measures and Fubini's theorem
		Understanding of the Radon-Nikodym theorem and the Lebesgue decomposition theorem
Analysis II	10MATH04-004-C	Good understanding of the basic theorems of functional analysis
		Familiarity with various kinds of topologies on function spaces
		Knowledge of Banach algebras
		Understanding of basic Hilbert space theory and C^*-algebras
Topology I	10MATH04-005-C	Solid understanding of point set topology
		Ability to use and compute fundamental groups and covering spaces
		Knowledge of basic homology theory

		Familiarity with applications of fundamental groups and homology groups
Topology II	10MATH04-006-C	Knowledge of advanced topics in homology theory
		Familiarity with cohomology theory and homotopy
		Understanding of basic notions of differential topology
		Knowledge of topics such as differential geometry, characteristic classes and Morse theory
Complex Analysis	10MATH04-007-C	Familiarity with analytic functions
		Knowledge of Cauchy's theorem, maximum modulus principle, Schwarz lemma
		Ability to apply conformal mappings and Mobius transformations
		Understanding of the Dirichlet problem and harmonic functions
Credit seminar	10MATH04-008-C	Appreciation of current research in chosen sub-area
Research Methodology	10MATH04-009-C	An introduction to the methods and techniques of academic research through a project and presentations - both oral and written.

Electives

Name of the Course	Course Code	Course Outcome
TOPICS IN ANALYTIC NUMBER THEORY	10MATH04-001-E	Possibilities for topics are: introduction to arithmetic functions, convolution and Mobius inversion formula, basic asymptotic formulas for arithmetic functions, characters and Fourier analysis on finite abelian groups, theory of Dirichlet series, primes in arithmetic progression, Riemann zeta function, Poisson summation and functional equation, The prime number theorem, error term in prime number theorem, its oscillation and the Riemann hypothesis, equivalent formulations of Riemann hypothesis, zero-free regions, explicit formula and Siegel's theorem, introduction to sieve methods, Brun and Selberg sieve, large sieve and the Bombieri-Vinogradov theorem and Vinogradov's three prime Theorem.
TOPICS IN ALGEBRAIC NUMBER THEORY	10MATH04-002-E	Possibilities for topics are: Dedekind domains, ramification, different and discriminants, decomposition and inertia groups, quadratic fields and genus theory, classification of primitive quadratic characters, Gauss sums and quadratic reciprocity, geometry of numbers, finiteness of class number and explicit computations, regulators and Dirichlet's unit theorem, cyclotomic fields and inverse Galois problem for abelian number fields, Artin symbol and splitting in cyclotomic fields, Dedekind zeta function, the analytic class number formula and introduction to the Chebotarev density theorem
TOPICS IN COMMUTATIVE ALGEBRA	10MATH04-003-E	One possibility is a course covering the second half of Matsumura's text including topics such as: regular sequences, Koszul complex, Cohen-Macaulay rings, Gorenstein rings, regular rings, UFDs, complete intersections, local flatness criterion, generic freeness, derivations and differentials, separability, I-smoothness, Cohen's structure theorems and applications of complete local rings.
TOPICS IN MODULAR FORMS	10MATH04-004-E	Possibilities include: Introduction to SL2(R) and its action on the Poincare upper half-plane H, discrete subgroups Γ of SL2(R) and their cusps, the modular group SL2(Z), Topology,

		measure theory and complex structure on H/Γ and its compactification, Modular functions, modular forms and cusp forms on SL2(Z), examples : Eisenstein Series and the delta Function, finite dimensionality of space of modular forms, the Miller basis and the Z-structure on the space of modular forms, growth of Fourier co-efficients of cusp forms, introduction to Ramanujan's conjectures, theory of Hecke operators and Petersson inner-product on the space of cusp forms, application to Ramanujan's conjectures, the L-function of modular forms, congruence subgroups, modular forms and cusp forms on congruence subgroups, spectral theory of automorphic forms, introduction to Galois representations and Deligne's theorem, Lehmer's conjecture and the Atkin-Serre Conjecture.
TOPICS IN ELLIPTIC CURVES	10MATH04-005-E	Possibilities for material to be covered include selected topics from Elliptic functions by Lang, The arith-metic of Elliptic curves by Silverman, Elliptic curves by Milne or Elliptic curves by Husemoller. Another possibility would be to prove Mazur's theorem which is a well-known and important result covering elliptic curves and abelian varieties, and the moduli of elliptic curves.
TOPICS IN ALGEBRAIC CURVES	10MATH04-006-E	Possibilities for material to be covered include selected topics from An invitation to arithmetic geometry by Lorenzini, Algebraic Curves by Fulton or lectures notes of Joseph Oesterle. Topics such as the basics of algebraic varieties over the complex numbers (with focus on dimension 1), singularities of curves (what are they and when is a curve nonsingular), desingularization of curves by normalization, the relationship between nonsingular algebraic curves and complex manifolds of dimension 1, nonsingular projective algebraic curves and function fields, the Riemann-Roch theorem, and also some of its applications.
TOPICS IN DIOPHANTINE GEOMETRY	10MATH04-007-E	Some possibilities are: introduction to Global fields, absolute values on global fields, theory of heights, rational points on conics. local-global principle and application to quadratic forms, affine and projective varieties, morphisms and rational

		maps, explicit arithmetic on function fields and their zeta-functions, divisors on curves, The Riemann-Roch theorem, elliptic curves over global fields, endomorphism rings of Elliptic curves, CM and non-CM curves, ehe Mordell-Weil group and rank of an elliptic curve and local-global principle on elliptic curves and the Tate-Shaferevich group.
TOPICS IN TRANSCENDENTAL NUMBER THEORY	10MATH04-008-E	Possibilities are: Liouville's theorem and Liouville Numbers, elements of rational approximation, transcendence of e and π, irrationality of $\zeta(3)$, introduction to algebraic independence, Lindemann-Weierstrass theorem, Schanuel's conjecture and Ax's theorem for for-mal power series, the Schneider-Lang Theorem, Hilbert's seventh problem and the Gelfond-Schneider theorem, Baker's Theorem and applications, six exponential theorem, introduction to heights and Roth's Theorem, the padic Baker theorem (by Brumer) and introduction to Leopoldt's conjecture and the padic subspace theorem and applications.
TOPICS IN ALGEBRAIC GROUPS	10MATH04-009-E	One possibility is to cover the basic theory of linear algebraic groups over an algebraically closed field up to the classification of the reductive groups by means of root data, developing the necessary background from algebraic geometry as and when needed. Thus covering preliminaries from algebraic geometry, linear algebraic groups: definition and first properties, commutative algebraic groups, derivations, differentials, and Lie algebras, topological properties of morphisms applied to this context, Parabolic subgroups, Borel subgroups, and solvable subgroups, Weyl group, roots, and root datum and reductive groups and their classification: isomorphism and existence theorems.
TOPICS IN INFINITE DIMENSIONAL LIE ALGEBRAS	10MATH04-010-E	Some possibilities are: generalized Cartan matrices and their associated Lie algebras, symmetrizability, the invariant bilinear form, the Weyl group, classification of indecomposable GCMs, finite, affine and indefinite types, affine Kac-Moody algebras, roots, the affine Weyl group, realizations of untwisted and twisted affine Kac-Moody algebras in terms of loop algebras, representation theory: integrable

		representations, category O, proof of the Weyl-Kac character formula, highest weight integrable representations, weights, representations of affine Kac-Moody algebras.
TOPICS IN FUNCTIONAL ANALYSIS	10MATH04-011-E	Some possibilities are: analytic Fredholm theory, compact and Fredholm operators, Atkinson's theorem, Gelfand duality, properties of the analytic index, Toeplitz operators on Hardy spaces, Pseudo-differential operators and Elliptic regularity, Fourier transforms and Sobolev spaces on Rn, Symbol calculus and Pseudo-differential operators, Elliptic-ity and Pseudo-differential operators on smooth manifolds, construction of para-metrices, Elliptic regularity theorem, Ellipticity and Fredholm property of Dirac operators on closed manifolds.
TOPICS IN NON-COMMUTATIVE GEOMETRY	10MATH04-012-E	Some possibilities are: Vector bundles, K-theory for topological spaces, Serre Swan theorem, K0 and K1for a C*-algebra, homotopy invariance, split exactness, half-exactness, stability of K-theory, inductive limits and K-theory, Bott periodicity, Six term exact sequences, computations with them, Pimsner-Voiculescu exact sequence, Thom isomorphism, Hilbert C*-modules, KK groups, Geometric index theory, Vector bundles, connec-tions and curvature on Riemannian manifolds, structure equations of Cartan, invari-ant forms and characteristic classes in de Rham cohomology, Chern-Gauss-Bonnet theorem and idea of proof, topological index and statement of the Atiyah-Singer index theorem
TOPICS IN LIE GROUPS	10MATH04-013-E	Some possibilities are: Introduction to Lie algebras, definitions, examples, abelian, nilpotent, solvable lie algebras, semisimple lie algebras, representation of Lie algebras, structure of general Lie algebras over characteristic zero field : statement of the Levi decomposition, statement of Ado's theorem, Introduction to real differentiable manifolds, and various standard objects associated with it, statement of the Frobenius theorem on integrability, definition of real Lie groups, examples, associated Lie algebra, the exponential map and its properties, closed subgroup theorem, continuous homomorphisms, definition of Lie subgroups and

		examples, association of lie subgroups and lie subalgebras, covering Lie groups, simply connected lie groups and association with real Lie algebras, the adjoint representation, the manifold structure of the left or right coset space with respect to a closed subgroup and the (subgroup)-principal bundle structure of the Lie group with respect to the projection to the coset space, Construction of left invariant Haar measure using left invariant differential forms, formula for modular function, compact Lie groups, Peter-Weyl theorem, embedding compact groups in linear Lie groups, Weyl group, conjugacy of maximal tori in connected compact Lie groups, Centralizers of tori, basic structure of semisimple Lie groups, existence of compact real forms of complex semi-simple Lie algebras, Cartan decomposition both at the Lie algebra and Lie group level, Iwasawa decomposition.
TOPICS IN ALGEBRAIC GEOMETRY	10MATH04-014-E	One possibility is an introduction to the language of schemes, properties of morphisms, and sheaf co-homology. So that the students gain an understanding of the basic notions and techniques of modern algebraic geometry.
TOPICS IN DIFFERENTIAL GEOMETRY	10MATH04-015-E	Some possibilities are: Definition of smooth manifolds, atlas, examples, tangent spaces, inverse and im-plicit functon theorems for manifolds, vector fields, flow, completeness of the flow function, integrability and Frobenius theorem, differential forms, pullback by func-tions, exterior derivative, orientations, manifolds with boundary, Stokes theorem, DeRham cohomology, computations using Mayer Vietoris, Riemannian metrics and geodesics.
TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS	10MATH04-016-E	Some possibilities are: Examples of partial differential equations, Strategies for studying PDE., Well posed problem, Brief introduction to classical solutions, weak solution and regularity, Transport equation, Laplace's equation, Heat equation and wave equation, Problems associated to these equations, notion of fundamental solution etc., Non-linear first order PDE, Hamilton Jacobi equations, calculus of variations, Hamilton's ode, Legendre transforms, etc., Theory of linear partial differential

		equations: Sobolev spaces, weak derivative, Sobolev inequalities, Elliptic equations, Weak solutions, the existence of weak solutions, regularity, maximum principles, eigenvalues and eigenfunctions of elliptic operators, compactness, etc.
TOPICS IN MATHEMATICAL PHYSICS	10MATH04-017-E	One possibility is to cover classical and quantum mechanics covering topics such as: review of Galilean group, mechanical system with one degree of freedom, mechanical system consisting of motion of a point in three dimensional space and motion of system of n points, review of calculus of variation, Lagrange’s equation, Hamilton’s equations, Liouville’s theorem, Symplectic structures on phase spaces and Noether’s theorem, D’Alembert’s principle, Symplectic manifolds, Hamiltonian mechanics on symplectic manifolds, moment map, postulates of quantum mechanics, mathematical aspects of Schrödinger’s equation, review of Lie group, Lie algebra and their representations with main focus on groups like U(1), SO(3), SU(2), Spin groups in 3 and 4 dimensions, Spin 1/2 particle in magnetic field, review of Fourier transforms, position and momentum space, Dirac notation, Heisenberg’s uncertainty principle, Hydrogen atom, quantization, canonical quantization, The Groenewold-van Hove no-go theorem, canonical quantization in n–dimensions, quantization and symmetries.
TOPICS IN ALGEBRA	10MATH04-018-E	One possibility is a course in commutative algebra covering prime ideals and maximal ideals, nilradical and jacobson radical, prime avoidance and the Chinese remainder theorem, extension and contraction of ideals, modules, submodules and quotient modules, direct sum and direct product, finitely generated modules and Nakayama lemma, exact sequences, tensor products, restriction and extension of scalars, exactness properties of the tensor product, algebras, tensor product of algebras, localization, local properties, extended and contracted ideals in rings of fractions, primary decomposition,

		integral extensions, lying over, going-up theorems, integrally closed domains and the going-down theorem, valuation rings, Noetherian and Artinian modules, Noetherian rings, Hilbert basis theorem, primary decomposition in Noetherian rings, Artinian rings and their structure, discrete valuation rings and Dedekind domains, fractional ideals, completions, filtrations, topologies, and completions, graded rings and modules, associated graded ring, dimension theory, Hilbert functions, dimension theory of Noetherian local rings, regular local rings, transcendental dimension, relation to algebraic varieties and algebraic geometry.
TOPICS IN OPERATOR ALGEBRAS	10MATH04-019-E	Some possibilities are: Banach algebras, spectrum, spectral radius formula, C*-algebras, Gelfand Naimark theorem, continuous functional calculus, GNS construction, positivity, measurable functional calculus, von Neumann algebras, Kaplansky density theorem, double commutant theorem, finite-dimensional C*-algebras, representation theory of the C*-algebra of compact operators, Toeplitz algebra, Coburn's theorem, group C*-algebras, crossed products, amenability, groupoid C*-algebras.
TOPICS IN REPRESENTATION THEORY	10MATH04-020-E	Some possibilities are: Lie algebras: definition and basic properties, ideals, subalgebras, homomorphisms, nilpotent and solvable Lie algebras, Lie's and Engel's theorems, semisimple Lie algebras, the Killing form, Cartan's criterion, abstract Jordan decomposition, classification of finite dimensional semisimple Lie algebras, Dynkin diagrams, the Weyl group, isomorphism and conjugacy theorems, representations, Verma modules, category O, irreducible highest weight modules, complete reducibility, Weyl character formula, Freudenthal weight multiplicity formula, Kostant and Steinberg formulas.
TOPICS IN ALGEBRAIC COMBINATORICS	10MATH04-021-E	Some possibilities are: Partially ordered sets and Mobius inversion, generating functions, permutations and statistics, Robinson-Schensted correspondence, partitions, Young's lattice, hook-length formula, Representation theory of symmetric groups, similarity classes of

		matrices and orthogonal polynomials.
TOPICS IN TOPOLOGY	10MATH04-022-E	Definitions and basic construction of homotopy groups, Whitehead's theorem, Hurewicz's theorem, stable homotopy groups, fibrations and obstruction theory, Bott's periodicity theorem, H-cobordism theorem, construction and applications of characteristic classes.
TOPICS IN SYMPLECTIC GEOMETRY	10MATH04-023-E	Possibilities include: Motivations of sympletic Geometry from Hamiltonian mechanics, neighbourhood theorems, compatible almost complex structure, and the contractibility of the space of almost complex structures, integrability of almost complex structures, Newlander-Nirenberg theorem, Hamiltonian circle actions on symplectic manifolds, moment maps, Fubini-Studi form on projective space, Kähler forms as Hessians of plurisubharmonic function on complex manifolds, introduction to pseudoholomorphic curves, outline of proof of Gromov's non-squeezing theorem.
PROGRAMMING FOR MATHEMATICIANS	10MATH04-024-E	Some possibilities are: Basic python syntax, Iterables and generators, Object oriented programming, introduction to Sage, the Numpy library, the Networkx library, graphics with Sage and Matplotlib and a Programming project.

Course Structure:

III. Courses at NISER

Program Code : MATH04	Programme Specific Outcome	A solid understanding of graduate level algebra, analysis and topology.
		Using their mathematical knowledge to tackle research problems.
		Identifying unsolved yet relevant problems in a specific field.
		To be able to undertake original research on a particular topic.
		Communicate mathematics accurately and effectively in both written and oral form.
		Conducting scholarly or professional activities in an ethical manner.

Core Subjects

(A) MATHEMATICS I

Sr. No.	**Name of the Course**	**Course code**
1	Algebra I	M601
2	Analysis I	M603
3	Topology and Complex Analysis	M659
4	Elective I	M***
5	Self-study course I	M***
6	Algebra II	M602
7	Analysis II	M604
8	Advanced Probability	M632
9	Elective II	M***
10	Self-study course II	M***

(B) MATHEMATICS II

Sr. No.	**Name of the Course**	**Course code**
1	Introduction to Stochastic Processes	M615
2	Statistical Inference I	M641
3	Regression Analysis	M644
4	Elective I	M***
5	Self-study course I	M***
6	Advanced Probability	M632

7	Time Series Analysis	M645
8	Statistical Inference II	M767
9	Elective II	M***
10	Self-study course II	M***

(C) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Representations of Finite Groups	M606
2	Commutative Algebra	M607
3	Algebraic Topology	M608
4	Advanced Functional Analysis	M612
5	Advanced Linear Algebra	M613
6	Algebraic Geometry	M616
7	Algebraic Graph Theory	M617
8	Algebraic Number Theory	M618
9	Algorithm	M620
10	Finite Fields	M623
11	Information and Coding Theory	M624
12	Mathematical Logic	M625
13	Measure Theory	M626
14	Nonlinear Analysis	M627
15	Operator Theory	M628
16	Abstract Harmonic Analysis	M630
17	Advanced Number Theory	M631
18	Algebraic Combinatorics	M633
19	Foundations of Cryptography	M634
20	Incidence Geometry	M635
21	Lie Algebras	M636
22	Optimization Theory	M637
23	Random Graphs	M639
24	Randomized Algorithms and Probabilistic Methods	M640
25	Multivariate Statistical Analysis	M642
26	Introduction to Manifolds	M643
27	Complex Analysis	M652
28	Discrete Mathematics	M654
29	Graph Theory	M655

30	Introduction to Number Theory	M656
31	Probability Theory-I	M657
32	Probability Theory-II	M658
33	Algebraic Computation	M751
34	Analytic Number Theory	M752
35	Classical Groups	M753
36	Ergodic Theory	M754
37	Harmonic Analysis	M755
38	Lie Groups and Lie Algebras-I	M756
39	Operator Algebras	M757
40	Representations of Linear Lie Groups	M758
41	Harmonic Analysis on Compact Groups	M759
42	Modular Forms of One Variable	M760
43	Elliptic Curves	M761
44	Brownian Motion and Stochastic Calculus	M762
45	Lie Groups and Lie Algebras-II	M764
46	Mathematical Foundations for Finance	M765

Course Outcomes:

(A) MATHEMATICS I

Name of the Course	Course code	Course Outcome
Algebra I	M601	Students will learn basic properties of groups, rings, and modules and will be able to use these algebraic structures to solve research problems.
Analysis I	M603	Upon successful completion of the course, students will be familiar with various advanced concepts and techniques from functional analysis, measure theory and harmonic analysis (on the real line).
Topology and Complex Analysis	M659	Upon successful completion of the course, students will aware of various properties of topological space and various properties of functions on topological spaces. The students also learn continuous maps between topological spaces, product topology, Quotient spaces, Connectedness, Compactness, Path connected spaces, separation axioms, Tychonoff spaces, Urysohns lemma and metrization theorem. Furthermore, the student will learn various properties of functions for several variable.

Elective I	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Self-study course I	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Algebra II	M602	Students will learn basic properties of fields and Galois theory and will be able to use these results to solve other mathematical problems.
Analysis II	M604	Upon successful completion of the course, students will aware of various properties of norm linear vector spaces and topological vector spaces. They will also learn various properties of linear transformations defined on these norm liner spaces and topological vector spaces.
Advanced Probability	M632	Probability spaces, Random Variables, Independence, Zero-One Laws, Expectation, Product spaces and Fubini's theorem, Convergence concepts, Law of large numbers, Kolmogorov threeseries theorem, Levy-Cramer Continuity theorem, CLT for i.i.d. components, In_nite Products of probability measures, Kolmogorov's Consistency theorem, Conditional expectation, Discrete parameter martingales with applications.
Elective II	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Self-study course II	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) MATHEMATICS II

Name of the Course	Course code	Course Outcome
Introduction to Stochastic Processes	M615	Discrete Markov chains with countable state space; Classification of states: recurrences, transience, periodicity. Stationary distributions, reversible chains, several illustrations including the Gambler's Ruin problem, queuing chains, birth and death chains etc. Poisson process, continuous time Markov chain with countable state space, continuous time birth and death chains.
Statistical Inference I	M641	joint and conditional distributions, order statistics, group family, exponential family.

		Introduction to parametric inference, sufficiency principle and data reduction, factorization theorem, minimal sufficiency statistics, Fisher information, ancillary statistics, complete statistics, Basu's theorem. Unbiasedness, best unbiased and linear unbiased estimator, Rao-Blackwell theorem, Lehmann- Scheffe theorem and UMVUE, Cramer-Rao lower bound and UMVUE, multi-parameter cases. Location and scale invariance, principle of equivarience.
		Methods of estimation: method of moments, likelihood principle and maximum likelihood estimation, properties of MLE: invariance, consistency, asymptotic normality. Hypothesis testing: error probabilities and power, most powerful tests, Neyman-Pearson lemma and its applications, p-value, uniformly most powerful (UMP) test via Neyman- Pearson lemma, UMP test via monotone likelihood ratio property, existence and nonexistence of UMP test for two sided alternatives, unbiased and UMP unbiased tests.
		Likelihood (generalized) ratio tests and its properties, invariance and most powerful invariant tests. Introduction to confidence interval estimation, methods of fining confidence intervals: pivotal quantity, inversion of a test, examples such as confidence interval for mean, variance, difference in means, optimal interval estimators, uniformly most accurate confidence bound, large sample confidence intervals.
Regression Analysis	M644	Introduction to simple linear regression, least square estimation and hypothesis testing of model parameters, prediction, interval estimation in simple linear regression, Coefficient of determination, estimation by maximum likelihood, multiple linear regression, matrix representation of the regression model, estimation and testing of model parameters and prediction, model adequacy checking-residual analysis, PRESS statistics, outlier detection, lack of fit test, serial correlation and Durbin-Watson test, transformation and weighting to correct model inadequacies-variance-stabilizing transformation, generalized and weighted least squares, diagnostics for influential observations, Cooks D test, multicollinearity-sources and effects, diagnosis and treatment for multicollinearity, ridge regression and LASSO, bootstrap estimation, dummy variable model, variable

		selection and model buildingstepwise methods, polynomial regression and interaction regression models, nonlinear regression, generalized linear models-logistic regression and Poisson regression.
Elective I	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Self-study course I	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Advanced Probability	M632	Probability spaces, Random Variables, Independence, Zero-One Laws, Expectation, Product spaces and Fubini's theorem, Convergence concepts, Law of large numbers, Kolmogorov three-series theorem, Levy-Cramer Continuity theorem, CLT for i.i.d. components, Infinite Products of probability measures, Kolmogorov's Consistency theorem, Conditional expectation, Discrete parameter martingales with applications.
Time Series Analysis	M645	Examples and objectives of time series, stationary time series and autocorrelation function, estimation and elimination of trend and seasonal components, testing for noise sequence, moving average process, autoregressive processes and ARMA processes, estimation of autocorrelation function, methods of Forecasting-Durbin-Levinson algorithm and Innovations algorithm, the Wold decomposition, ARMA models-the auto-covariance and partial auto-covariance function, forecasting ARMA processes, spectral analysis-spectral densities, periodogram, modeling with ARMA processes, Yule-Walker estimation, maximum likelihood estimation, diagnostic checking, non-stationary time series-ARIMA models, identification techniques, forecasting ARIMA models, seasonal ARIMA models, multivariate time series, ARCH and GARCH models.
Statistical Inference II	M767	General decision problem, loss and risk function, minimax estimation, minimaxity and admissibility in exponential family. Introduction to Bayesian estimation, Bayes rule as average risk optimality, prior and posterior, conjugate families, generalized Bayes rules. Bayesian intervals and construction of credible sets, Bayesian hypothesis testing. Empirical and nonparametric empirical Bayes analysis, admissibility of Bayes and

		generalized Bayes rules, discussion on Bayes versus non-Bayes approaches. Large sample theory: review of modes of convergences, Slutsky's theorem, Berry-Essen bound, delta method, CLT for iid and non iid cases, multivariate extensions. Asymptotic level _ tests, asymptotic equivalence, comparison of tests: relative efficiency, asymptotic comparison of estimators, efficient estimators and tests, local asymptotic optimality. Bootstrap sampling: estimation and testing.
Elective II	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Self-study course II	M***	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(C) ELECTIVES

Name of the Course	Course code	Course Outcome
Representations of Finite Groups	M606	Group representations, Maschke's theorem and completely reducibility, Characters, Inner product of Characters, Orthogonality relations, Burnside's theorem, induced characters, Frobenius reciprocity, induced representations, Mackey's Irreducibility Criterion, Character table of some well-known groups, Representation theory of the symmetric group: partitions and tableaux, constructing the irreducible representations.
Commutative Algebra	M607	Commutative rings, ideals, operations on ideals, prime and maximal ideals, nilradicals, Jacobson radicals, extension and contraction of ideals, Modules, free modules, projective modules, exact sequences, tensor product of modules, Restriction and extension of scalars, localization and local rings, extended and contracted ideals in rings of fractions, Noetherian modules, Artinian modules, Primary decompositions and associate primes, Integral extensions, Valuation rings, Discrete valuation rings, Dedekind domains, Fractional ideals, Completion, Dimension theory.
Algebraic Topology	M608	Rational and Jordan canonical forms, Inner product spaces, Unitary and Normal operators, Forms on inner product spaces, Spectral

		theorems, Bilinear forms, Matrix decomposition theorems, Courant- Fischer minimax and related theorems, Nonnegative matrices, Perron- Frobenius theory, Generalized inverse, Matrix Norm, Perturbation of eigenvalues.
Advanced Functional Analysis	M612	Definition and examples of topological vector spaces (TVS) and locally convex spaces (LCS); Linear operators; Hahn-Banach Theorems for TVS/ LCS (analytic and geometric forms); Uniform boundedness principle; Open mapping theorem; Closed graph theorem; Weak and weak* vector topologies; Bipolar theorem; dual of LCS spaces; Krein-Milman theorem for TVS; Krien-Smulyan theorem for Banach spaces; Inductive and projective limit of LCS.
Advanced Linear Algebra	M613	Rational and Jordan canonical forms, Inner product spaces, Unitary and Normal operators, Forms on inner product spaces, Spectral theorems, Bilinear forms, Matrix decomposition theorems, Courant- Fischer minimax and related theorems, Nonnegative matrices, Perron- Frobenius theory, Generalized inverse, Matrix Norm, Perturbation of eigenvalues.
Algebraic Geometry	M616	Prime ideals and primary decompositions, Ideals in polynomial rings, Hilbert Basis theorem, Noether normalisation lemma, Hilbert's Nullstellensatz, A_ne and Projective varieties, Zariski Topology, Rational functions and morphisms, Elementary dimension theory, Smoothness, Curves, Divisors on curves, Bezout's theorem, Riemann-Roch for curves, Line bundles on Projective spaces.
Algebraic Graph Theory	M617	Adjacency matrix of a graph and its eigenvalues, Spectral radius of graphs, Regular graphs and Line graphs, Strongly regular graphs, Cycles and Cuts, Laplacian matrix of a graph, Algebraic connectivity, Laplacian spectral radius of graphs, Distance matrix of a graph, General properties of graph automorphisms, Transitive and Arc-tranisitve graphs, Symmetric graphs.
Algebraic Number Theory	M618	Number Fields and Number rings, prime decomposition in number rings, Dedekind domains, Ideal class group, Galois theory applied to prime decomposition, Gauss reciprocity law, Cyclotomic fields and their ring of integers, finiteness of ideal class group,

		Dirichlet unit theorem, valuations and completions of number fields, Dedekind zeta function and distribution of ideal in a number ring.
Finite Fields	M623	Structure of finite fields: characterization, roots of irreducible polynomials, traces, norms and bases, roots of unity, cyclotomic polynomial, representation of elements of finite fields, Wedderburn's theorem; Polynomials over finite field: order of polynomials, primitive polynomials, construction of irreducible polynomials, binomials and trinomials, factorization of polynomials over small and large finite fields, calculation of roots of polynomials; Linear recurring sequences: LFSR, characteristic polynomial, minimal polynomial, characterization of linear recurring sequences, Berlekamp-Massey algorithm; Applications of finite fields: Applications in cryptography, coding theory, finite geometry, combinatorics.
Information and Coding Theory	M624	Information Theory: Entropy, Huffman coding, Shannon-Fano coding, entropy of Markov process, channel and mutual information, channel capacity
		Error correcting codes: Maximum likelihood decoding, nearest neighbour decoding, linear codes, generator matrix and parity-check matrix, Hamming bound, Gilbert-Varshamov bound, binary Hamming codes, Plotkin bound, nonlinear codes, Reed-Muller codes, Cyclic codes, BCH codes, Reed-Solomon codes, Algebraic codes.
Mathematical Logic	M625	Propositional Logic, Tautologies and Theorems of propositional Logic, Tautology Theorem.
		First Order Logic: First order languages and their structures, Proofs in a first order theory, Model of a first order theory, validity theorems, Metatheorems of a first order theory, e. g., theorems on constants, equivalence theorem, deduction and variant theorems etc. Completeness theorem, Compactness theorem, Extensions by definition of first order theories, Interpretations theorem, Recursive functions, Arithmatization of first order theories, Godels first Incompleteness theorem, Rudiments of model theory including Lowenheim-Skolem theorem and categoricity.

Measure Theory	M626	σ- algebras of sets, measurable sets and measures, extension of measures, construction of Lebesgue measure, integration, convergence theorems, Radon-Nikodym theorem, product measures, Fubini's theorem, differentiation of integrals, absolutely continuous functions, Lp-spaces, Riesz representation theorem for the space C[0; 1].
Nonlinear Analysis	M627	Calculus in Banach spaces, inverse and multiplicit function theorems, fixed point theorems of Brouwer, Schauder and Tychonofi, fixed point theorems for nonexpansive and set-valued maps, predegree results, compact vector fields, homotopy, homotopy extension, invariance theorems and applications.
Operator Theory	M628	Linear programming problem and its formulation, convex sets and their properties, Graphical method, Simplex method, Duality in linear programming, Revised simplex method, Integer programming, Transportation problems, Assignment problems, Games and strategies, Two-person (non) zero-sum games, Introduction to non-linear programming and techniques.
Abstract Harmonic Analysis	M630	Topological Groups: Basic properties of topological groups, subgroups, quotient groups. Examples of various matrix groups. Connected groups. Haar measure: Discussion of Haar measure without proof on R, T, Z and simple matrix groups, Convolution, the Banach algebra L1(G) and convolution with special emphasis on L1(R), L1(T) and L1(Z).
		Basic Representation Theory: Unitary representation of groups, Examples and General properties, The representations of Group and Group algebras, C_-algebra of a group, GNS construction, Positive de_nite functions, Schur's Lemma. Abelian Groups: Fourier transform and its properties, Approximate identities in L1(G), Classical Kernels on R, The Fourier inversion Theorem, Plancherel theorem on R, Plancherel measure on R; T; Z. Dual Group of an Abelian Group: The Dual group of a locally compact abelian group, Computation of dual groups for R; T; Z, Pontryagin's Duality theorem.
Advanced Number Theory	M631	Review of Finite fields, Gauss Sums and Jacobi Sums, Cubic and biquadratic reciprocity, Polynomial equations over finite fields, Theorems of Chevally and Warning,

		Quadratic forms over prime fields. Ring of p-adic integers, Field of p-adic numbers, completion, p-adic equations, Hensel's lemma, Hilbert symbol, Quadratic forms with p-adic coe_cients. Dirichlet series: Abscissa of convergence and absolute convergence, Riemann Zeta function and Dirichlet L-functions. Dirichlet's theorem on primes in arithmetic progression. Functional equation and Euler product for L-functions. Modular Forms and the Modular Group, Eisenstein series, Zeros and poles of modular functions, Dimensions of the spaces of modular forms, The j-invariant L-function associated to modular forms, Ramanujan τ function.
Algebraic Combinatorics	M633	Catalan Matrices and Orthogonal Polynomials, Catalan Numbers and Lattice Paths, Combinatorial Interpretation of Catalan Numbers, Symmetric Polynomials and Functions, Schur Functions, Jacobi-Trudi identity, RSK Algorithm, Standard Tableaux, Young diagrams and q- binomial coefficients, Plane Partitions, Group actions on boolean algebras, Enumeration under group action, Walks in graphs, Cubes and the Radon transform, Sperner property, Matrix-Tree Theorem.
Foundations of Cryptography	M634	Introduction to cryptography and computational model, computational difficulty, pseudorandom generators, zero-knowledge proofs, encryption schemes, digital signature and message authentication schemes, cryptographic protocol.
Incidence Geometry	M635	Definitions and Example as, projective planes, affine planes, projective spaces, affine spaces, collineations of projective and affine spaces, fundamental theorem of projective and affine spaces, polar spaces, generalized quadrangles, quadrics and quadratic sets.
Lie Algebras	M636	Definitions and Examples, Derivations, Ideals, Homomorphisms, Nilpotent Lie Algebras and Engel's theorem, Solvable Lie Algebras and Lie's theorem, Jordan decomposition and Cartan's criterion, Semisimple Lie algebras, Casimir operator and Weyl's theorem, Representations of $sl(2; F)$, Root space decomposition, Abstract root systems, Weyl group and Weyl chambers, Classification of irreducible root systems, Abstract theory of weights, Isomorphism and conjugacy

		theorems, Universal enveloping algebras and PBW theorem, Representation theory of semi-simple Lie algebras, Verma modules and Weyl character formula.
Optimization Theory	M637	Linear programming problem and its formulation, convex sets and their properties, Graphical method, Simplex method, Duality in linear programming, Revised simplex method, Integer programming, Transportation problems, Assignment problems, Games and strategies, Two person (non) zero-sum games, Introduction to non-linear programming and techniques.
Random Graphs	M639	Models of random graphs and of random graph processes; illustrative examples; random regular graphs, configuration model; appearance of the giant component small subgraphs; long paths and Hamiltonicity; coloring problems; eigenvalues of random graphs and their algorithmic applications; pseudo-random graphs.
Randomized Algorithms and Probabilistic Methods	M640	Inequalities of Markov and Chebyshev (median algorithm), first and second moment method (balanced allocation), inequalities of Chernoff (permutation routing) and Azuma (chromatic number), rapidly mixing Markov chains (random walk in hypercubes, card shuffling), probabilistic generating functions (random walk in d-dimensional lattice)
Multivariate Statistical Analysis	M642	Review of matrix algebra (optional), data matrix, summary statistics, graphical representations.
		Distribution of random vectors, moments and characteristic functions, transformations, some multivariate distributions: multivariate normal, multinomial, Dirichlet distribution, limit theorems. Multivariate normal distribution: properties, geometry, characteristics function, moments, distributions of linear combinations, conditional distribution and multiple correlation.
		Estimation of mean and variance of multivariate normal, theoretical properties, James-Stein estimator (optional), distribution of sample mean and variance, the Wishart distribution, large sample behavior of sample mean and variance, assessing normality. Inference about mean vector: testing for normal mean, Hotelling T^2 and likelihood ratio test, confidence regions and simultaneous

		comparisons of component means, paired comparisons and a repeated measures design, comparing mean vectors from two populations, MANOVA. Techniques of dimension reduction, principle component analysis: definition of principle components and their estimation, introductory factor analysis, multidimensional scaling. Classification problem: linear and quadratic discriminant analysis, logistic regression, support vector machine. Cluster analysis: non-hierarchical and hierarchical methods of clustering.
Introduction to Manifolds	M643	Differentiable manifolds and maps: Definition and examples, Inverse and implicit function theorem, Submanifolds, immersions and submersions. The tangent and cotangent bundle: Vector bundles, (co)tangent bundle as a vector bundle, Vector fields, flows, Lie derivative. Differential forms and Integration: Exterior differential, closed and exact forms, Poincaré lemma, Integration on manifolds, Stokes theorem, De Rham cohomology.
Complex Analysis	M652	Review of basic Complex Analysis: Cauchy-Riemann equations, Cauchy's theorem and estimates, power series expansions, maximum modulus principle, Classification of singularities and calculus of residues; Normal families, Arzela-Ascoli theorem, Riemann mapping theorem; Weierstrass factorization theorem, Runges theorem, Mittag-Lefiers theorem; Hadamard factorization theorem, Analytic Continuation, Gamma and Zeta functions.
Discrete Mathematics	M654	Combinatorics: Counting principles, Generating functions, Recurrence relation, Polyas enumeration theory, partially ordered sets.
		Graph Theory: Graphs, Trees, Blocks, Connectivity, Eulerian and Hamiltonian graphs, Planer graphs, Graph colouring.
		Design Theory: Block Designs, Balanced incomplete block design, Difference sets and Automorphism, Latin squares, Hadamard matrices, Projective planes, Generalized quadrangles.
		Algorithm: Algorithm, Asymptotic analysis, Complexity hierarchy, NP-complete problems.
Graph Theory	M655	Basic definitions, Eulerian and Hamiltonian graphs, Planarity, Colourability, four colour problem, Matching and Halls marriage

		theorem, Max-ow Min-cut theorem, Ramsey theory, Line graphs, Enumeration, Digraphs. Matroids, Groups and Graphs, Matrices and graphs, Eigenvalues of graphs, The Laplacian of a graph, Strongly regular graphs.
Introduction to Number Theory	M656	The Fundamental Theorem of Arithmetic, Distribution of prime numbers, Congruences, Chinese remainder theorem, Congruences with prime-power modulus, Fermat's little theorem, Wilson's theorem, Euler function and its applications, Group of units, Primitive roots, Quadratic residues and Quadratic reciprocity law, Arithmetic functions, Mobius Inversion formula, Dirichlet product, Sum of squares, Introduction to Zeta function and Dirichlet Series.
Probability Theory-I	M657	Review of Basic undergraduate probability: Random variables, Standard discrete and continuous distributions, Expectation, Variance, Conditional Probability.
		Discrete time Markov chains: countable state space, classification of states Characteristic functions, modes of convergences, Borel-Cantelli Lemma, Central Limit Theorem, Law of Large numbers, Convergence Theorems in Markov Chains.
Probability Theory-II	M658	Martingale Theory: Radon-Nikoydm Theorem, Doob-Meyer decomposition.
		Weak convergence of probability measures
		Brownian motion, Markov processes and Stationary processes.
Algebraic Computation	M751	Linear algebra and lattices: Asymptotically fast matrix multiplication algorithms, linear algebra algorithms, normal forms over fields, Lattice reduction; Solving system of non-linear equations: Gröbner basis, Buchberger's algorithms, Complexity of Gröbner basis computation;
		Algorithms on polynomials: GCD, Barlekamp-Massey algorithm, factorization of polynomials over finite field, factorization of polynomials over Z and Q; Algorithms for algebraic number theory: Representation and operations on algebraic numbers, trace, norm, characteristic polynomial, discriminant, integral bases, polynomial reduction, computing maximal order, algorithms for quadratic fields; Elliptic curves: Implementation of elliptic curve, algorithms for elliptic curves.

Analytic Number Theory	M752	Arithmetic functions, Averages of arithmetical functions, Distribution of primes, finite abelian groups and characters, Gauss sums, Dirichlet series and Euler products, Reimann Zeta function, Dirichlet L-functions, Analytic proof of the prime number theorem, Dirichlet Theorem on primes in arithmetic progression.
Classical Groups	M753	General and special linear groups, bilinear forms, Symplectic groups, symmetric forms, quadratic forms, Orthogonal geometry, orthogonal groups, Clifford algebras, Hermitian forms, Unitary spaces, Unitary groups.
Ergodic Theory	M754	Measure preserving systems; examples: Hamiltonian dynamics and Liouvilles theorem, Bernoulli shifts, Markov shifts, Rotations of the circle, Rotations of the torus, Automorphisms of the Torus, Gauss transformations, Skew-product, Poincare Recurrence lemma: Induced transformation: Kakutani towers: Rokhlins lemma. Recurrence in Topological Dynamics, Birkhoffs Recurrence theorem, Ergodicity, Weak-mixing and strong-mixing and their characterizations, Ergodic Theorems of Birkhoff and Von Neumann. Consequences of the Ergodic theorem.
		Invariant measures on compact systems, Unique ergodicity and equidistribution. Weyls theorem, The Isomorphism problem; conjugacy, spectral equivalence, Transformations with discrete spectrum, Halmosvon Neumann theorem, Entropy. The Kolmogorov-Sinai theorem. Calculation of Entropy. The Shannon Mc-MillanBreiman Theorem, Flows. Birkhoffs ergodic Theorem and Wieners ergodic theorem for flows. Flows built under a function.
Harmonic Analysis	M755	Fourier series and its convergences, Dirichlet kernel, Frejer kernel, Parseval formula and its applications. Fourier transforms, the Schwartz space, Distribution and tempered distribution, Fourier Inversion and Plancherel theorem. Fourier analysis on Lp-spaces. Maximal functions and boundedness of Hilbert transform. Paley-Wiener Theorem for distribution. Poisson summation formula, Heisenberg uncertainty Principle, Wiener's Tauberian theorem.

Lie Groups and Lie Algebras-I	M756	General Properties: Definition of Lie groups, subgroups, cosets, group actions on manifolds, homogeneous spaces, classical groups. Exponential and logarithmic maps, Adjoint representation, lie bracket, Lie algebras, subalgebras, ideals, stabilizers, center Baker-Campbell-Hausdor formula, Lie's Theorems. Structure Theory of Lie Algebras: Solvable and nilpotent Lie algebras (with Lie/Engel theorems), semisimple and reductive algebras, invariant bilinear forms, Killing form, Cartan criteria, Jordan decomposition. Complex semisimple Lie algebras, Toral subalgebras, Cartan subalgebras, Root decomposition and root systems. Weight decomposition, characters, highest weight representations, Verma modules, Classification of irreducible finite dimensional representations, BGG resolution, Weyl character formula.
Operator Algebras	M757	Banach algebras/C*{algebras: De_nition and examples; Spectrum of a Banach algebra; Gelfand transform; Gelfand-Naimark theorem for commutative Banach algebras/ C*-algebras; Functional calculus for C*-algebras; Positive cone in a C*-algebra; Existance of an approximate identity in a C*-algebra; Ideals and Quotients of a C*-algebra; Positive linear functionals on a C*-algebra; GNS construction. Locally convex topologies on the algebras of bounded operators on a Hilbert space, von-Neumann's bi-commutant theorem; Kaplansky's density theorem. Ruan's characterization of Operator Spaces (if time permites).
Representations of Linear Lie Groups	M758	Introduction to topological group, Haar measure on locally compact group, Representation theory of compact groups, Peter Weyl theorem, Linear Lie groups, Exponential map, Lie algebra, Invariant Differential operators, Representation of the group and its Lie algebra. Fourier analysis on $SU(2)$ and $SU(3)$. Representation theory of Heisenberg group. Representation of Euclidean motion group.
Harmonic Analysis on Compact Groups	M759	Review of General Theory: Locally compact groups, Computation of Haar measure on R; T, $SU(2)$, $SO(3)$ and some simple matrix groups, Convolution, the Banach algebra L1(G). Representation Theory: General properties of representations of a locally compact group,

		Complete reducibility, Basic operations on representations, Irreducible representations. Representations of Compact groups: Unitarilzibality of representations, Matrix coefficients, Schur's orthogonality relations, Finite dimensionality of irreducible representations of compact groups. Various forms of Peter-Weyl theorem, Fourier analysis on Compact groups, Character of a representation. Schur's orthogonality relations among characters. Weyl's Chracter formula, Computing the Unitary dual of $SU(2)$; $SO(3)$; Fourier analysis on $SO(n)$.
Modular Forms of One Variable	M760	$SL2(Z)$ and its congruence subgroups, Modular forms for $SL2(Z)$, Modular forms for congruence subgroups, Modular forms and deferential operators, Hecke theory, L-series, Theta functions and transformation formula.
Elliptic Curves	M761	Congruent numbers, Elliptic curves, Elliptic curves in Weierstrass form, Addition law, Mordell-Weil Theorem, Points of finite order, Points over finite fields, Hasse-Weil L-function and its functional equation, Complex multiplication.
Brownian Motion and Stochastic Calculus	M762	Brownian Motion, Martingale, Stochastic integrals, extension of stochastic integrals, stochastic integrals for martingales, Itô's formula, Application of Itô's formula, stochastic differential equations.
Lie Groups and Lie Algebras-II	M764	General theory of representations, operations on representations, irreducible representations, Schur's lemma, Unitary representations and complete reducibility. Compact Lie groups, Haar measure on compact Lie groups, Schur's Theorem, characters, Peter-Weyl theorem, universal enveloping algebra, Poincare-Birkoff-Witt theorem, Representations of Lie (SL (2; C)). Abstract root systems, Weyl group, rank 2 root systems, Positive roots, simple roots, weight lattice, root lattice, Weyl chambers, simple reections, Dynkin diagrams, classification of root systems, Classification of semisimple Lie algebras. Representations of Semisimple Lie algebras, weight decomposition, characters, highest weight representations, Verma modules, Classification of irreducible finite-dimensional representations, Weyl Character formula, The representation theory of SU (3), Frobenius Reciprocity theorem, Spherical Harmonics.

Mathematical Foundations for Finance	M765	Financial market models in finite discrete time, Absence of arbitrage and martingale measures, Valuation and hedging in complete markets, Basic facts about Brownian motion, Stochastic integration, Stochastic calculus: Itô's formula, Girsanov transformation, Itô's representation theorem, Black-Scholes formula

BACK TO MAIN

PH.D. IN COMPUTER SCIENCE (PROGRAM CODE: MATH04)

Course Structure:

I. Courses at IMSc

Program Code : MATH04	Programme Specific Outcome	Original research results in chosen area of specialisation
		A thorough knowledge of the literature in chosen area
		Ability to summarize major themes and current open problems in chosen area and to critically evaluate current research
		Ability to apply acquired knowledge and learnt techniques to new areas
		Ability to communicate major principles in the field and in own work, orally and in writing

CORE SUBJECTS

Sr. No.	Name of the Course	Course code
1	Theory of computation	10MATH04-001-C-CS
2	Algorithms	10MATH04-002-C-CS
3	Discrete mathematics	10MATH04-003C-CS

4	Logic	10MATH04-004-C-CS
5	Computational complexity	10MATH04-005-C-CS
6	Credit Seminar	10MATH04-006-C-CS

ELECTIVES

Sr. No.	Name of the Course	Course code
1	Advanced Data Structures	10MATH04-001-E-CS
2	Algorithms for special classes of graphs	10MATH04-002-E-CS
3	Graph Theory	10MATH04-003-E-CS
4	Kernelization	10MATH04-004-E-CS
5	Mathematical foundations of computer science	10MATH04-005-E-CS
6	Parameterized Complexity	10MATH04-006-E-CS
7	Advanced Parameterized Complexity	10MATH04-007-E-CS
8	Algorithmic Game Theory	10MATH04-008-E-CS
9	Computational Social Choice Theory	10MATH04-009-E-CS
10	Algebraic Graph Theory	10MATH04-010-E-CS
11	Topological Graph Theory	10MATH04-011-E-CS
12	Machine Learning	10MATH04-012-E-CS
13	Algebraic Graph Algorithms	10MATH04-013-E-CS
14	Algorithms for Genomics	10MATH04-014-E-CS

15	Matroid Theory	10MATH04-015-E-CS
16	Probabilistic Method	10MATH04-016-E-CS
17	Exact Exponential Algorithms	10MATH04-017-E-CS
18	Randomized Algorithms	10MATH04-018-E-CS
19	Computational complexity - II	10MATH04-019-E-CS
20	Algebraic Complexity Theory	10MATH04-020-E-CS
21	Analysis of Boolean functions	10MATH04-021-E-CS
22	Circuit complexity	10MATH04-022-E-CS
23	Communication Complexity	10MATH04-023-E-CS
24	Concrete Lower Bounds	10MATH04-024-E-CS
25	Expanders, PCPs, and Derandomization	10MATH04-025-E-CS
26	Proof Complexity	10MATH04-026-E-CS
27	Small Space Computation	10MATH04-027-E-CS
28	Incidence Theorems and their Applications	10MATH04-028-E-CS
29	Randomness and Computation	10MATH04-029-E-CS
30	Algorithmic Geometry of Numbers	10MATH04-030-E-CS
31	Algorithms for solving polynomial equations	10MATH04-031-E-CS
32	Computational geometry	10MATH04-032-E-CS
33	Computational Topology	10MATH04-033-E-CS

34	Convex Optimization	10MATH04-034-E-CS
35	Linear programming and combinatorial optimiza- tion	10MATH04-035-E-CS
36	Algebraic theory of automata	10MATH04-036-E-CS
37	Automata and concurrency	10MATH04-037-E-CS
38	Concurrency theory	10MATH04-038-E-CS
39	Programming languages and correctness	10MATH04-039-E-CS
40	Programming language theory	10MATH04-040-E-CS
41	Theory of computation: a second course	10MATH04-041-E-CS
42	Artificial intelligence	10MATH04-042-E-CS
43	Game theory	10MATH04-043-E-CS
44	Automata and games	10MATH04-044-E-CS
45	Distributed algorithms	10MATH04-045-E-CS
46	Infinite discrete structures	10MATH04-046-E-CS
47	Mathematical Logic: a second course	10MATH04-047-E-CS
48	Logics of programs	10MATH04-048-E-CS
49	Verification	10MATH04-049-E-CS
50	Topics in Algorithms	10MATH04-050-E-CS
51	Topics in Complexity Theory	10MATH04-051-E-CS
52	Algebra and Computation	10MATH04-052-E- CS

53	Algebra and Computation: a second course	10MATH04-053-E-CS

Course Outcomes:

CORE SUBJECTS

Name of the Course	Course code	Course Outcome
Theory of computation	10MATH04-001-C-CS	A fine understanding of the robustness of finite-state automata and their properties and limitations.
		A fine understanding of the robustness and power of Turing machines as an abstract model of computation.
		Ability to generalise learned concepts to other definitions of models of computation.
Algorithms	10MATH04-002-C-CS	Familiarity with the basic building blocks of algorithm design.
		Familiarity with the techniques used to analyse their performance.
		Ability to apply these ideas to develop and analyse algorithms for previously unseen problems.
Discrete Mathematics	10MATH04-003-C-CS	A good understanding of the basic combinatorial and algebraic tools used in theoretical computer science.
		Ability to use these abstract tools in concrete settings to solve routine and not-so-routine problems.
Logic	10MATH04-004-C-CS	A good familiarity with the fundamental concepts of mathematical logic.
		Ability to comprehend issues of compactness, completeness, decidability in a variety of logics.
Computational complexity	10MATH04-005-C-CS	A good grasp of issues concerning:
		efficiency of computation

		the relationships between basic computational models and the trade-offs between various computational resources
		Various computational notions of proof.
Credit Seminar	10MATH04-006-C-CS	An appreciation of the current research in the chosen sub-area.
		An ability to critically analyse the techniques in use.

ELECTIVES

Name of the Course	Course code	Course Outcome
Advanced Data Structures	10MATH04-001-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algorithms for special classes of graphs	10MATH04-002-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Graph Theory	10MATH04-003-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Kernelization	10MATH04-004-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Mathematical foundations of computer science	10MATH04-005-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Parameterized Complexity	10MATH04-006-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Advanced Parameterized Complexity	10MATH04-007-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algorithmic Game Theory	10MATH04-008-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Computational Social Choice Theory	10MATH04-009-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algebraic Graph Theory	10MATH04-010-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Topological Graph Theory	10MATH04-011-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Machine Learning	10MATH04-012-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algebraic Graph Algorithms	10MATH04-013-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algorithms for Genomics	10MATH04-014-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Matroid Theory	10MATH04-015-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Probabilistic Method	10MATH04-016-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Exact Exponential Algorithms	10MATH04-017-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Randomized Algorithms	10MATH04-018-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Computational complexity - II	10MATH04-019-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algebraic Complexity Theory	10MATH04-020-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Analysis of Boolean functions	10MATH04-021-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Circuit complexity	10MATH04-022-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Communication Complexity	10MATH04-023-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Concrete Lower Bounds	10MATH04-024-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Expanders, PCPs, and Derandomization	10MATH04-025-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Proof Complexity	10MATH04-026-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Small Space Computation	10MATH04-027-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Incidence Theorems and their Applications	10MATH04-028-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Randomness and Computation	10MATH04-029-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algorithmic Geometry of Numbers	10MATH04-030-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algorithms for solving polynomial equations	10MATH04-031-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Computational geometry	10MATH04-032-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Computational Topology	10MATH04-033-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Convex Optimization	10MATH04-034-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Linear programming and combinatorial optimiza- tion	10MATH04-035-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algebraic theory of automata	10MATH04-036-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Automata and concurrency	10MATH04-037-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Concurrency theory	10MATH04-038-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Programming languages and correctness	10MATH04-039-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Programming language theory	10MATH04-040-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.

		Preparedness to critically read state-of-the-art research material in the subject.
Theory of computation: a second course	10MATH04-041-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Artificial intelligence	10MATH04-042-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Game theory	10MATH04-043-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Automata and games	10MATH04-044-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Distributed algorithms	10MATH04-045-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Infinite discrete structures	10MATH04-046-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.

Mathematical Logic: a second course	10MATH04-047-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Logics of programs	10MATH04-048-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Verification	10MATH04-049-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Topics in Algorithms	10MATH04-050-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Topics in Complexity Theory	10MATH04-051-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.
Algebra and Computation	10MATH04-052-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.

Algebra and Computation: a second course	10MATH04-053-E-CS	A good grasp of the topics laid out in the syllabus.
		An ability to apply learned concepts to new settings.
		Preparedness to critically read state-of-the-art research material in the subject.

BACK TO MAIN

Course Structure:

II. Courses at NISER

Program Code : MATH04	Programme Specific Outcome	The program is aimed at graduates with good academic potential and strong interest in research. With a focus on some fundamental areas of Computer Science like Algorithms, Cryptography, Complexity Theory, Machine Learning etc., the program expects to nurture researchers producing high impact research results. After the completion of the program, the doctorates will be suitable to academic and industry jobs in any part of the world.

CORE SUBJECTS

Sr. No.	Name of the Course	Course code
1	Modern Cryptology	CS651
2	Algorithmic Coding Theory	CS652
3	Complexity Theory	CS653
4	Linear Programming and Combinatorial Optimization	CS654
5	Distributed Network Algorithms	CS655
6	Cyber Forensics	CS656
7	Penetration Testing	CS657
8	Social and Information Network Analysis	CS658
9	Advanced Algorithms	CS659
10	Machine Learning	CS660
11	Randomized Algorithms and Probabilistic Analysis	CS661

SEMINAR COURSES

Sr. No.	Name of the Course	Course code
1	Seminar Course-I	CS791
2	Seminar Course-II	CS792
3	Seminar Course-III	CS793

PASS/FAIL COURSE

Sr. No.	Name of the Course	Course code
1	Research Methods	CS601

COURSE OUTCOMES:

CORE SUBJECTS

Name of the Course	Course code	Course Outcome
Modern Cryptology	CS651	Understanding basic concepts in Mathematical Cryptology
		Ability to design and analysis of security algorithms
Algorithmic Coding Theory	CS652	Students will be introduced to formalization of the notion of uncertainty of a random variable, Source coding for error-free reconstruction, channel coding and the fundamental theorem, introduction to some algebraic codes (Parity-check codes, Reed-Solomon codes).
Complexity Theory	CS653	Students would be able to Understand P vs NP arguments and corresponding proofs.
		Learn about interactive proofs and randomized computation
Linear Programming and Combinatorial Optimization	CS654	Students will learn de_nition and properties of convex sets and functions, convex and a_ne hulls, recession cones and hyperplanes, constrained optimization, Duality, Minimax Theory
Distributed Network Algorithms	CS655	Understand basics of distributed network algorithms and systems.
		Gain knowledge on applications of distributed network algorithms to real-world networks and analysis of such algorithms.
Cyber Forensics	CS656	Understand the key concepts in computer forensics across domains of systems (Windows, linux and Mac) as well as Internet artifacts.
		Investigate mobile systems and get a brief idea on intellectual property and cyber laws.
Penetration Testing	CS657	Understand the basics of penetration testing both passive and active.

		Able to test the system for exploits in system, network and web as well as run penetration test in vulnerable systems.
Social and Information Network Analysis	CS658	Learn the basics of social and information network and how to analyze them.
		Key concepts in information maximization and community detection in large graphs.
Advanced Algorithms	CS659	Augment their understanding of algorithms with hashing and online algorithms.
		Gain knowledge about parameterized algorithms and computational geometry.
		Learn to prove hardness and equivalences.
Machine Learning	CS660	Students would be able to Learn key concepts of machine learning.
		Understand and implement supervised, unsupervised learning algrithms as well as introduction to reinforcement learning.
Randomized Algorithms and Probabilistic Analysis	CS661	Understand probabilistic analysis and the manners in which it can be used in designing efficient algorithms
		Study key concepts in Probability Theory and learning about various applications to well-known problems in Computer Science.

Ph.D. in PHYSICAL SCIENCES (Program Code: PHYS04)

Course Structure:

II. Courses at IGCAR

Program Code : PHYS04	Programme Specific Outcome	Training in carring out fast reactor based research.
		Unique exposure to nuclear fuel cycle activities
		Material development for specific applications

Course Structure:

Sr. No.	**Name of the Course**	**Course code**
1	Mathematical Methods	PY1
2	Computational Methods	PY2
3	Introductory Reactor Physics and Engineering	PY3
4	Nuclear Physics and Nuclear Data	PY4
5	Engineering Drawing and Laboratory Practices and Experimental Methods	PY5
6	Reactor Materials	PY6
7	Radiation Detection and Measurements	PY7
8	Reactor Types and Advanced Reactor Concepts	PY8
9	Radiation Shielding Design and Protection	PY9
10	Reactor Dynamics and Safety Analysis	PY10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	PY11
12	Fluid Dynamics and Thermal Hydraulics	PY12
13	Advanced Computational Methods in Reactor Physics	PY13
14	Experimental and Operational Reactor Physics	PY14
15	Design Methods in Thermal and Fast Reactors and Computer codes	PY15
16	In Core of Fuel Management	PY16

Course Outcomes:

Name of the Course	Course code	Course Outcome
Mathematical Methods	PY1	Students learn vector spaces, Hilbert space, matrix methods, eigen value problems, differential and integral equations, complex variables.
Computational Methods	PY2	Since some complex equations cannot be solved analytically, numerical and computational methods are important. Students study the basics of computer architecture - hardware and software,
		Learn Various numerical methods
		Programming in Fortran and C
Introductory Reactor Physics and Engineering	PY3	Learn neutron physics, reactor physics including fast reactors; reactor kinetics and reactor control, all needed for working with nuclear reactors.
Nuclear Physics and Nuclear Data	PY4	Learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, nuclear models, nuclear data evaluation and processing which are Needed to work with nuclear reactors and for nuclear research.
Engineering Drawing and Laboratory Practices and Experimental Methods	PY5	Machine Drawings Projections, drafting, Autocad other material in this course are essential for engineers to produce accurate drawing for fabrication of small and large components for nuclear reactors and associated facilities.
Reactor Materials	PY6	Properties of nuclear fuels such as uranium, uranium oxide, plutonium, carbide and nitride fuels, MOX fuel, fuel fabrication, structural materials and clad materials, zirconium and alloys, moderators, Mechanical properties of materials, Radiation effects in materials, corrosion of metals and related topics makes this course a very important one for nuclear scientists and engineers.
		Ability to Solve unforeseen materials problems in operational reactors
		Ability to look for future candidate materials
Radiation Detection and Measurements	PY7	Required for radiation, safety workers and related scientists: Interaction of radiation with matter, radiation detectors including

		gas, semiconductor and scintillation detectors; ionization chambers; high resolution gamma spectroscopy, Monte Carlo simulations
Reactor Types and Advanced Reactor Concepts	PY8	Students will learn about different type of reactors such as Thermal reactors, fast reactors, High Temperature Reactor(HTR) and Advanced Heavy Water Reactor (AHWR). Metal fuelled FBR and Accelerator driven systems (ADS); Indian reactors APSARA, CIRUS, DHRUVA, PHWR, FTBR AND PFBR
Radiation Shielding Design and Protection	PY9	Students will study Radiation sources, its interaction with matter; summary of basic interaction mechanisms of alpha, beta, gamma/x -rays and neutrons with matter; radiation dosimetry; Interaction of radiation with biological matter; Radiation toxicity, Risk factors; radiation protection, shielding, and nuclear emergency management
Reactor Dynamics and Safety Analysis	PY10	Neutron kinetics and thermal effects. Feedback effects; Description of main reactor systems. Coolant system behaviour. Plant dynamics; safety systems; Reliability and Probabilistic Safety Analysis and related topics are taught in this course
Fuel Cycle Physics and Introduction to Fuel Cycle	PY11	Basic fuel cycles – once through and multiple recycle strategies, neutron economy, fissile material conservation and three stage program of India. Physics of U exploration methods. Recovery of the starting compounds bearing U,Pu,Th from their primary and secondary sources. Mining and milling. Issues related recycling – Effective fissile content of discharged fuel for next cycle; re-fabrication of fuel for the next cycle Activity and toxicity of discharged fuel
Fluid Dynamics and Thermal Hydraulics	PY12	Fluid continuum – Properties of fluids – Methods of describing fluid motion – Kinematics of fluid streamlines; Navier Stokes equations; Hydrostatics – Manometry; Fluids subjected to uniform linear acceleration and uniform rotation; Thermal hydraulics.

		Important specialisation for understanding behaviour of reactor coolants (liquid sodium and water) for safe reactor operation
Advanced Computational Methods in Reactor Physics	PY13	Students will learn Methods of solving neutron Diffusion equation; Finite element method- its advantages and disadvantages. Coarse mesh rebalancing. Methods of solving neutron transport equation; (a) PN method (b) Discrete ordinates method (c) Collision probabilities methods; Detailed burnup chain with all minor actinides. Solution of the burnup equations. Constant flux and constant power approximations.
Experimental and Operational Reactor Physics	PY14	In-depth exposure and develop expertise to experiential aspects of Reactor operations
		Dynamical methods to evaluate and monitor reactivity measurements
		Expertise to monitor delayed neutron counting and noble gas fission products to detect early stages of fuel failures.
		Exposure to operation aspects of various types of reactors
Design Methods in Thermal and Fast Reactors and Computer codes	PY15	Exposure to model and design of both thermal and fast reactors using neutron production, transport and reactions
		Expertise to use various design and validation codes for neutronics
In Core of Fuel Management	PY16	Develop expertise in various safety aspects of in-core fuel handling and management in different types of reactors
		Exposure to reactor specific fuel handling methods and controls
		Exposure to specialised computer codes for in-core fuel handling

III. Courses at RRCAT- PhD

Program Code : PHYS04	Programme Specific Outcome	Impart training to students to increase the knowledge base required for research work
		Enhance analytical and computational skill of the students required for carrying out research work
		Provide training to work with various scientific equipment including sophisticated lasers and radiation available from synchrotron sources Indus-1 and Indus -2

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	03PHYS04-001-C
2	Magnet Physics and Technology	03PHYS04-002-C
3	Laser Physics and Technology	03PHYS04-003-C
4	Electromagnetic Theory	03PHYS04-004-C
5	Accelerator Physics andBeam Diagnostics	03PHYS04-005-C
6	Reactor Physics, Radiation Physics, and Safety Issues	03PHYS04-006-C
7	Numerical and Mathematical Techniques and Scientific	03PHYS04-007-C
8	Materials Science and Technology- I	03PHYS04-008-C
9	Applications of Lasers in Nuclear Science, Industry	03PHYS04-009-C
10	Applications of Accelerators in Nuclear Science, Industry	03PHYS04-010-C
11	Vacuum Physics and Technology	03PHYS04-011-C
12	Quantum Mechanics	03PHYS04-012-C
13	Research Methodology	03PHYS04-013-C

(B) Elective Courses

Sr. No.	Name of the Course	Course code
1	Modern optics	03PHYS04-001-E
2	Advanced accelerator physics	03PHYS04-002-E
3	Statistical physics	03PHYS04-003-E
4	Plasma Physics and Technology	03PHYS04-004-E
5	Materials Science and Technology	03PHYS04-005-E
6	Advanced Beam Dynamics	03PHYS04-006-E
7	Bio-photonics	03PHYS04-007-E
8	Advance Course on Atom-Photon Interaction	03PHYS04-008-E
9	Concepts in X-Ray Physics	03PHYS04-009-E
10	Physics of Semiconductor Quantum Structures	03PHYS04-010-E

(C) Laboratory Courses

Sr. No.	Name of the Course	Course code
1	Laser and Applications	03PHYS04-001-L
2	Accelerators related applications	03PHYS04-002-L
3	Electronics	03PHYS04-003-L

(D) Reading Courses

Sr. No.	Name of the Course	Course code
1	Self-Reading	03PHYS04-001-R

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Engineering Mathematics	03PHYS04-001-C	This course reviews topics in Mathematics which are usually covered at the Master's level and are essential to understand the concepts of science and engineering This Course also deals with the advanced topics needed for carrying out research work in different areas of science and engineering
Magnet Physics and Technology	03PHYS04-002-C	Basic understanding of magnetism and its application. Analytical approach of magnet design mainly for accelerator application and field measurement technique. Fabrication technique and alignment of magnets.
Laser Physics and Technology	03PHYS04-003-C	This course introduces basic mechanism and principles of lasers, beam propagation, and optical resonators Introduction to physics and technology of various types of lasers This course introduces basic nonlinear optics
Electromagnetic Theory	03PHYS04-004-C	This course is meant for physicists and engineers. It reviews the M. Sc. Level and B. Tech level electromagnetic theory, and further strengthens some of the intricate concepts, and introduces new topics It emphasizes basic concepts needed to solve the electromagnetic boundary value problems, and prepares the students to develop better understanding of the computer codes used for that Students are expected to develop a better and rigorous understanding of generation of electromagnetic radiation, typically in synchrotron radiation source. Students learn about different types of electromagnetic waves – (i) plane waves, including its reflection and refraction at dielectric surface. (ii) Gaussian beams and Bessel beams, (iii) modes in waveguides and cavities, including its transport in microwave components and (iv) modes in optical fiber.

Accelerator Physics and Beam Diagnostics	03PHYS04-005-C	The course introduces basic concepts of accelerator physics and beam diagnostics.
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Reactor Physics, Radiation Physics, and Safety Issues	03PHYS04-006-C	Awareness about natural, man-made radiation, dose contribution from various practises, units and quantities, biological effects of radiation exposure and ICRP recommendations on radiation protection
		Awareness about the radiation hazards at work place, safe practises to be followed, exposure control measures, shielding philosophy and radiation detection.
		Understanding the radiation hazards at high energy electron and proton accelerators and laser facilities. Dose build up effects due to electromagnetic and hadronic cascade and its impact on radiation safety and tackling mechanisms
		Gaining fundamental concepts in reactor physics, interaction of various kind of radiation with matter.
Numerical and Mathematical Techniques and Scientific	03PHYS04-007-C	For rigorous and correct analysis of data (which are the outcome of research work), learning numerical and mathematical techniques is absolutely essential.
		This course teaches interpolation, extrapolation, error analysis etc which are integral parts of data analysis. The finite element method is a numerical method for solving problems of applied science and engineering, for example, structural analysis, heat transfer, fluid flow, mass transport etc
		Concept of scientific computing is necessary for numerically analyzing experimental and analytical results. For the same, programming languages (C and fortran) are taught.
		Different operating systems (windows, linux etc), which are taught, also help in understanding the working of computers, in turn, different aspects of scientific computing
Materials Science and Technology- I	03PHYS04-008-C	The course reviews the master's level solid state physics with certain advanced topics
		The advanced topics covered include: nonlinear properties of optical materials,

		electronic materials for novel applications like spintronics and introduction to symmetry and ferroelectric materials
		Students learn structures of various materials including alloys, ceramics, glasses, polymers, and composites
Applications of Lasers in Nuclear Science, Industry	03PHYS04-009-C	This course covers various applications of lasers in high resolution spectroscopy in metrology and medicine
		This courses exposes application of lasers in material processing
		This course introduces application of lasers in isotope separation
Applications of Accelerators in Nuclear Science, Industry	03PHYS04-010-C	This course aims to expose students to various applications of accelerators.
		Students become aware of applications in accelerator based radiotherapy and radiation processing
Vacuum Physics and Technology	03PHYS04-011-C	This course aims to introduce the basics of theory of vacuum
		Introduces various vacuum systems and components
		Students learn how to design a vacuum system
Quantum Mechanics	03PHYS04-012-C	This course reviews master’s level quantum mechanics with more emphasis on problem solving and applications
		This course also covers advanced topics which will enhance understanding in many-electron systems and photo-atom interaction
Research Methodology	03PHYS04-013-C	Definition and characteristics of research, objectives and importance of research, planning of research, types and stages of research, scientific methods, searching for scientific information, accessing scientific literature, reading scientific papers.

(B) Elective Courses

Name of the Course	Course code	Course Outcome
Modern Optics	03PHYS04-001-E	This course reviews the basic understanding of geometrical & wave optics with emphasis on topics of importance to lasers, laser-based measurements and laser-based systems.
		This course helps scholars to develop a sound understanding of optics required for designing and modelling lasers and laser-based systems.
Advanced Accelerator Physics	03PHYS04-002-E	This course discusses electron and ion sources, and the processes involved.
		This course discusses concepts related to proton and heavy ion linacs, transport of ion beams, and beam instabilities
		The course introduces advanced topics of free electron lasers, linear accelerator-based synchrotron radiation sources, laser plasma based accelerators and the concept of Accelerator Driven Systems.
Statistical Physics	03PHYS04-003-E	This course reviews master's level statistics focusing attention on quantum degenerate gases.
		This course helps scholars to develop deeper understanding of phase transition and concepts required to handle many-body systems of condensed matter and plasma physics
Plasma Physics and Technology	03PHYS04-004-E	This course aims to make students of basic plasma physics and the involved technology
		This course exposes students various aspects of plasma physics like waves in plasma, plasma production, plasma diagnostics, and plasma radiation
		This course introduces laser-plasma interaction at ultrahigh intensities
Materials Science & Technology	03PHYS04-005-E	To understand and interpret phase diagram for material synthesis.
		To learn about material synthesis by solid state and liquid phase route and methods of preparation of ceramics, thin film, nano-powder and single crystal
		To evaluate the direct & indirect band-gap, impurity & defect absorption, molecular vibrations by spectroscopic

		techniques like UV-vis-NIR spectroscopy, FTIR and Raman spectroscopy.
		To get acquainted with various spectroscopic instruments for materials like polarized light microscope, Scanning electron microscope, Transmission electron microscope and Scanning probe microscopes (AFM, STM).
Advanced Beam dynamics	03PHYS04-006-E	This course is meant for physicists, specializing in the field of particle accelerators. The selected topics on beam dynamics form the basis of design of modern particle accelerators.
		Students are expected to develop a clear understanding of how a charge particle beam evolves under the influence of applied electromagnetic field, including the self-force due to space charge
		Students learn about the physics underlying the phenomenon of emittance growth, and beam halo formation, which is a topic of current interest.
		The course prepares the students for using computational tools to address the design problems in the area of beam dynamics
Bio-photonics	03PHYS04-007-E	This course aims to introduce interaction of light with cells and tissues
		This course introduces optical imaging of tissues in turbid medium
		This course exposes the students to aspect of biomedical diagnosis and micromanipulation
Advance course on atom-photon interaction	03PHYS04-008-E	This course deals with interaction of light with matter at fully quantum and semi-classical levels
		This course exposes students to various perturbative and non-perturbative techniques to determine probabilities
		This course covers coherent dynamics of atoms in the interaction with light
		This course covers concepts of coherence of light and various quantum state of radiation field
Concepts in X-ray Physics	03PHYS04-009-E	The course deals with the basics of interaction between matter with x-rays
		The various x-ray based materials characterisation techniques like X-ray diffraction, X-ray absorption and

		photoelectron spectroscopy are dealt in details.
		This course is beyond the content matter of normal master level courses.
Physics of semiconductor Quantum structures	03PHYS04-010-E	The aim of this course is to introduce the students to various aspects of semiconductor nanostructures
		Students learn aspects of growing nanostructures
		Students learn various methods of characterising nanostructures

(C) Laboratory Courses

Name of the Course	Course code	Course Outcome
Laser and Applications	03PHYS04-001-L	Students get first-hand experience in handling various lasers and laser-based instrumentations
		Students learn various techniques to align and characterize lasers
Accelerators related applications	03PHYS04-002-L	Students get first-hand experience in handling various instruments needed for accelerator technology
Electronics	03PHYS04-003-L	Students get first-hand experience in handling various instruments required for electronics, image processing, and RF components
		Students are also expected to learn and handle GUI software and communication protocols

(D) Reading Courses

Name of the Course	Course code	Course Outcome
Self-Reading	03PHYS04-001-R	This course helps scholars to develop understanding in some of the key topics related to his/her research work

Course Structure:

IV. Courses at VECC

Program Code : PHYS04	Programme Specific Outcome	Impart knowledge in Experimental and Theoretical Nuclear Physics(and Allied Areas), Material Sciences, Theoretical Physics and High EnergyPhysics.
		Develop human resource for faculty position in physics and applied physicsin academic institutions and National Laboratories.
		Learning to work in mega-science projects through National and International collaborations.

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Mathematical Physics	04PHYS04-001-C
2	Quantum Mechanics	04PHYS04-002-C
3	Classical Mechanics	04PHYS04-003-C
4	Statistical Mechanics	04PHYS04-004-C
5	Classical Electrodynamics	04PHYS04-005-C
6	Research Methodology Computational Methods and Programming	04PHYS04-006-C
7	Experimental techniques and methods	04PHYS04-007-C
8	Basic Field Theory	04PHYS04-008-C
9	Basic Accelerator physics	04PHYS04-009-C
10	Basic Condensed Matter Physics	04PHYS04-0010-C
11	Basic Nuclear physics	04PHYS04-011-C
12	Laboratory experiments	04PHYS04-012-C
13	Advanced Nuclear Structure	04PHYS04-013-C
14	Advanced nuclear reaction	04PHYS04-014-C
15	Advanced Accelerator physics	04PHYS04-015-C
16	Advanced High Energy Physics	04PHYS04-016-C
17	Advanced Materials Science – I	04PHYS04-017-C
18	Advanced Material Science II	04PHYS04-018-C

19	Advanced High Energy Physics (Experiment)	04PHYS04-001-E
20	Project	04PHYS04-001-P

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Mathematical Physics	04PHYS04-001-C	Understanding the underlying mathematical structure of Quantum Physics
		Using the techniques of complex analysis to solve realistic physical problems
		Model the Regression Learning Models
		Understanding the Geometric ideas behind modern physics
QUANTUM MECHANICS	04PHYS04-002-C	Learn approximation methods used in quantum mechanics
		Basic understanding in Collision theory
		Exposure to relativistic quantum mechanics
		Learn Lagrangian formulation
Classical Mechanics	04PHYS04-003-C	Introduction of Lagrangian formulation
		Introduction of Hamiltonian formulation
		Connection of classical mechanics with quantum mechanics
Statistical Mechanics	04PHYS04-004-C	Detailed understanding of the different distribution functions, statistical techniques and their application to different physical systems
		Understanding of different statistical methods, thermodynamic connection and their application to different physical problems related to condensed matter physics and nuclear physics
		Learnt advance topics of equilibrium and non-equilibrium statistical mechanics (ex: phase transition kinetics, transport theory) which are extensively used in state-of-the art research problems.
Classical Electrodynamics	04PHYS04-005-C	Impart knowledge on classical field theory
		Learn the basic science of electricity and magnetism
		Develop skill in applications of electromagnetic theory invarious practical problems
		Develop mathematical skill to solve partial differential equations.

Research Methodology	04PHYS04-006-C	This is an essential course to pursue research work for PhD in Physical Sciences and Engineering Sciences
		Impart knowledge and skills to analyse data and prepare scientific manuscript.
		Learn about Ethical aspects in research
Computational Methods and Programming		Applications of the machine learning and programming in understanding the numerical approach to solve a scientific project which can hardly be solved analytically
		Use of the numerical methods for simulating detection techniques and performances a priori and check the feasibility
		Implement the machine learning and numerical approach to understand the human learning aspects.
		Implementation of numerical techniques in the analysis of experimental data and understand them in the framework of numerical modelling with associated physics.
		Machine learning and numerical methods have an important role in illustrating and predicting in the field of Bioinformatics, Linguistics, Data mining and Big data analysis both in the social and scientific paradigm
Experimental techniques and methods	04PHYS04-007-C	Imparts knowledge on laboratory safety, vacuum techniques, cryogenics and workshop practices
		Provides understanding on different material characterization techniques viz. electron microscopy, XRD, optical, electrical and magnetic measurements
		Learns about different detectors and techniques used in nuclear and high energy physics.
Basic Field Theory	04PHYS04-008-C	This course is designed to provide an elementary idea about the Lorentz invariance and Relativistic kinematics.
		Basic concepts about the classical field theory and symmetries and conservation laws are provided.
Basic Accelerator physics	04PHYS04-009-C	The Basic Accelerator Physics course focuses on the key concepts of particle accelerators and their applications. The objective of the course is to emphasize the

		knowledge of beam dynamics in Linear and circular accelerator including the effect of space charge. Exposure regarding various types of accelerators is given.
Basic Condensed Matter Physics	04PHYS04-0010-C	In the basic materials science courses the covered areas are mainly crystal structure and crystallography, defects in solids, electronic structure of solids. Also the magnetism, superconductivity, superfluidity and dielectric properties of solids have been taught.
Basic Nuclear physics	04PHYS04-011-C	Learning basic properties of nuclei like mass, charge, shape etc.
		Learning nuclear models related to nuclear collective dynamics and fission decay
		Learning microscopic many-body thoery for nucleus
Laboratory experiments	04PHYS04-012-C	Gives hands on experience and understanding on topics discussed in the experimental techniques and methods course (PHY04007L)
		Provides practical understanding on the operation and use of a different types of instrument and facility
		Get basic training for planning a goal oriented real life experiment
		Learn to prepare scientific reports
Advanced Nuclear Structure	04PHYS04-013-C	Different model calculations of nuclear structure physics
		Different modes of excitations in nuclei and associated observables
		Specific knowledge of gamma ray spectroscopy and its application to nuclear structure
		Methods of lifetime and moment measurements in nuclei
		Total absorption spectroscopy and beta-delayed neutron emission measurements and their practical application.
		A detailed and overall theoretical understanding on the ground and excited state properties in nuclei along with a detailed knowledge on the experimental know-how in the measurement of different nuclear structure quantities. Students are expected to connect the experimental observables and the deduced quantities

		with the theoretical parameters related to nuclear structure.
Advanced nuclear reaction	04PHYS04-014-C	Advanced nuclear reaction course is designed to develop basic understanding of nature around us which includes formation of stars to discovery of new elements using accelerator based research. It includes following modules
		Study of fusion –fission dynamics, deep - inelastic reactions, multi fragmentation etc.
		Nuclear Astro physics and Equation of State for dense nuclear matter
Advanced Accelerator physics	04PHYS04-015-C	The Advance Accelerator Physics course focuses on the key concepts of modern particle accelerators and their applications. The objective of the course is to emphasize the knowledge of beam dynamics in Linear and circular accelerator including the effect of space charge. Various advanced accelerator projects has also been discussed.
		It covers Advance accelerators: Free electron laser, Plasma accelerators, Spallation neutron sources, Rare ion beam facilities. Accelerators driven subcritical systems.
		It covers Storage rings and synchrotron radiation**:** Radiation from moving charges, Radiation power and angular distribution, Quantum fluctuation, Beam lifetime, beam cooling.
		It covers Beam with space charge**:** Envelope oscillations, modes and instabilities, Sources of emittance growth, Wake fields and image charge effects**.**
Advanced High Energy Physics	04PHYS04-016-C	This course is designed to provide an elementary idea about the Standard Model of particle physics with particular emphasis on Quantum Chromodynamics.
		Basic concepts about the structure of hadrons as well as relativistic heavy ion collisions are also provided
Advanced Materials Science – I	04PHYS04-017-C	Understand formation of defects due to particle irradiation in materials
		Understand effect of radiation damage on physical and mechanical properties of materials

		Correlate defects and property changes due to irradiation in materials
		Emulate neutron damage with ion irradiation in structural materials.
Advanced Material Science II	04PHYS04-018-C	In this course mainly properties of advance functional materials, e.g., multi-functional materials, nano-particle system and advanced oxide materials have been covered. Defect characterization in oxides by positron annihilation techniques and Mossbauer spectroscopy in oxides have also been covered
Advanced High Energy Physics (Experiment)	04PHYS04-001-E	Advanced EHEP course is tuned to train the students with following objectives (a) experimental techniques and methodologies used specifically in EHEP (b) detailed courses on research topics being followed in experimental high energy heavy ion collision research like, collectivity, correlation, particle production mechanism, heavy flavour production
		The students after completion of course can handle EHEP data to extract physics information after various levels of corrections and error analysis. They are also trained to handle particle detectors for HEP applications
		Students have a detailed overview on particle production mechanism both in hard and soft sector
		Students, after completion of course know about production of heavy flavours (open and hidden charm)
		Students can handle Monte-Carlo models for particle production
Project	04PHYS04-001-P	Exposure to a particular experimental or theoretical work
		Literature survey and develop expertise in problem identification
		Data collection and subsequent analysis of data , presentation of data
		Develop documentation and presentation skills

Course Structure:

V. Courses at SINP

Program Code : PHYS04	Programme Specific Outcome	Aims to fill the gaps in the understanding of students through Core course and Optional courses in advanced specialised area of research to prepares the students for future research topic.

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Computational & Numerical Methods	CNM
2	Statistical Mechanics	SM2
3	Quantum Mechanics	QM2
4	Optional course 1	OPT1
5	Research Methodology	RM
6	Optional course 2	OPT3
7	Optional course 3	OPT2
8	Optional course 4	OPT4

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Computational & Numerical Methods	CNM	These numerical techniques are aimed for use in research and Ph.D. work
		Numerical and error analysis, interpolation/extrapolation, root finding etc
		C++, phython, languages and comparison
		Differential equations Fourier transform
Statistical Mechanics	SM2	SM course prepares Ph.D. students
		Landau theory, Critical phenomenon, Ising model are taught
		2d Ising model, Onsanger relations etc.

		Hydrodynamics, Navier-Stokes theorem, heat conduction are covered.
Quantum Mechanics	QM2	Time dependant perturbation, scattering theory are taught
		Relativistic quantum mechanics and covariant approach
		Path Integral techniques are introduced
Optional course 1	OPT1	Quantum Field theory-I basic course is given to research students
		Quantization of free fields scalar, vector, spinor
Research Methodology	RM	RM course through direct participation in seminars and evaluating existing research
		A first prototype Project thesis work is given
		Psychological and social factors are introduced, through directly working with a faculty and in various Laboratory facility
		Fair research methodology
Optional course 2	OPT3	Advanced Quantum Field Theory-II course is given
		QED, QCD, Cross section and decay rates
		Path integral method, running couplings, Renormalisation group are taught
Optional course 3	OPT2	Thermal Field Theory is taught to research students.
		Astroparticle physics, nutron stars
		Dark Matter physics is also taught
		Advanced plasma physics is also taught
Optional course 4	OPT4	General relativity course to Ph.D. students
		Expanding solutions, singular FRW and black hole (charged and rotating) solutions taught
		Involves introduction to quantum gravitation and string theory as well

Course Structure:

VI. Courses at IPR

Program Code : PHYS04	Programme Specific Outcome	Trained in theoretical and experimental Plasma Physics
		Trained to do research in exotic plasmas
		Trained in Fusion Science and Technology
		Trained in Plasma technologies for societal applications.

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Fundamentals of Plasma Physics – A	FPP – A
2	Fundamentals of Plasma Physics – B	FPP – B
3	Plasma Production and Measurements-I	PPM – I
4	Mathematical Methods – I	MM – I
5	Electromagnetic Theory – I	EMT – I
6	Mechanics –I (Classical Mechanics)	MEC-I
7	Laboratory Practical – I	LAP – I
8	Advance Plasma Physics – A	APP – A
9	Advance Plasma Physics – B	APP – B
10	Plasma Production & Measurement – II	PPM – II
11	Mathematical Methods – II	MM – II
12	Electromagnetic Theory – II	EMT – II
13	Mechanics –II (Fluid & Statistical Mechanics)	MEC – II
14	Numerical Methods and Advance Computing	NMAC
15	Laboratory Practical – II	LAP – II
16	Research Methodology	RM

17	Introduction to Materials Science	MS
18	Credit Seminar	CS
19	Mini Project	PROJ

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Fundamentals of Plasma Physics – A	FPP – A	**Course provide detailed information on**
		- Plasma Physics and its applications.
		- Charged Particle interaction.
		- Particle orbit theory, polarisation drift.
Fundamentals of Plasma Physics – B	FPP – B	**Course provide detailed information on**
		- Statistical description of plasma.
		- Macroscopic Transport Equations.
		- Elementary Waves in Warm Plasma.
		- Fluid Drifts.
Plasma Production and Measurements-I	PPM – I	**Course provide detailed information on**
		- Fundamentals of Vacuum Science
		- Fundamentals of Gaseous Discharge
		- Equilibrium Discharge Properties
		- Plasma Sheaths & Discharge
Mathematical Methods - I	MM – I	**Course provide detailed information on**
		- Ordinary Differential Equations (ODE)
		- Approximate Methods for solving ODE:
		- Complex Analysis
		- Difference Equations (DE)
Electromagnetic Theory- I	EMT – I	**Course provide detailed information on**
		- Fundamentals of electrostatics and its application
		- Fundamental of magneto-statics drawing analogy to electrostatics
		- Laws of electrodynamics (Maxwell's equations) and its relevance in Plasma production, measurement.
Mechanics –I (Classical Mechanics)	MEC-I	**Course provide detailed information on**
		- Lagrangian mechanics and Central force
		- Hamiltonian mechanics and Canonical transformations (CT)
		- Hamilton Jacobi Theory and Canonical perturbation
	APP – A	**Course provide detailed information on**

Advance Plasma Physics – A		- Derivation of generalized Cold plasma dielectric constant. Electrostatic Waves, Electromagnetic Waves ,CMA Diagram
		- Kinetic Description of Plasma i.e. Many body description for plasma, The Klimontovich Dupree system of equations ,Kinetic Instability – Two Stream Instability and negative energy waves
		- Concept of Landau damping
Advance Plasma Physics – B	APP – B	**Course provide detailed information on**
		- Non-Linear Effects in Plasma
		- Magneto-hydrodynamics
		- Application of MHD and tokamak physics
Plasma Production & Measurement – II	PPM – II	**Course provide detailed information on**
		- Fundamentals of different types of Plasma Sources and its discharge circuits i.e. RF Capacitive Discharge-RF Inductive Discharge-ECR and Wave based (Helicon) discharge
		- Principles of Spectroscopic and Laser Diagnostics.
		- Microwave and Interferometric diagnostic techniques i.e. Fundamentals of Microwave interferometry and its methodology.
Mathematical Methods – II	MM – II	**Course provide detailed information on**
		- Partial Differential Equations (PDE) i.e. Introduction, Classification of PDEs , First order PDEs, complete integral and general solution,
		- Integral equations i.e. Definition, homogeneous, inhomogeneous, linear, non-linear equations and Applications of integral equations.
		- Integral Transforms i.e. Fourier Transforms, Laplace Transforms and the inverse transforms, connection to physical problems
Electromagnetic Theory – II	EMT – II	**Course provide detailed information on**
		- EM wave in bounded region and Introduction to waveguides
		- Gauges and Radiation
		- Scattering of electromagnetic waves
		- Relativistic electrodynamics
Mechanics –II (Fluid & Statistical Mechanics)	MEC – II	**Course provide detailed information on**
		- Dimensional analysis and its application:
		- Types of flow with their mathematical description and Dynamics of flow

		- Kinematics of linear flow of incompressible fluid
		- Kinematics of rotational flow of incompressible fluid
		- Classical Statistical Mechanics
		- Non-Equilibrium Phenomena and Non-equilibrium dynamics
		Numerical Statistical Mechanics and Quantum statistical Mechanics
Numerical Methods and Advance Computing	NMAC	**Course provide detailed information on**
		- Numerical methods i.e. Taylor series and its application, Eigenvalue problems, Modeling of Data, Integration of Ordinary Differential equations
		- Fast Fourier transform (FFT) and its applications
		- Programming for particle motion simulation considering large number of particles.
Research Methodology	RM	**Course provide detailed information on**
		- Meaning of Research: Objectives of Research, Motivation in Research, Defining the Research Problem
		- Documentation in doing Research; proposal writing, report writing, manuscript writing
		- Data collection and Statistical analysis techniques
Introduction to Materials Science	MS	**Course provide detailed information on**
		- Atomic Bonding and Crystal structure
		- Physical Properties of materials
		- Material Development Using Plasma
		- Common Material Characterisation Techniques

(B) Experimental and Lab Courses

Laboratory Practical – I	LAP – I	**Provides practical knowhow of**
		- Experimental Electronics i.e. Application of Operational Amplifier and various networks.
		- Characteristics of DC Discharge i.e. Operation of rotary and diffusion pumps, creating vacuum from atmosphere and back, leak detection experiment, estimation of pumping speed.
		- Computer Laboratory Practical through numerical programming i.e. Root finding, Interpolation and extrapolation

		programing, Differentiation and Integration programming.
Laboratory Practical – II	LAP – II	**Provides practical knowhow of laboratory setups,**
		- Excitation of Ion Acoustic Waves in Plasma and ion acoustic speed measurement, Electric Probe diagnostics.
		- Measurements of Space potential / Electric Field in Plasma using Emissive Probe , B-dot probe measurement and Spectroscopic measurements
		- Plasma density measurement by Microwave

BACK TO MAIN

Course Structure:

VII. Courses at IOP

Program Code : PHYS04	Programme Specific Outcome	Students are given an adequate exposition to advanced subjects relevant for their Phd studies. These courses bridge the gap between formal MSc physics courses and modern fundamental as well as applied research subjects.
		Students are trained for problem solving capability, programming skills as well as application and understanding of advanced experimental techniques.
		This course also prepare the students as better teachers in the field of higher education as they need to present seminars and presentations as part of the course work.

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Advanced Quantum Mechanics	101
2	Experimental Physics - Lab course	108
3	Mathematical methods, Numerical Methods and Research methodology	201
4	Project	214

(B) Optional Courses

Sr. No.	Name of the Course	Course code
1	Quantum Field theory-I	102
2	Advanced Statistical Mechanics	103
3	Advanced classical field theory	104
4	Many body Physics	105
5	Soft Condensed matter Physics	106

6	Advanced Experimental Techniques	107
7	Advanced Condensed Matter Physics	202
8	Advanced Nuclear Physics	203
9	Quantum Field theory II	204
10	High Energy Physics	205
11	Quantum information and computation	206
12	Nonlinear dynamics and Chaos	207
13	Special topics in Condensed Matter Physics	208
14	Special topics in High Energy Physics	209
15	Special topics in Mathematical Methods	210
16	Special topics in Quantum Mechanics	211
17	Special topics in Nuclear Physics	212
18	Special topics in Statistical Physics	213

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Advanced Quantum Mechanics	101	Mastering the approximate methods for solution of quantum mechanical problems.
		Understanding the role of symmetry in the formulation and solution of physical problems.
		Understanding relativistic effects through Dirac equation.
		Learning Geometric phase and its modern applications.
		Second quantization and its application to matter-radiation interaction.
Experimental Physics - Lab course	108	Developing the experimental skills of the students and inculcating scientific temperament in them by solving practical problems.
		Introducing students to various advanced research facilities of the institute like surface science, transport, X-ray, workshop, etc. and

		showing them how to perform experiments using them for their research work.
		Students are allowed to independently perform experiments at various facilities with the aim to build their background for future research work in this area.
Mathematical methods, Numerical Methods and Research methodology	201	Either MM or NM is chosen, depending on the interest of the instructor and students. In MM, Review of complex variable theory and ordinary differential equations through problem solving.
		Learning partial differential equations, group throry, statistics and probability theory, and basic concepts of topology and its applications.
		In NM course, students get to learn basics of various numerical methods and tools. Study applications of various numerical techniques in solving complex physical process, such as boundary value and eigenvalue problems, scattering, Monte-Carlo simulation. Understanding data analysis techniques, curve fitting and testing goodness of fit.
		Learning advanced programming languages, such as C++, python etc. and writing programmes to solve numerical problems. Learning various available software packages and libraries, such as Mathematica, for doing numerical calculations.
		In RM, students develop skills for wrting research articles, good communication and presentation of results in seminars, and reviewing research papers.
Project	214	The students choose a particular topic of his/her choice and work out in details under the guidance of a faculty.
		Learning how to survey literature and approach a problem.
		Acquire capability to understand and explain the problem to the scientific community in written as well as in verbal communication.
		Finding the relevant extension of the problem towards his/her Ph D.

(B) Optional Courses

Name of the Course	Course code	Course Outcome
Quantum Field theory-I	102	Understand concepts of fields and its quantization such as free scalar field, Dirac field, electromagnetic field. Definition of propagators, Wicks theorem, normal ordering.
		Modelling the interactions between scalar fields. Perturbation theory and calculation of basic Feynman diagram.
		Knowledge about symmetries and conservation laws
		Introduction to the path-integral quantization of scalar field theory and S-matrix formalism, symmetries and ward identity.
		Understanding concept of renormalization group. Wilsonian-RG and concept of effective low energy field theory description.
Advanced Statistical Mechanics	103	Understanding of basic ensemble theory: microcanonical, canonical and grand canonical ensembles; examples: classical ideal gas, Harmonic oscillator, statistical theory of Para magnetism etc.
		Formulation of quantum statistical mechanics: concept of density matrix, Bose-Einstein and Fermi-Dirac distribution, ideal Bose gas: understanding of Bose-Einstein condensation, Phonos, Deby theory, Black-body radiation etc., free Fermi gas: understanding of electronic specific heat, Pauli Para magnetism and Landau diamagnetism etc.
		Understanding of classical interacting systems: Ising model, exact solution and mean-field solution, Landau-Ginzburg theory, Ising universality class and basics of phase transition.
		Understanding of basics of dynamics: classical Fluctuation-Dissipation theorem, Langevin and Fokker-Planck equation etc.
Advanced classical field theory	104	Thorough understanding of electrostatistics and magnetostatics, Maxwell's laws and origin of electromagnetic waves.

		Understanding origin of electromagnetic radiation by moving charges. Interactions of radiation with matter.
		Understanding covariant formulation of electrodynamics and its application.
		Understanding basic formalism of general relativity in terms of principles of equivalence and covariance. Application to black holes, cosmology etc.
		Basic understanding of advanced topics such as hydrodynamics, Landau-Ginzberg theory and Continuum Mechanics
Many body Physics	105	Understanding of second quantization, occupation number representation, tight binding and Hubbard model as examples.
		Concept of zero temperature single particle and two particle Green's function (Bosons and Fermions), spectral function, Understanding of finite temperature Green's function; Matsubara formalism.
		Understanding of interaction picture, Dyson series, S-matrix, constructing Feynman diagrams and Feynman rules at zero and finite temperatures, concept of self-energy.
		Understanding of linear response theory, quantum version of fluctuation-dissipation theorem, computation of correlation functions: spin-spin (magnetic susceptibility) for free Fermi gas and current-current (conductivity via Kubo formula).
		Development of Feynman diagrams for random disordered potential, concept of disorder averaging, understanding of microscopic basis of Drude conductivity.
		Understanding of electron-phonon interaction, Fröhlich Hamiltonian, development of Feynman diagrams and concept of phonon self-energy.
		Understanding of microscopic origin of attractive electron-electron interaction from electron-phonon interaction: Schrieffer-Wolf transformation, Cooper problem, understanding of microscopic BCS theory of superconductivity (pairing mean-field solution), Nambu formalism and Nambu Green's function of superconductivity.

Soft Condensed matter Physics	106	Quick review of thermodynamic principles and probability theory
		Kinetic theory, Liouville's theorem, BBGKY hierarchy, Boltzmann transport equation, H-theorem, conservation laws, hydrodynamics
		Ensembles, connection to thermodynamics, quantum statistical mechanics
		Interacting particles, cumulant expansion, cluster expansion, van der Waals equation, mean field theory of condensation, critical point
		Landau-Ginzburg theory, Goldstone modes, Mermin-Wagner theorem, Ginzburg criterion
		Master equation, Langevin equation, Fokker-Planck equation, Fluctuation-dissipation relation, Onsager reciprocity
Advanced Experimental Techniques	107	Learning about materials science from bulk to nano and to thin films. Various experimental techniques are to understand the structure-property relation at the local (atomic) and global scale.
		Introduction to Crystallography. Experience on X-ray scattering and diffraction and X-ray reflection of various hybrid systems of interest.
		Introduction to Optical spectroscopy, Raman spectroscopy, Photoluminescence spectroscopy, Infrared spectroscopy
		Photo emission spectroscopy (PES) to study the electronic structure, angle integrated and angle resolved photoemission spectroscopy, electron spectroscopy for chemical analysis (ESCA)
		Learning Synchrotron radiation, application of X-ray absorption spectroscopy (XAS), X-ray (magnetic) circular and linear dichroism in absorption (XMCD,XMLD)
		Introduction to particle accelerator, Ion Implantation, Rutherford back scattering (RBS), particle induced x-ray emission (PIXE)
		Learning Resonance and its application, nuclear magnetic resonance (NMR), electron spin resonance (ESR), ferromagnetic Resonance (FMR),

		Mossbauer spectroscopy, muon spin spectroscopy (μSR)
		Introduction to Surface Science and fundamental aspects of thin film growth, and its characterization by scanning tunnelling/electron microscopy (STM/SEM), Atomic force microscopy (AFM), Low energy electron diffraction (LEED), Reflection high energy electron diffraction (RHEED), transmission electron microscopy (TEM).
		Understanding electronic/magnetic properties via transport (magneto) and magnetic measurements: Four probe resistivity (R_{xx} and R_{xy}), SQUID-VSM, electronic motion in a magnetic field and Fermi surface measurement, scanning tunneling spectroscopy (STS)
Advanced Condensed Matter Physics	202	Modelling and understanding effect of coulomb interactions among electrons in condensed matter system.
		Understanding effect of disordered potential on electron gas.
		Understanding the phenomena of superconductivity and conceive a microscopic model for it.
		Understanding the origin of magnetism and modelling various magnetic system and different type of magnetic interactions.
		Understanding effect of confinement due to potential and field in reduced dimensional system such as Quantum dots, Luttinger liquid, Quantum Hall effect.
Advanced Nuclear Physics	203	Modelling of Atomic Nuclei. It will give the structure and other properties of finite nuclei and that of Neutron stars.
		It will give knowledge for the search of various fissionable nuclei, which are very much important for the energy production.
		It will highlight the origin of the Universe and the formation of various particles.
		It will provide a bridge between the Nuclear Physics and the Astrophysics. The Nuclear Physics inputs will be given a better understanding on the Astrophysics.
		It will give insight in the nature of all four fundamental forces and their influences on Astrophysical Objects.

Quantum Field theory II	204	Learning how to do one-loop calculations
		Quantization of gauge theories
		Renormalization of gauge theories, beta function and RG
		Role and importance of anomalies
		Basics of solitons and instantons
High Energy Physics	205	Understanding the importance global and local symmetries and the language of Lie groups
		Construction of gauge theories
		Importance of spontaneous symmetry breaking
		Basics of QED and QCD and elementary processes
		Construction of the standard model and some of its consequences
Quantum information and computation	206	Understanding basic formalism of Quantum Mechanics
		Learning measures of entanglement, its detection and manipulation
		Understanding quantum operations, quantum gates, nonlocality, and quantum communication protocols
		Understanding quantum cryptography
		Understanding basic quantum algorithms
Nonlinear dynamics and Chaos	207	Introduction to the concept of fixed points, bifurcation, limit cycles for one and two dimensional non-linear system.
		Modelling interacting systems such as Predator-Prey model/Lotka-Volterra system.
		Understanding various non-linear systems such as Enzyme Kinetics, Neuron dynamics, Travelling waves etc
		Understanding the meaning of Chaos and its characterization.
		Introduction to turbulence and Kolmogorov scaling.
Special topics in Condensed Matter Physics	208	Understanding emerging topics in condensed matter system such as Topological insulator, unconventional superconductivity, many body localization, frustrated magnetism etc.
		Acquiring basic analytical and conceptual understanding of the above fields.
Special topics in High Energy Physics	209	Will depend on choice of topics.
		Topics will be at the forefront of research.
	210	Will depend on choice of topics.

Special topics in Mathematical Methods		Topics will be at the forefront of research.
Special topics in Quantum Mechanics	211	Will depend on choice of topics.
		Topics will be at the forefront of research.
Special topics in Nuclear Physics	212	Will depend on choice of topics.
		Topics will be at the forefront of research.
Special topics in Statistical Physics	213	Learning continuous phase transition, universality and scaling
		Exactly solvable models, computations of various critical exponents
		Mean field theory
		Perturbative renormalization: in position and momentum space
		Quantum Phase Transition
		Physics at the critical point: introduction to conformal field theory.

Course Structure:

VIII. Courses at HRI

Program Code : PHYS04	Programme Specific Outcome	Understanding and knowledge of physics in the classical and quantum domain.
		Understanding of mathematical methods in their applications in diverse settings.
		Understanding and application of statistical methods in physics
		Provide exposure to various specialised areas such as condensed matter, atomic physics, particle physics, astrophysics, and quantum information.
		Learning many body techniques as well as quantum field theoretic methods and applying them to solve problems.

SEMISTER – I

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Quantum Field Theory I	08PHYS04-001-C
2	Mathematical Methods II	08PHYS04-002-C
3	Project	08PHYS04-003-C

(B) Electives (choose any one)

Sr. No.	Name of the Course	Course code
1	Fluid Mechanics	08PHYS04-001-E
2	General Theory of Relativity	08PHYS04-002-E
3	Nonlinear Dynamics	08PHYS04-003-E
4	Quantum Information and Computation I	08PHYS04-004-E
5	Quantum Mechanics III	08PHYS04-005-E

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Quantum Field Theory I	08PHYS04-001-C	Acquiring knowledge of the method of second quantization for the study of many particle non-relativistic systems.
		Acquiring knowledge of the Lorentz group and its role in relativistic quantum field theory.
		Acquiring knowledge of the quantization of the Klein Gordon, Dirac and Maxwell fields.
		Acquiring knowledge of the basics of quantum electrodynamics and the study of various processes at tree level.
		Understanding of the role of gauge invariance in quantum electrodynamics.
Mathematical Methods II	08PHYS04-002-C	Ability to analyse phenomena using Fourier and Laplace transformation
		Ability to construct and solve higher order differential equation
		Understanding to apply Laplace and Poisson equation to electrostatics, Heat equation, Wave equation
		Understanding Group theory concepts and its application in Lie algebras
Project	08PHYS04-003-C	Ability to formulate a research problem
		Developing scientific skills to solve the problem
		Acquiring knowledge to interpret, discuss and communicate scientific results in written and oral form

(B) Electives

Name of the Course	Course code	Course Outcome
Fluid Mechanics	08PHYS04-001-E	Acquiring knowledge of the basic concepts in the study of ideal fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity.
		Study of viscous fluids.
		Acquiring knowledge of the basic topics in the theory of turbulence.

		Understanding of Thermal Conduction in fluids.
		Acquiring basic knowledge of Relativistic Fluid dynamics.
General Theory of Relativity	08PHYS04-002-E	Acquiring basic knowledge of differential geometry.
		Understanding of the equivalence principle and its applications.
		Acquiring knowledge of Einstein equation
		Acquiring knowledge of Schwarzschild solution along with applications.
		Acquiring knowledge of the theory of gravitational waves.
		Acquiring knowledge of the basics of Friedman-Robertson-Walker cosmology.
Nonlinear Dynamics	08PHYS04-003-E	Acquiring knowledge of long time behavior of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.
		Acquiring knowledge of the nature of orbits for conservative and non-conservative systems.
		Understanding of different kinds of perturbation theory for calculating orbits.
		Understanding of maps, fixed points, cycles and stability, bifurcations.
		Basic understanding of chaos.
Quantum Information and Computation I	08PHYS04-004-E	Learning the concept of decoherence.
		Understanding the Markovian vs non-Markovian processes and their master equations.
		Acquiring the knowledge of the entanglement theory, and quantum correlations.
		Learning about the resource theory.
		Developing the understanding of quantum thermodynamics.
		Relating the quantum information systems with the condensed matter systems.
Quantum Mechanics III	08PHYS04-005-E	Acquiring knowledge of the basics of atomic spectra in single electron atoms.

		Acquiring knowledge of atomic spectra in many electron atoms and molecules.
		Acquiring knowledge of the interaction of light and matter.
		Understanding of the basic theory involved in the study of cold atoms.
		Acquiring knowledge of the basics of atomic spectra in single electron atoms.
		Acquiring knowledge of atomic spectra in many electron atoms and molecules.

SEMISTER – II

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Statistical Mechanics	08PHYS04-004-C
2	Research Methodology and Numerical Methods	08PHYS04-005-C

(B) Electives (choose any two)

Sr. No.	Name of the Course	Course code
1	**Astrophysics**	08PHYS04-006-E
2	Condensed Matter Physics II	08PHYS04-007-E
3	Cosmology	08PHYS04-008-E
4	Introduction to Electronic Structure Calculations	08PHYS04-009-E
5	Particle Physics	08PHYS04-010-E
6	Quantum Field Theory II	08PHYS04-011-E
7	Quantum Information and Computation II	08PHYS04-012-E
8	Quantum Optics	08PHYS04-013-E
9	Soft Matter	08PHYS04-014-E
10	Ultra cold Atoms	08PHYS04-015-E

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Statistical Mechanics	08PHYS04-004-C	Acquiring knowledge of basics concepts such as phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.
		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Research Methodology and Numerical Methods	08PHYS04-005-C	Acquiring knowledge of research Methodology including quantitative methods, communication skills, seminar presentation and review of research papers.
		Introduction to programming languages: F77, F90 or C.
		Acquiring knowledge of numerical linear algebra, interpolation techniques, generation and use of random numbers.
		Acquiring knowledge of numerical differentiation and integration (including Monte Carlo techniques).
		Acquiring knowledge of numerical methods to treat ODEs and PDEs: including FFT and finite difference methods, integral equations.

(B) Electives

Name of the Course	Course code	Course Outcome
Astrophysics	08PHYS04-006-E	Learning about magnetohydrodynamics with applications to Astrophysical systems.

		Study of stellar structure and developing detailed understanding of structure of stars.
		Developing understanding of the models of galaxies.
		Acquiring knowledge of the accretion of matter due to a point mass.
		Developing introductory understanding of cosmology.
Condensed Matter Physics II	08PHYS04-007-E	Learning the skill to study low dimensional systems.
		Understanding theories which describe charge transport in mesoscopic systems.
		Acquiring knowledge of the electronic structure in low dimensional systems.
		Learning about the effects of phonons in metals and dielectric properties of insulators.
		Learning formalism necessary to study Quantum Hall systems, quantum wires and dots.
		Acquiring knowledge of correlated electron systems.
		Learning about the Mott transition, the Kondo systems, Superconductivity and magnetism.
Cosmology	08PHYS04-008-E	Learning about the cosmological model, the cosmological constant and the dark matter.
		Developing the understanding of the thermal history of the universe and its imprints on CMB.
		Understanding the horizon problem and its resolution by inflation.
		Acquiring the knowledge of the theory of cosmological perturbations.
		Studying the implications of the cosmological perturbation on the structure formation.
Introduction to Electronic Structure Calculations	08PHYS04-009-E	Acquiring the knowledge of the first principle computation, methods like the H-F approximation.
		Learning the Density Functional theory, and various approximations within the formulation.
		Learning the pseudo potential method and its applications.
		Application of these methods to study the band structure of various materials.

Particle Physics	08PHYS04-010-E	Understanding physics of elementary particles.
		Learning about fundamental interactions in terms of gauge principle.
		Acquiring skills to carry out computation in Strong, Weak and Electromagnetic theory.
		Learning various techniques useful for particle physics phenomenology.
		Learning methods to compute physical observables which can tested in the laboratory
Quantum Field Theory II	08PHYS04-011-E	Understanding the Path Integral formulation of quantum field theory.
		Acquiring the knowledge of the regularisation methods and the renormalisation.
		Developing the understanding of spontaneous symmetry breaking and its implications.
		Learning the non-abelian gauge theories and their quantisation.
		Learning the renormalisation of the non-abelian gauge theories both in the symmetric and symmetry broken phase.
Quantum Information and Computation II	08PHYS04-012-E	Learning the concept of decoherence.
		Understanding the Markovian vs non-Markovian processes and their master equations.
		Acquiring the knowledge of the entanglement theory, and quantum correlations.
		Learning about the resource theory.
		Developing the understanding of quantum thermodynamics.
		Relating the quantum information systems with the condensed matter systems.
Quantum Optics	08PHYS04-013-E	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.
		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.

Soft Matter	08PHYS04-014-E	Learning about what scales are involved in soft matter.
		Studying the phase transition using various techniques.
		Understanding the colloidal systems.
		Developing the intuition about polymers and membranes.
		Learning about the experimental methods.
Ultra cold Atoms	08PHYS04-015-E	Learning about the scales involved in the system.
		Understanding the experimental background, like trapping, optical lattices, Feshbach resonance, etc.
		Using many body methods to study phase transition, perturbation theory.
		Learning about the Bose condensation and its theoretical aspects.
		Developing the understanding of the BCS instability in sermonic system.
		Studying the quantum spin systems.

Course Structure:

IX. Courses at IMSc

Program Code : PHYS04	Programme Specific Outcome	Integrated Ph.D. students in Physics at IMSc need to do 1st two semesters of course work in standard Master Degree level courses in Classical Mechanics, Quantum Mechanics I & II, Classical Electromagnetism, Mathematical Methods, Statistical Mechanics, Classical Field Theory, and Condensed Matter Physics I.
		The 3rd and 4th semester courses for Integrated Ph.D. students in IMSc are respectively same as the 1st and 2nd semester courses for the Ph.D. students in Physics at IMSc.
		In their 3rd semester, the students are being taught advanced level courses (aiming to take up research problems) in Statistical Mechanics, Mathematical Methods, as well as introductory courses on Particle Physics and Quantum Field Theory (which includes a part on Many-Body Field Theory, used for advanced courses in Condensed Matter Physics).
		In their 4th semester, the students need to credit two research-level courses either in High Energy Physics (Quantum Field Theory II, Cosmology and Gravitation, Particle Physics II) or in Low Energy Physics (Advanced Condensed Matter Physics, Non-linear Dynamics, Quantum Information and Computation, Statistical Field Theory) as well as a research project, which is, generally taken up by the student towards pursuing his/her Ph.D. research work here at IMSc.
		The students do have the freedom to shift their choice of topics for Ph.D. even if they do their 4th

		semester courses entirely in High Energy Physics or Low Energy Physics – provided the students are confident enough and they can find suitable Ph.D. guides at IMSc in that directions.

(A) Semester III:

Sr. No.	Name of the Course	Course code
1	Quantum Field Theory I	31
2	Mathematical Methods II	32
3	Statistical Mechanics II	33
4	Particle Physics I	34

(B) Semester IV:

1. High Energy Physics (HEP):

Sr. No.	Name of the Course	Course code
1	Quantum Field Theory II	41
2	Cosmology-and-Gravitation Or Particle Physics	42a 42b

2. Low Energy Physics (LEP):

Sr. No.	Name of the Course	Course code
1	Advanced Condensed Matter Physics	43
2	Nonlinear Dynamics Or Quantum Information-and-Computation Or Statistical Field Theory	44a 44b 44c

Course Outcomes:

(A) Semester III:

Name of the Course	Course code	Course Outcome
Quantum Field Theory I	31	Students should develop a mastery over elementary processes in Quantum Electrodynamics (QED): electron-positron annihilation, Compton scattering, Bhabha scattering, etc.
		Students should learn and internalize different radiative corrections for scalar field theory. They also learn techniques of scalar field quantization, as well as the techniques of dealing with non-interacting electrons from field theoretic perspectives.
		In the remaining one-third of the QFT-I course, LSZ formalism, Path integral formalism, and renormalization techniques are being taught for HEP-oriented students in order that they can use these techniques for their research in HEP.
		Similarly, in the other remaining one-third of the QFT-I course, operator techniques of second quantization, Kubo formula, system of interacting bosons, techniques mean- field theory, etc. Are being taught for LEP- oriented students in order that they can use these techniques for their research in LEP.
Mathematical Methods II	32	Students are supposed to learn and thereby apply different numerical techniques : interpolation methods, numerical solutions of ordinary and partial differential equations, Monte-Carlo method, numerical optimization, numerical techniques of dealing with fast Fourier transforms, etc.
		Students should develop a thorough working knowledge (together with the corresponding theoretical development) in the representation theories of discrete as well as continuous groups used in Classical and Quantum Mechanics.
		Students should develop working knowledge (as well as theoretical understanding) in

		topics of advanced Complex Analysis: analytic continuation, branch cuts, Riemann surfaces, conformal mapping, etc.
		Students should develop working knowledge in rudiments of Probability Theory.
		Students should develop a working knowledge about critical phenomena: scaling hypothesis, self-similarity, and fractals. Moreover, they should develop a thorough knowledge regarding criticality in spin systems, classical field theory, etc.
Statistical Mechanics II	33	Students should understand, internalize, and thereby, apply techniques of renormalization group – including both perturbative as well as non-perturbative cases.
		Students should develop a very good understanding about broken symmetry, how deal with disorders in systems, and dynamics of fluctuations (including the fluctuation-dissipation theorem).
		Students should develop a thorow knowledge on standard model in Particle Physics, including symmetries & quarks, Parton model & QCD, etc.
Particle Physics I	34	Moreover, students should develop concrete ideas about different decay processes, V-A theory of weak interactions, CP violation, etc.
		They should have a very good working knowledge in the unification of electromagnetic and weak interactions.
		Working knowledge about neutrinos.

(B) Semester IV:

1. **Electives- HEP**

Name of the Course	Course code	Course Outcome
Quantum Field Theory II	10PHYS04-041-E	This advanced-level course in Quantum Field Theory (QFT) aims at training the students to the extent where they can initiate some research project in High Energy Physics.
		In this course, students are supposed to develope working expertise in topics like: functional methods in QFT, funtional integral quantization of non-Abelian gauge fields, applications of renormalization group, anomalies in abelian as well as non-abelian gauge theories, etc.
Cosmology and Gravitation	10PHYS04-042a-E	This advanced-level course in Cosmology & Gravitation aims at training the students to the extent where they can initiate some research project in Astrophysics, Cosmology, etc.
		In this course, students are supposed to develope working expertise in topics like: Einstein's field equations and their different solutions, Hamiltonian formulation of Gravity, Cosmology, singularity theorems, etc.
Particle Physics-II	10PHYS04-042b-E	This advanced-level course in Particle Physics aims at training the students to the extent where they can initiate some research project in Particle Physics.
		In this course, students are supposed to develope working expertise in topics like: basics of the Standard Model, Electroweak interaction, Quantum Chromodynamics, Neutrino Physics, CP violation, Supersymmetry, Grand unified theory, etc.

2. **Electives- LEP**

Advanced Condensed Matter Physics	10PHYS04-043-E	This advanced-level course in Condensed Matter Physics aims at training the students to the extent where they can initiate some research project in Hard/Soft Condensed Matter Physics.
		In this course, students are supposed to develope working expertise in: Correlated Electron Physics and Soft Condensed Matter Physics.

Nonlinear Dynamics	10PHYS04-044a-E	This advanced-level course in Nonlinear Dynamics (NLD) aims at training the students to the extent where they can initiate some research project in different branches of Physics where Nonlinear Dynamics plays a vital role – apart from Nonlinear Dynamics itself.
		In this course, students are supposed to develope working expertise in: Hamiltonian formulation of NLD, Deterministic NLD, Integrability of Hamiltonian Dynamics, Chaos, Semiclassical Analysis of NLD, Quantum Aspects of NLD, etc.
Quantum Information-and-Computation	10PHYS04-044b-E	This advanced-level course aims at training the students to the extent where they can initiate some research project in different branches of Physics where Information Theory plays a vital role – apart from Quantum Information & Computation itself.
		In this course, students are supposed to develope working expertise in: Entanglement Theory and its applications, Shannon's Theory of Classical Information & its Quantum generalizations, Quantum Cryptography, Quantum Computation, physical implementaions, etc.
Statistical Field Theory	10PHYS04-044c-E	This advanced-level course aims at training the students to the extent where they can initiate some research project in Statistical Mechanics or its applications in fields like Condensed Matter Physics, Particle Physics, etc.
		In this course, students are supposed to develope working expertise in: Bose-Einstein condensation, Fermions, diagrammatic techniques, self-coupled scaler field theory, Yukawa theory, spontaneous symmetry breaking & Higgs model of Quantum Chromodynamics, deconfinement phase transition, Salam-Weinberg model and symmetry restoration, early universe, nuclear matter & pion condensation, neutron stras, etc.

Course Structure:

X. Courses at NISER

Program Code : PHYS04	Programme Specific Outcome	Understanding and knowledge of physics in the classical and quantum domain.
		Understanding of mathematical methods in their applications in diverse settings.
		Understanding and application of statistical methods in physics
		Provide exposure to various specialised areas such as condensed matter, atomic physics, particle physics, astrophysics, and quantum information.
		Learning many body techniques as well as quantum field theoretic methods and applying them to solve problems.
		Introduction to methods that will be lifelong assets for careers in research and development.

(A) Core Courses:

Sr. No.	Name of the Course	Course code
1	Classical Mechanics	P601
2	Mathematical Methods	P602
3	Electromagnetism	P603
4	Self-Study/Mini project/credit seminar	P698
5	Statistical Mechanics	P614
6	Quantum Mechanics	P615
7	Mini Project	P699

(B) Elective Courses:

Sr. No.	Name of the Course	Course code
1	Nuclei and Particle Physics	P648
2	Atoms Molecules and Radiation	P649
3	Introduction to Condensed Matter Physics	P650
4	Advanced Solid State Physics	P651
5	Computational Physics	P652
6	Quantum Field Theory I	P653
7	Particle Physics	P654
8	Introduction to Phase transitions and Critical phenomena	P655
9	Nonlinear Optics and Lasers	P656

10	General Relativity and Cosmology	P657
11	Soft Condensed Matter	P658
12	Applied Nuclear Physics	P659
13	Many Particle Physics	P660
14	Physics of Mesoscopic Systems	P661
15	Introduction to Quantum Optics	P662
16	Astronomy and Astrophysics	P663
17	Plasma Physics and Magnetohydrodynamics	P664
18	Biophysics	P665
19	Quantum Nanoelectronics	P666
20	Nonlinear Physics, Chaos and Turbulence	P667
21	Magnetism and Superconductivity	P668
22	Density Functional Theory of Atoms, Molecules and Solids	P669
23	Quantum Field Theory II	P670
24	Quantum Information and Quantum computation	P671
25	Experimental High Energy Physics	P672
26	Experimental Techniques	P673
27	Introduction to Cosmology	P674

Course Outcomes:

(A) Core Courses

Name of the Course	Course code	Course Outcome
Classical Mechanics	P601	This course reviews the concepts of Masters level classical mechanics with more emphasis on the applied/problem solving aspects.
		This course is meant to prepare the students for more rigorous analytical treatment of the subject required for research.
Mathematical Methods	P602	This course reviews the important mathematical tools required for physicists for implementation in research work in all specialization of physical sciences.
Electromagnetism	P603	This course reviews masters level electricity and magnetism with more emphasis on problem solving and applications.
		This course is meant to prepare students for taking up realistic research challenges involving one of the most important class of interactions in Physics.

Self-Study/Mini project/credit seminar	P698	To meet the research requirement of the individual student.(Course content varies according to instructor's choice.)
Statistical Mechanics	P614	This course reviews masters level statistical mechanics and thermodynamics and prepares students for analyzing research problems/results in a wide variety of situations involving statistical mechanics.
Quantum Mechanics	P615	This course reviews masters level quantum mechanics and prepares students for analyzing research problems/results in a wide variety of situations involving quantum mechanics.
Mini Project	P699	To meet the research requirement of the individual student.(Course content varies according to instructor's choice.)

(B) Elective Courses:

Name of the Course	Course code	Course Outcome
Nuclei and Particle Physics	P648	Provides training in basic concepts and methods in nuclear physics, stability of nucleons and classification of interactions.
		The course prepares the student to begin working in experimental and theoretical high energy physics.
Atoms Molecules and Radiation	P649	Important topics in atomic physics, selection rules, atomic and molecular spectroscopy is taught.
		The training is imperative to work in the area of applied solid state physics and optics.
Introduction to Condensed Matter Physics	P650	This is the first course in condensed matter physics and draws on quantum and statistical mechanics to provide a foundation in basic concepts and techniques required to tackle advanced courses in the area of solid state physics.
Advanced Solid State Physics	P651	This is a course which aims to prepare students with advanced concepts, techniques and knowledge of solid state physics that allows them to start working on basic research problems in the broad area of condensed matter theory, materials theory or solid state experiments.
Computational Physics	P652	This course provides training in computation tools required in research across a wide variety of fields including condensed matter, high energy phenomenology and lattice field theories.

Quantum Field Theory I	P653	This first course on quantum field theory prepares the student for tackling future advanced courses in the area of high energy physics.
Particle Physics	P654	This course teaches the basics of particle physics and allows the student to start beginning research work in high energy phenomenology.
Introduction to Phase transitions and Critical phenomena	P655	This course teaches the students advanced concepts and methods in statistical mechanics crucial for the student to take up basic research work.
Nonlinear Optics and Lasers	P656	This course teaches the students advanced concepts and methods in modern topics in laser optics and non-linear optics necessary for the student to take up basic research work in optics.
General Relativity and Cosmology	P657	This course teaches the students, advanced concepts and methods in general relativity crucial for the student for building their background for research work in general relativity and cosmology.
Soft Condensed Matter	P658	This course teaches the students advanced concepts and methods in soft matter physics, with the aim to build their background for future research work in this area.
Applied Nuclear Physics	P659	This course teaches the students advanced concepts and methods in applied nuclear physics, with the aim to build their background for future research work in this area.
Many Particle Physics	P660	This course teaches the students advanced concepts and methods in many particle physics, with the aim to build their background for future research work in this area.
Physics of Mesoscopic Systems	P661	This course teaches the students advanced concepts and methods in mesoscopic physics, with the aim to build their background for future research work in this area.
Introduction to Quantum Optics	P662	This course teaches the students important concepts and methods in quantum optics, with the aim to build their background for future research work in this area.
Astronomy and Astrophysics	P663	This course teaches the students important concepts and methods in Astronomy and Astrophysics, with the aim to build their background for future research work in this area.

Biophysics	P665	This course teaches the students important concepts and methods in Biophysics, with the aim to build their background for future research work in this area.
Quantum Nanoelectronics	P666	This course teaches the students important concepts and methods in nanoelectronics, with the aim to build their background for future research work in this area.
Nonlinear Physics, Chaos and Turbulence	P667	This course teaches the students important concepts and methods in classical nonlinear dynamics, with the aim to build their background for future research work in this area.
Magnetism and Superconductivity	P668	This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.
Density Functional Theory of Atoms, Molecules and Solids	P669	This course teaches the students important concepts and methods in density functional theory, with the aim to build their background for future research work in this area.
Quantum Field Theory II	P670	This course teaches the students important concepts and methods in advanced quantum field theory, with the aim to build their background for future research work in this area.
Quantum Information and Quantum computation	P671	This course teaches the students important concepts and methods in quantum information and computation, with the aim to build their background for future research work in this area.
Experimental High Energy Physics	P672	This course teaches the students important concepts and methods in experimental high energy physics, with the aim to build their background for future research work in this area.
Experimental Techniques	P673	This course teaches the students important concepts and methods in experimental techniques, with the aim to build their background for future research work in this area.
Introduction to Cosmology	P674	This course teaches the students important concepts and methods in introductory cosmology, with the aim to build their background for future research work in this area.

BACK TO MAIN

Ph.D. in MEDICAL & HEALTH SCIENCES (Program Code: HLTH04)

Course Structure:

1. Courses at TMC:

Program Code: HLTH04	**Program Specific Outcomes**	To train candidates in regards to all aspects in relation to conducting scientific research.
		To make students understand basics of cancer biology.
		To understand various aspects of research methodologies; use of ethical practices in conduct of research; application of statistics in research; & how to critically read and analyze scientific literature.
		To introduce aspects of clinical and translational research in relation to oncology during the program.
		To develop analytical thinking in students and help in developing ability to raise appropriate / relevant questions for doing research.

(A) CORE COURSES:

Sr. No.	CORE COURSES	COURSE CODE
1	Cell Biology & Cancer Biology	09HLTH04-001-C
2	Cell Proliferation and Cell death	09HLTH04-002-C
3	Oncogenes and Tumor Suppressors	09HLTH04-003-C
4	Metastasis and Angiogenesis	09HLTH04-004-C
5	Cancer Epigenetics and Genetics	09HLTH04-005-C
6	Carcinogenesis	09HLTH04-006-C

7	Tumor Immunology	09HLTH04-007-C
8	Structural Biology and Biophysics	09HLTH04-008-C
9	Research Methodology	09HLTH04-009-C

(B) ELECTIVE COURSES:

Sr. No.	ELECTIVE COURSES	COURSE CODE
1	Biostatistics	09HLTH04-001-E
2	Animal Models in Cancer Research	09HLTH04-002-E
3	Cancer Therapeutics	09HLTH04-003-E
4	Carcinogenesis, Chemoprevention and DNA Repair	09HLTH04-004-E
5	Deregulation of Cell Growth in Cancer	09HLTH04-005-E
6	Structural Bioinformatics, Biophysics & Structural Biology	09HLTH04-006-E
7	Tumor Immunology	09HLTH04-007-E
8	Metastasis	09HLTH04-008-E
9	Bioinformatics	09HLTH04-009-E
10	Epidemiology & Preventive Oncology	09HLTH04-010-E
11	Medical Physics	09HLTH04-011-E
12	Nutrition	09HLTH04-012-E

(C) SPECIAL LECTURES:

Sr. No.	SPECIAL LECTURES	COURSE CODE
1	Epidemiology & Bioinformatics	09-HLTH04-001-S
2	Intellectual Property Rights	09-HLTH04-002-S

Course Outcomes:

(A) CORE COURSES:

CORE COURSES	COURSE CODE	COURSE OUTCOMES
Cell Biology & Cancer Biology	09HLTH04-001-C	Over-view on what is cancer and its causes, differences between normal and cancer cells, detailed understanding of cell organelles, intracellular protein transport.
		Understanding of normal stem cells and cancer stem cells, biomarkers to identify cancer stem cells.
		Reprogramming and pluri-potency. Demonstrations and lectures on advanced microscopy and in vivo - cell imaging using luminescence and micro PET-CT
Cell Proliferation & Cell death	09HLTH04-002-C	A detailed analysis of the pathways underlying cell cycle progression and cell death. Study on animal models for understanding phenotype of cyclin and cyclin dependent kinases.
		Understanding the mechanisms of cell death and methods to detect apoptosis.
		Understanding differences between apoptosis, necrosis and autophagy. How cancer metabolism is distinct from normal cells and how this can be exploited therapeutically.
Oncogenes & Tumor Suppressors	09HLTH04-003-C	Understanding the mechanism of action of oncogenes and tumor suppressor genes and their function.
		Understand the difference between mouse and human telomeres and how this

		affects tumor progression in both species.
Metastasis & Angiogenesis	09HLTH04-004-C	Mechanisms underlying cell adhesion and migration and how these are altered in tumors.
		Mechanisms underlying metastatic progression. Understanding how a tumor deals with nutrient and oxygen deprivation.
		Understanding how hypoxia contributes to angiogenesis and vasculogenesis. Various models to study angiogenesis.
Cancer Epigenetics & Genetics	09HLTH04-005-C	Epigenetic mechanisms that affect tumor growth.
		Cancer as an inherited genetic disease. Understanding chromatin structure, histone-variants and their modifications in cancer.
		Understanding DNA methylation and gene-regulation.
		Detailed methodology to study chromatin-biology.
		Advanced knowledge on application of proteomics, Next Generation Sequencing and Genomics
Carcinogenesis	09HLTH04-006-C	Understanding Mechanisms of carcinogenesis. DNA repair and its role in inhibiting tumor progression.
		Understanding carcinogen metabolism and activation of cellular oncogenes and their contribution to carcinogenesis.
		Understanding role of tumor viruses and micro-organisms contributing to carcinogenesis.

Tumor Immunology	09HLTH04-007-C	Basics of tumor immunology. Differences between adaptive and innate immunity.
		Cell types contributing to tumor immunity and their role in cancer immuno therapy. Applications of monoclonal antibodies, vaccines in cancer diagnosis and therapy.
		Advanced technologies to study immune biomarkers on cells, immuno deficient mouse models to study tumor development and immune responses.
Structural Biology & Biophysics	09HLTH04-008-C	Basics of spectroscopy. Principles of protein-protein interactions and protein folding.
		Understanding mechanism of action of enzymes and assays to study their function.
Research Methodology	09HLTH04-009-C	Develop understanding on various kinds of research, objectives of doing research, research process, research designs and sampling.
		Have basic knowledge on qualitative research techniques
		Have adequate knowledge on measurement & scaling techniques as well as the quantitative data analysis
		Have basic awareness of data analysis-and hypothesis testing procedures
		To develop an understanding of the ethical dimensions of conducting applied research.

(B) ELECTIVE COURSES:

ELECTIVE COURSES	COURSE CODE	COURSE OUTCOME
Biostatistics	09HLTH04-001-E	Probability distribution (normal, Poisson, t, F, Chi-square)
		Sample size determination and justification of power estimates in a research protocol - observational studies, clinical trials (superiority, non-inferiority / equivalence), animal studies
		Hypothesis testing: analysis of categorical or continuous data
		Biostatistics pertaining to survival analysis
Animal Models in Cancer Research	09HLTH04-002-E	Anatomy and biology of small animals used in cancer research.
		Transgenic and knockout technology to generate animal models
		Animal models for carcinogenesis, chemoprevention and drug screening and testing.
		Using imaging to study tumor progression in animal models.
Cancer Therapeutics	09HLTH04-003-E	Modules of cancer therapy – chemo, radio and targeted therapy.
		Mechanisms of resistance to chemo and radio therapeutics.
		Drug design, development and screening
		Immunotherapy and gene therapy including RNAi
Carcinogenesis, Chemoprevention and DNA Repair	09HLTH04-004-E	Determination of carcinogen exposure and dosage
		Short term and long term assays for carcinogenesis

		The role of DNA damage, viruses and epigenetics in carcinogenesis
		Basics of chemoprevention.
Deregulation of Cell Growth in Cancer	09HLTH04-005-E	Detailed analysis of the molecular mechanisms underlying Rb and p53 function.
		Mechanisms underlying tumor progression upon activation of Ras, PI3K, Myc and wnt-signaling.
		Checkpoint pathways and cancer
		Senescence and cancer
Structural Bioinformatics, Biophysics & Structural Biology	09HLTH04-006-E	Spectroscopic Techniques: Absorption Spectroscopy and Fluorescence Spectroscopy Spectropolarimetry: Circular Dichroism
		Biophysical methods: Protein conformation, interactions and oligomeric properties
		X-ray Crystallography (lecture and hands-on)
		NMR Spectroscopy
		Structural Bioinformatics: Molecular Modeling (homology, threading, ab initio); small molecule/peptide design; MDS: Different tools available for these in silico studies
		Molecular Docking (protein-protein, protein-ligand/small molecules)
		Drug Designing-challenges, in-silico design-advantages, steps and tools (QSAR, 3D-QSAR etc.). Application: How drug design leads to clinical trials with example.

		Hands-on training in Bioinformatics
Tumor Immunology	09HLTH04-007-E	Basic concepts of innate and adaptive immunity and their role in tumor immunity
		Immunodiagnostics and immunotherapy of Cancer. Role of monoclonal antibodies, vaccines and cell-based therapies
		Understanding of the tumor microenvironment, cells soluble factors contributing to immunosuppressive networks
		Animal models that have immune defects used to transplant human tumors and study their application for drug development and immunotherapies
		Understanding how Flow Cytometer works. Principle and applications followed by demonstration
Metastasis	09HLTH04-008-E	Molecular basis underlying detachment, intravasation and invasion in tumor cells.
		Survival in the bloodstream, invasion and metastatic colonization.
		Pathways contributing to the spread of metastatic disease including EMT, Hippo, Notch Wnt and CSC pathways.
		Targeted therapy and immunotherapy in metastasis and models and imaging in metastasis.
Bioinformatics	09HLTH04-009-E	To get introduced to the basic concepts of Bioinformatics and its significance in Biological data analysis.

		Be capable of using critical thinking and research methods in Bioinformatics to understand computational and experimental data.
		Conduct scholarly activities in a professional and ethical manner.
		Develop the ability to communicate clearly the meaning, potential impacts and risks associated with one's research activities to a non-technical audience in ways that confer a sense for its value to society.
Epidemiology & Preventive Oncology	09HLTH04-010-E	Describe population patterns of health-related risk factors & health-related outcomes in terms of person, place, & time.
		Compare the relative strengths and weaknesses of common epidemiologic study designs (e.g., cross-sectional, cohort, case-control, randomized experiments).
		Elucidate risk and prognostic factors for common and high-mortality cancers, with a focus on lifestyle, environmental and molecular exposures.
		Discover and implement prevention strategies, incorporating environmental, 'omic', and imaging approaches.
		Develop and operationalize novel bio-statistical and analytic methods for big data and personalized prevention.
Medical Physics	09HLTH04-011-E	Student will learn how different ionizing radiation effects influence biological systems.

		Student will acquire special competence within one or more academic fields. This may be radiation physics, modern radiation technology, radiobiology, radiation therapy for cancer, radio immuno-therapy
		While working on their assignments, students will, in cooperation with the academic staff, learn to develop quantitative measurement methods, plan, execute and analyse relevant experiments and model central physical, biochemical or biological processes and systems within the subject area.
		Student will train in critical thinking, ethics and accountability, problem-solving, project management and in addition be able to express themselves in a precise manner, both in writing and orally.
Nutrition	09HLTH04-012-E	Comprehensive understanding of core nutrition knowledge.
Nutrition	09HLTH04-012-E	Identify and conduct original research and scholarship in the field of nutrition.
Nutrition	09HLTH04-012-E	Effectively communicate in their field of study.
Nutrition	09HLTH04-012-E	Think critically, creatively and solve problems in their field of study. Skills in research methodologies demonstrated by conducting original scholarly research.
Nutrition	09HLTH04-012-E	Conduct research in an ethical and responsible manner.
Nutrition	09HLTH04-012-E	Demonstrate attributes of professional

		development consistent with the expectation within their field of study. Effective dissemination of research findings via peer-reviewed publications, seminars and practical applications such as teaching

(C) SPECIAL LECTURES:

SPECIAL LECTURES	COURSE CODE	COURSE OUTCOME
Epidemiology & Bioinformatics	09-HLTH04-001-S	Discuss the strengths and weaknesses of study designs (e.g., cross-sectional, cohort, case-control, randomized experiments) and the appropriate measure of association for a given study design
		Communicate clinical or translational research findings to a medical audience
		Analyze research data and interpret these results from a population health or clinical-translational perspective
		Demonstrate knowledge of regulatory requirements for clinical research
		To get introduced to the basic concepts of Bioinformatics and its significance in Biological data analysis.
		Be capable of using critical thinking and research methods in Bioinformatics to understand computational data and apply it to epidemiological data.
Intellectual Property Rights	09-HLTH04-002-S	The students once they complete their academic projects, will get awareness of acquiring the patent and copyright for their innovative works
		They also get the knowledge of plagiarism in their innovations which can be questioned legally
		Students should be able to apply intellectual property law principles

		(including copyright, patents, designs and trademarks) to real problems and analyze the social impact of intellectual property law and policy

BACK TO MAIN

INTEGRATED Ph.D. ENGINEERING SCIENCES

(DUAL DEGREE)

(Program Code: ENGG05)

Course Structure:

I. Courses at BARC

Program Code : ENGG05	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	**Name of the Course**	**Course code**
1	Accelerator Physics and Technology	EN501
2	Engineering Mathematics	EN502-505
3	Health Physics and Rad & Indl Safety	EN506
4	Nuclear Fuel Cycle Technology	EN508
5	NPP & Advanced Reactor Concepts	EN509
6	Reactor Physics and Engineering	EN510

Course Outcomes:

FOUNDATION COURSES

Name of the Course	**Course code**	**Course Outcome**
Accelerator Physics and Technology	EN501	The course introduces basic concepts of accelerator physics, Vacuum and cryogenic systems
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Engineering Mathematics	EN502-505	Advanced knowledge in computational data analysis, data fitting and error analysis

		Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
Health Physics and Rad & Indl Safety	EN506	Learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Nuclear Fuel Cycle Technology	EN508	Familiarisation with font and back end of nuclear fuel cycle technology
		Knowledge of radioactive waste generation on nuclear fuel burning and its processing
NPP & Advanced Reactor Concepts	EN509	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts
		Familiarization with reactor physics design challenges
Reactor Physics and Engineering	EN510	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with nuclear reactors.

(A) MECHANICAL COURSES

(A1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Code design for PVP	EN610
2	Computational fluid Dynamics and Heat Transfer	EN611
3	Finite Element Method	EN621
4	Fracture Mechanics	EN622
5	Mechanics of Solids	EN624

(A2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Machine Design	EN711
4	Material Science in Nuclear Engineering	EN712
5	Multi-scale material modelling	EN715
6	Nuclear Emergencies	EN716
7	Reliability Engineering	EN718
8	Vibration	EN721

(A3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(A1) Core Engineering

Name of the Course	Course code	Course Outcome
Code design for PVP	EN610	Basis of ASME Sec.VIII and Sec.III eqns. for Pressure Vessel and Piping Design
		Nozzle openings, Vessel design under ext. pressure
		ANSI / ASME B31.1 and B31.3 piping code
		NDE Examination of welds, Acceptance standard
Computational fluid Dynamics and Heat Transfer	EN611	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer

Finite Element Method	EN621	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Fracture Mechanics	EN622	LEFM and EPFM, Material fracture props. determination
		PTS event of RPV and Master Curve Concept
		Computational Fracture Mechanics
		Fracture Mechanisms
Mechanics of Solids	EN624	Principles and Fundamental Equations of Elasticity
		Analysis of Stress and Strain, Thermal Stresses
		Introduction to Plasticity
		Theory of Plates and Shells

(A2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Programming Language C++
		Parallel Programming
		Scientific Visualization
		Artificial Neural Network
Fluid Power Technology	EN709	Basic principles of hydraulics and pneumatics, pressure control
		Fluid power pumps and compressors, Fluid experiments
		Directional and flow control valves, Fluid Logic & Control
		Advanced Hydraulic Control Circuits, Electronics and Instrumentation for Hydraulics
Machine Design	EN711	Basic Principles of Machine Design, Design and Drawing Practices
		Sealing Methods
		Special Dimensional Inspection Techniques
		Advanced Manufacturing Techniques
Material Science in Nuclear Engineering		Metallurgy of steels
		Nuclear Materials

	EN712	Advanced Polymeric materials and Composites
		Corrosion
Multi-scale material modelling	EN715	Atomistic models: Molecular dynamics, Monte Carlo methods
		Inter-atomic potentials, Mesoscopic methods
		Modeling at microscale
		Bridging the scale gaps between different simulation levels
Nuclear Emergencies	EN716	Radiation Shielding, Nuclear Waste Management
		Nuclear Accidents/emergencies, Effects of Hiroshima & Nagasaki bombing
		Medical decontamination with demonstration
		Monitoring of High radiation field area
Reliability Engineering	EN718	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Vibration	EN721	Single and Multi-degree-of-freedom Systems, Free vibration
		Response of Systems To Ground Motion: Earthquake motion
		Flow Induced Vibration
		Vibration Measurement and Signal Analysis

(A3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
MiniProject		To provide a hands-on experience of working in an

	EN593	ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee

(B) CHEMICAL ENGINEERING COURSES

(B1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Chemical Reaction Engineering	EN601
2	Advanced Mass Transfer	EN604
3	Code design for PVP	EN610
4	Computational Fluid Dynamics and Heat Transfer	EN611
5	Nuclear Chemical Engineering	EN628
6	Process Dynamics and Control	EN634
7	Process Modeling, Simulation and Optimization	EN635

(B2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Material Science in Nuclear Engineering	EN712
4	Membrane Technology	EN714

(B3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591

2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(B1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Chemical Reaction Engineering	EN601	Fundamentals of Non-ideal reactors & RTD studies
		Understanding Non-isothermal effects & dynamical behaviour
		Overview of Heterogeneous reactions
		Approaches in Advanced reaction engineering & reactor design
Advanced Mass Transfer	EN604	Understanding Mass transfer with and without chemical reactions
		Rate based approaches for design
		Selection and design of various contacting equipment
		Process intensification approaches
Code design for PVP	EN610	Overview of Theories for pressure vessel design
		ASME Sec. VIII Div. 1 and Div - II equations
		Pressure vessel design as per ASME
		Design of piping as per B31.1 piping code.
Computational Fluid Dynamics and Heat Transfer	EN611	Understanding Kinematics of fluid flow and governing equations
		Classification of Partial Differential Equations & their discretization
		Convective heat transfer for internal and external flows
		Numerical Solution of fluid flow and heat transfer equations
Nuclear Chemical Engineering	EN628	Overview of Recovery and processing of nuclear materials
		Uranium conversion and reconversion

		Isotope Separation
		Nuclear Waste Management
Process Dynamics and Control	EN634	Introduction to process control & control loop dynamics
		Fundamentals of state-space controls, state, measurement equations
		General solution of the state equation
		Multi-variable controls, de-coupling, relative gain array
Process Modeling, Simulation and Optimization	EN635	Formulation of Dynamic and steady state models
		Flow sheet Analysis & Plant Simulation
		General Approaches for Non-Linear Systems
		Plant optimisation by Genetic Algorithms and Neural Nets

(B2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Understanding Programming Language C++
		Finite difference, finite volume, finite element discretization, grid generation, artificial neural network
		Parallel Programming, Message Passing Interface and MPI communications
		Scientific Visualization methods
Fluid Power Technology	EN709	Basic principles of Hydraulics and pneumatics
		Properties of hydraulic fluids and pneumatic air
		Roto-dynamic pumps, pressure and flow control
		Approaches in Hydraulic Circuit Design
Material Science in Nuclear Engineering	EN712	Overview of Nuclear Materials & their classifications
		Structure and properties of nuclear materials
		Processing of Nuclear Materials

		Material characterization techniques
Membrane Technology	EN714	Overview of Novel Membranes
		Preparation and Characterization
		Membrane Technologies
		Applications of Membrane Technology

(B3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering

(C) METALLURGY

(C1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Corrosion	EN615

2	Extractive Metallurgy	EN620
3	Mechanical Metallurgy	EN623
4	Nuclear Materials	EN628
5	Nuclear Metallurgy	EN629
6	Physical Metallurgy	EN630
7	Process Control & Instrumentation	EN631

(C2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Digital Signal Processing & Image Processing	EN706
3	Image processing and Machine Vision	EN710
4	Materials Characterization	EN713
5	Multi scale Material Modeling	EN715
6	Nuclear Chemical Engineering	EN628
7	Nuclear Emergencies	EN716
8	Welding Science & Technology	EN723

(C3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(C1) Core Engineering

Name of the Course	Course code	Course Outcome
Corrosion	EN615	Understanding electrochemical theory of corrosion & corrosion basics
		General principles of corrosion control
		Forms of corrosion and its mitigation
		Corrosion problems in nuclear industry and its mitigation
Extractive Metallurgy	EN620	Thermodynamics and kinetics of metal extraction
		Advanced material processing techniques
		Process metallurgy of rare metals, special materials and alloys
		Process metallurgy of U, Th, Pu, Be, Zr, Hf, Nb, Ta & rare earths
Mechanical Metallurgy	EN623	Exposure to stress tensor, state of stress, principal stress, hydrostatic, deviatoric stress
		Dislocations and deformation behaviour
		Creep & creep law, deformation mechanism map
		Fracture mechanics and fatigue of metals
Nuclear Materials	EN628	Vacuum melting & solidification, controlling casting defects of U, Zr and Ti alloys
		Cold & hot working, dynamic recovery, recrystallization of fuel tube, texture microstructure control
		Powder metallurgy of oxide, mixed oxide, carbide, intermetallic nuclear fuel material
		Applications of powder metallurgy in applications relevant to DAE
Nuclear Metallurgy	EN629	Fabrication of different types of fuel for research and power reactors

		Health physics, radioactivity and safety aspects of Pu handling
		Effects of irradiation on nuclear fuel and structural materials, hydriding related problems in Zr alloys
		Post irradiation examination (PIE) of nuclear fuel and structural material
Physical Metallurgy	EN630	Understanding basics of crystallography, crystal defects during irradiation
		Thermodynamics, phase equilibria & phase transformation
		Diffusion mechanism, equations & solutions
		Recovery, Recrystalization and Grain Growth
Process Control & Instrumentation	EN631	Understanding basic principles of measurement
		Sensors, transducers & transmission methods for pressure, vacuum, flow, level
		Principles of Automatic Control Systems
		Fail safe principles, simple logic circuits, ladder circuits for control action

(C2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Exposure to programming languages: C and C++
		Application of finite difference, finite volume, finite element techniques, ANN etc. in DAE
		Introduction to parallel programming concepts
		Data storage & visualisation techniques and case studies
Digital Signal Processing & Image Processing	EN706	Introduction to digital signal processing system & applications
		Discrete Fourier transform, fast Fourier transform

		Image processing, image enhancement, image segmentation & analysis, morphological operations
Image processing and Machine Vision	EN710	Introduction to digital image model representation, image sensor, digitizer, computer, standard file format
		Image enhancement segmentation and analysis, restoration
		Morphological operations and image compression
		Machine vision & introduction to image understanding
Materials Characterization	EN713	Introduction to microscopy techniques: optical, SEM, TEM, AFM, STEM, EBSD, FIM
		XRD and applications, basics of SIMS, RBS
		Analytical TEM, chemical analysis in materials science
		Thermal expansion and conductivity, TGA/DTA/DSC, mechanical properties
Multi scale Material Modeling	EN715	Introduction to types of models and multiscale approaches
		Atomistic models – molecular dynamics
		Basics of Monte Carlo methods
		Analysis of simulation results, bridging scale gap between different simulation levels
Nuclear Chemical Engineering	EN628	Recovery & processing of U, Th, Zr, rare earths from from ores / intermediates
		Uranium Conversion/reconversion
		Isotope Separation
		Nuclear Waste Management
Nuclear Emergencies	EN716	Introduction to nuclear fuel cycle, transportation of radioactive material
		Radiological accidents / emergencies
		Effects of nuclear detonation, testing nuclear weapons
		Emergency Response methodology/ Philosophy

Welding Science & Technology	EN723	Overview of various welding processes - arc welding, beam welding, hybrid welding
		Cold Bonding/Solid State Bonding
		Welding metallurgy under high cooling rates
		Types of welding defects and its prevention

(C3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I & VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
Mini Project	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee

(D) CIVIL ENGINEERING

(D1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1

2	Civil Engg Design of Concrete & Steel Strct II	EN608.2
3	Design Basis Hazards & Geotechnical Engg	EN621
4	Earthquake Engineeing & Structural Dyanmics	EN609
5	Finite Element Method	EN626
6	Mechanics of Solids	EN624

(D2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Struct Dynamics & Earthquake Engg	EN724
2	Construction Materials, Management & Quality	EN614
3	Safety & Reliability of Civil Engineering	EN722
4	Project Management	EN717

(D3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(D1) Core Engineering

Name of the Course	Course code	Course Outcome
Civil Engg Design of Concrete & Steel Strct I	EN608.1	Various structures of nuclear facilities; safety, seismic, design and quality classifications of structures
		Design loads on structures and load combinations as per BIS, ACI and AERB standards
		Design of RC structures; fracture mechanics concept in RC design

		Shallow and deep foundation design; machine foundation design
Civil Engg Design of Concrete & Steel Strct II	EN608.2	Design of prestressed concrete structures
		Design of lined and unlined reactor containment structures using RCC-G/BPEL/BAEL and ASME codes
		Design of steel structures using BIS, AERB and AISC standards
		Design of underground and overhead water retaining structures; design of natural draft cooling tower
Design Basis Hazards & Geotechnical Engg	EN621	Siting of nuclear facilities; hazards due to internal and external events; design basis natural hazards, such as, seismic, flood, wind, snow and solar radiations
		Human-induced design basis hazards, such as, aircraft/missile impact, explosions/blast, and toxic gas release
		Soils and its classifications; laboratory and field tests on soils and rock; compaction of soils; bearing capacity of soils and rocks
		Stages of geotechnical investigations; soil and rock sampling; geophysical investigations; seismic refraction survey, cross-hole seismic test; ERT; liquefaction potential of sites
Earthquake Engineeing & Structural Dyanmics	EN609	Seismic waves and wave propagation; time history; response spectra; seismic instrumentation
		Dynamic loadings; dynamic response of SDOF and MDOF systems; dynamics of continuum system
		Response spectra and time history approaches for determining seismic structural

		response; SSI and FSI; structural response in frequency domain
		Seismic requalification of existing installations; retrofitting techniques
Finite Element Method	EN626	Basis of FEM; energy principles; shape function requirements; C0 and C1 continuity
		Derivation of stiffness matrix and load vector for bar, beam, 2D plane and 2D iso-parametric elements; evaluation of strain and stress
		Incompatible quadrilateral elements; Tetrahedron, and hexahedron elements; plate bending elements; shell elements; patch test; adoptive meshing; error analysis
		Non-linear problems; material and geometric non-linearity
Mechanics of Solids	EN624	Concepts of elasticity; Equilibrium equations; Solution of 1-D boundary value problem; tensors algebra
		Analysis of stress and strain; transformation using direction cosines; principal planes; octahedral plane; state of pure shear; strain deviator tensor
		Strain displacement relationship; Isotropy and Anisotropy; Strain energy; Plane stress and plane strain problems; solution for beam bending problem; solution in polar co-ordinates; thermal stresses
		Analysis of thin and thick plates; shear deformation theories; membrane theory of shells of revolution and translation; bending analysis of shells; application to cylindrical, spherical and conical shells; introduction to plasticity

(D2) Electives

Name of the Course	Course code	Course Outcome
Advanced Struct Dynamics & Earthquake Engg	EN724	Concept of performance based seismic design; seismic demand; capacity of structures; performance levels
		Concept of seismic and vibration control; passive control; semi-active control; active control; base isolation techniques
		Methods of testing; qualification of system by testing; seismic instrumentation; measurement of displacement, velocity, acceleration
		Fluid-structure interaction techniques; multibody dynamics
Construction Materials, Management & Quality	EN614	Construction materials, such as, concrete, reinforcement, structural steel, paints, water-proofing materials
		Design of formworks; slip forms; prestressing systems
		QA in civil design, materials, construction, O&M, and regulatory inspection
		Dewatering; rock excavation, construction safety and JHA; mode of tendering; contract clauses; dispute adjudication
Safety & Reliability of Civil Engineering	EN722	Statistics and probability; discrete and continuous random variables; probability distributions
		Concept of structural safety; limit states; MVFOSM; Hasofer Lind reliability index; Cornell reliability index; Monte Carlo simulation
		Probabilistic safety assessment; seismic fragility analysis; seismic risk; health assessment of existing concrete and steel structures; rehabilitation and retrofitting

		techniques; service life prediction
		Concept of industrial safety; fire hazard analysis; safety in handling machinery, equipment and tools; fitness and protection of personnel
Project Management	EN717	Type, cost and schedule of nuclear power projects; resources of project; project organization chart; delegation of power
		Scheduling in a project by PERT, CPM, precedence diagram method; project management software for planning, scheduling and monitoring
		Preparation of target plan, updating of progress, monitoring variance and reporting; physical and financial monitoring; capital budgeting and expenditure control
		Contingency plan; construction management; project management; SWOT analysis; problem solving techniques

(D3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
Mini Project	EN5A93	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg.

(E) ELECTRICAL ENGINEERING

(E1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design I	EN602
2	Computer Based System Design I	EN612
3	Electrical Systems for Nuclear Power Plants	EN618
4	Modern Control Systems Design and Simulation	EN625
5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(E2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design II	EN702
2	Artificial Intelligence and its Applications	EN703
3	Computer Based System Design II	EN704
4	Digital Signal Processing & Image Processing	EN706
5	Image Processing & Machine Vision	EN710
6	Signal Conditioning, Recovery and EMI Aspects	EN719
7	Software Engineering	EN720

(E3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(E1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design I	EN602	Materials and Electrical Properties, NDT, MFL
		Superconducting Properties
		Understanding Control Techniques of Electrical Motors and Electronics
		FEM and Applications
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Electrical Systems for Nuclear Power Plants	EN618	Recapitulation of Power System Design Analysis
		Basics of Switchyard Design Principles
		Understanding Protection Systems
		Exposure to Electrical Systems in NPP
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity

		Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(E2) Electives

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design II	EN702	Understanding Vector Control of PM Synchronous Motors
		Exposure to Design and Applications of Variable Reluctance Stepper Motors and Switched Reluctance
		Understanding Pulse Power Techniques
		High Voltage Systems
Artificial Intelligence and its Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies

		Understanding Reinforcement Learning and Dynamic Programming
Computer Based System Design II	EN704	Exposure to Data Communication Interfaces for Control Applications, Fieldbuses
		Understanding Real Time System Design Principles
		Understanding IPC mechanisms in RTOS
		Exposure to Safety System Design Regulations
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics

		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(E3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(F) ELECTRONICS ENGINEERING

(F1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electronic Circuit Design Techniques	EN603
2	Advanced Nuclear Instrumentation	EN605
3	Embedded & Computer Based Sys. Design	EN619
4	Modern Control Systems Design and Simulation	EN625

5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(F2) Electives

Sr. No.	**Name of the Course**	**Course code**
1	Artificial Intelligence & Applications	EN703
2	Digital Signal Processing & Image Processing	EN706
3	Embedded Electronics Software	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720
7	Artificial Intelligence & Applications	EN703

(F3) Non-Subject Assignments

Sr. No.	**Name of the Course**	**Course code**
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(F1) Core Engineering

Name of the Course	**Course code**	**Course Outcome**
Advanced Electronic Circuit Design Techniques	EN603	Introduction to VLSI Design Flow, HDL, Design and Simulation of HPD
		Understanding Semiconductor Detectors , MEMS Desin
		Introduction to RF Electronics

		Understanding Transmission Lines, Waveguides, RF Amplifiers,
Advanced Nuclear Instrumentation	EN605	Understanding Electronics in Spectroscope Design
		Nuclear Instruments, Alpha, Beta and Gamma Detectors, Scintillation Counters
		Introduction to Accelerator Instrumentation
		Understanding Reactor Neutronic Instruments and Signal Processing
Embedded & Computer Based Sys. Design	EN619	Overview of Microprocessors and Interfacing
		Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements
		Exposure to Computer Communication, Encoding and Technologies
		Understanding Software Developments for NPP/Accelerator C&I
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters

		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(F2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models

		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

(F3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(G)INSTRUMENTATION ENGINEERING

(G1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Applied Process Instrumentation	EN607
2	Computer Based System Design I	EN612
3	Modern Control Systems Design and Simulation	EN625
4	Reactor C&I and Human Machine Interface	EN636
5	Reactor Control Engineering and Instrumentation	EN637-8
6	Reliability Engineering	EN639

(G2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Computer Based System Design II	EN706
3	Digital Signal Processing & Image Processing	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720

(G3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(G1) Core Engineering

Name of the Course	Course code	Course Outcome
Applied Process Instrumentation	EN607	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation
		Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and

		Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Reactor C&I and Human Machine Interface	EN636	Overview of Reactor C&I & Power Supply Requirements for Instrumentation
		Understanding Control Room Design and Exposure to Codes & Guides
		Exposure to Relay & Control Logic Design, Critera for Relay, PLC & DCS Technologies
		C&I Cable Requirements
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(G2) Electives

Name of the Course	**Course code**	**Course Outcome**
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

Computer Based System Design II	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Digital Signal Processing & Image Processing	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(G3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(H)COMPUTER SCIENCE AND ENGINEERING

(H1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Operating Systems	EN606
2	Computer Graphics & Visualisation	EN613
3	Distributed Computing	EN616
4	Networking & Information Security	EN627
5	Reactor Control Engineering	EN637
6	Software Engineering and Formal Methods	EN640

(H2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Data Base Management System & Web Technology	EN705
3	Digital Signal Processing & Image Processing	EN706
4	Embedded Electronics Software	EN707
5	Feedback Control System	EN708
6	Image Processing & Machine Vision	EN710

(H3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(H1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Operating Systems	EN606	Understanding IPC Calls
		Shell Programming
		Understanding Distributed File Systems
		Applications of System Calls
Computer Graphics & Visualisation	EN613	Understanding Geometric Transformations
		Applications of Geometric Projections
		Techniques for Hidden Surface Removals
		Applications of Scientific Visualisation
Distributed Computing	EN616	Understanding modern CPU Architectures
		Understanding Interconnect Techniques
		Understanding and Applications of HPC

		Understanding Grid Computing and Workflows
Networking & Information Security	EN627	Understanding Issues in the transport of data and Techniques
		Satellite Communications
		Understanding Network Security Concepts
		Advances in Cryptography and Cryptanalysis
Reactor Control Engineering	EN637	Understanding Physics behind Rector Control
		Understanding Point Kinetics Model and Reactor Periods
		Understanding Issues with Large Reactor Control and Modelling
		Understanding Control Requirements for PWR, PHWR, BWR and FBR
Software Engineering and Formal Methods	EN640	Understanding Techniques for modelling software
		Application of Model Checking and Theorem Proving
		Understanding Agile Programming
		Understanding Software Testing

(H2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Data Base Management System & Web Technology	EN705	Understanding SQL and Complex queries
		Understanding Clusters and Distributed Databases
		Understanding and Working with Web Technologies
		Modelling data and design of real data bases

Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Feedback Control System	EN708	State Space Representation and Applications
		Time Domain Analysis
		Appreciating need for Stability Analysis & Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications

(H3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Training in formulating and execution of research project.
		Training in documentation and presentation skills.

Course Structure:

II. Courses at IGCAR

Program Code: ENGG05	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	**Name of the Course**	**Course code**
1	Nuclear Reactors	NR
2	Engineering Mathematics	EM
3	Materials and Metallurgy	MM
4	Fast Reactor Physics and Shielding	RP
5	Reactor Engineering	RE
6	Health Physics and Radiological Safety	HP
7	Project Management	PM

Course Outcomes:

FOUNDATION COURSES

Name of the Course	**Course code**	**Course Outcome**
Nuclear Reactors	NR	Exposure to mechanical aspects of power plant engineering Details understanding of thermal and fast power reactors Introduction to sodium technology
Engineering Mathematics	EM	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering Introduction to numerical methods for solving ordinay and partial differential equations Probability and statistics Different types of transformations
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Reactor Engineering	RE	Basic understanding of core design of LMFBR Coolant circuits of LMFBR and special characteristics of sodium technology
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation Principles of radiation detection and Radiation Protection procedures Familiarization with principles of radiation detection and radiation Protection procedures
Project Management	PM	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(A) MECHANICAL ENGINEERING

(A1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for Pressure Vessels and Piping	ME1
2	High Temperature Design and Inelastic Analysis	ME4
3	Computational Fluid Dynamics	ME6
4	Finite Element Method	ME8
5	Advanced Heat and Mass Transfer	ME10
6	Reliability Engineering	ME13
7	Manufacturing Technology	ME14

(A2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Machine Design	ME3
2	Structural Integrity Assessment Methods and NDE	
3	Vibration Engineering and condition Monitoring	
4	Seismic Design of Nuclear Reactors and Facilities	ME5
5	Plant Dynamics	

6	Experimental Mechanics	
7	Process Control and Instrumentation	ME15

(A3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-001-P
2	Seminar -1,2,3	02ENGG04-001-S

Course Outcomes:

(A1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for Pressure Vessels and Piping	ME1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles.
		The course also include introduction to tubesheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered. It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
High Temperature Design and Inelastic Analysis	ME4	This course has direct relevance with the design of fast breeder reactor components & piping system. It covers mainly about the role of high-Temperature design concerning FBR programme, significant failure modes and associated design guidelines and advanced inelastic analysis methods. The high temperature design aspect is followed based on the RCC MRx RB procedure. Reliable design of components and piping system operating under high temperature operating conditions should address the additional damage associated with creep, fatigue and creep-fatigue interactions predominantly under thermo-mechanical loadings. There are many unresolved problems in the area of high-temperature

		design such as visco-plasticity behaviour, ratcheting behaviour, high temperature crack initiation behaviour etc. These aspects are addressed in this course with the support of tutorials.
Computational Fluid Dynamics	ME6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis Numerical Solution of Complete Fluid Flow and Energy Equation
Finite Element Method	ME8	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Advanced Heat and Mass Transfer	ME10	Advanced knowledge in heat and mass transfer Laminar boundary layer and forced convective heat, turbulent flow and heat transfer Heat transfer in porous media and heat transfer with phase change Radiation heat transfer
Reliability Engineering	ME13	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Manufacturing Technology	ME14	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles plastic deformation, processes like rolling, forging, extrusion etc in the case of metal forming module. Arc welding process,welding metallurgy, defects, inspection, quality control aspects are covered inwelding module. Extraction of Uranium and Zirconium from ore to final product form is coveed in the material processingmodule.

(A2) ELECTIVES

Name of the Course	Course code	Course Outcome
Machine Design	ME3	Basic concepts in vibrations analysis
Structural Integrity Assessment Methods and NDE		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
Vibration Engineering and condition Monitoring		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	ME5	Introduction to earthquakes, design basis ground motion and IS 1893 spectra Introduction of earthquake engineering and analysis for multi degree freedom systems
Plant Dynamics		Analysis and design of structures, equipments and piping
Experimental Mechanics		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Process Control and Instrumentation	ME15	Understanding the concepts of instrumentation and control for nuclear power plants
		Able to identify and define instrumentation and control needs of a process or machine
		Able to provide indicative choice of instruments in the design

(A3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-001-P	Training in formulating and execution of research project.
Seminar -1,2,3	02ENGG04-001-S	Training in oral communication of research results.

(B) ELECTRONIC AND INSTRUMENTAL ENGINEERING

(B1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	EL2
2	Nuclear Instrumentation	EL3
3	Reliability Engineering	EL4
4	Software Engineering	EL5
5	Human Machine Interface for Reactor Control Instrumentation	EL8
6	Modern Control of Dynamic Systems	EL10

(B2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence and Digital Signal Processing	EL6
2	Process Instrumentation	EL7
3	Embedded and Computer based systems Design	EL9
4	Analytical Instrumentation	EL11

(B3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-002-P
2	Seminar -1,2,3	02ENGG04-002-S

Course Outcomes:

(B1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	EL2	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	EL3	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Reliability Engineering	EL4	Introduction to reliability engineering applied to C&I systems
		Basic concepts of reliability, statistics and fault tolerence
		Probabilistic Safety (Risk) Assessment methods in the NPPs
Software Engineering	EL5	Introduction to software engineering and standards
		Software quality assurance, verification and validation
		Software analysis, design and configuration management
Human Machine Interface for Reactor Control Instrumentation	EL8	The subject is aimed on advanced design in new trends and development philosophy in the area of human machine interface. The student should obtain an overview of technologies implemented for reactor programmes and acquire an insight of the technical background to apply the same in context of reactor applications.
		The course work is framed in order to give an Introduction to various PFBR systems and HMI models in Distributed Digital Control System and their application to process systems such as special supervision systems, component handling systems, Reactor Protection Systems & Reactor Regulating Systems and Incident monitoring & mitigation systems. Learn about PC based process control system, Supervisory Control and Data Acquisition Systems.
		This course includes Familiarisation of plant automation overview, Soft Console versus conventional control panels, Guidelines for design of HMI displays, Building HMI systems, designing plant databases, alarm management techniques,

		Security features, creating process mimics, Trending historical data, Methods of passing data to HMI package etc. The capabilities of commercially available Professional HMI packages will also be explored.
Modern Control of Dynamic Systems	EL10	Introduction to state variable description with examples
		Controllability, observability and control system design

(B2) ELECTIVES

Name of the Course	Course code	Course Outcome
Artificial Intelligence and Digital Signal Processing	EL6	Exposure to fundamentals of digital signal processing algorithms
		Exposure to practical DSP algorithms and its implementation on different platforms
		Exposure to system design using pre conditioning circuits, anti-aliasing filters and digital signal controllers
		Exposure to system design case studies like Condition Monitoring System for rotating equipments And radar signal processing
		After course completion the student will be able to handle practical engineering problems solvable by digital signal processing techniques
		It is a specialised course which will give an introduction to AI techniques.
		It will give a flavour to fuzzy logic, robotics, neural networks, genetic algorithm.
Process Instrumentation	EL7	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Embedded and Computer based systems Design	EL9	Understanding of VME bus and cPCI bus architecture.
		'C' programming with MISRA C compliant.
		Electronics design in analog and digital domain
		Learning of VLSI based design using EDA tools.
		Learning of VHDL based digital design.
		Electronics system design using TMR architecture, fault tolerant design
		Introduction of reliability analysis for electronics system.
Analytical Instrumentation	EL11	Introduction to the principles and applications of modern analytical instruments Sensitivity, precision, and limitations of analytical instruments

(B3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-002-P	Training in formulating and execution of research project.
Seminar -1,2,3	02ENGG04-002-S	Training in oral communication of research results.

(C) CHEMICAL ENGINEERING

(C1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Nuclear Chemical Engineering	CE1
2	Chemical Engineering Thermodynamics	CE2
3	Transport Phenomena	CE3
4	Multi-Phase Flow Systems	CE4
5	Code Design for Pressure Vessels and Piping	CE5
6	Computational Fluid Dynamics and Heat Transfer	CE6
7	Advanced Chemical Reaction Engineering	CE7

(C2) SPECIALIZED COURSES

Sr. No.	Name of the Course	Course code
1	Process Analysis and Control	CE8
2	Advanced Mass Transfer	CE9

(C3) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Preparedness &Response to Nuclear Emergencies Artificial Intelligence Methods &Applications Membrane/ Separation Process and Technology	CEEL

(C4) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-003-P
2	Seminar -1,2,3	02ENGG04-003-S

Course Outcomes:

(C1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Nuclear Chemical Engineering	CE1	Introduction to nuclear chemical engineering for production, processing and management of nuclear materials
		Modelling and Simulation in Nuclear Chemical Engineering
Chemical Engineering Thermodynamics	CE2	Understanding the concepts of Thermodynamics , scope of Classical Thermodynamics, Phase Equilibrium, Chemical Reaction Equilibria.
Transport Phenomena	CE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyze transport problems
		Analyze transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyze transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Multi-Phase Flow Systems	CE4	Introduction to multiphase flow and its classification
		Modeling and Simulation in Nuclear Chemical Engineering
		Applications of two-phase flow in the design of steam generators
		The phenomena of fluidization and its industrial application
Code Design for Pressure Vessels and Piping	CE5	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design

		for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
Computational Fluid Dynamics and Heat Transfer	CE6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer
Advanced Chemical Reaction Engineering	CE7	Understanding of thermodynamics and kinetics of chemical reactions
		Design and analysis of chemical reactors
		Modelling of multiphase reactors

(C2) SPECIALIZATION

Name of the Course	Course code	Course Outcome
Process Analysis and Control	CE8	Understanding of dynamics of chemical process systems and nonlinear process dynamics
		Design of multivariable controllers
Advanced Mass Transfer	CE9	Introduction to theories of mass transfer and advanced mass transfer processes
		Selection and design of contacting equipment in nuclear chemical industries

(C3) ELECTIVES

Name of the Course	Course code	Course Outcome
Preparedness & Response to Nuclear Emergencies	CEEL	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Artificial Intelligence Methods & Applications		
Membrane/ Separation Process and Technology		

(C4) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-003-P	Training in formulating and execution of research project.
Seminar -1,2,3	02ENGG04-003-S	Training in oral communication of research results.

(D) MATERIALS SCIENCE

(D1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	MS1
2	Computational Methods	MS2
3	Materials and Metallurgy	MS3
4	Reactor Physics and Fuel Design	MS4
5	Health Physics	MS5
6	Metallurgical Thermodynamics	MS6
7	Experimental Methods for Materials Research	MS7
8	Structural Materials for Nuclear Reactors	MS8
9	NDE Science and Technology	MS9
10	Physical Metallurgy	MS10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	MS11
12	Introduction to Materials Science and Engineering	MS12
13	Corrosion Science and Engineering	MS13
14	Mechanical Behavior of Engineering Materials	MS14
15	Manufacturing Technology	MS15

Course Outcomes:

(D1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Engineering Mathematics	MS1	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
		Introduction to numerical methods for solving ordinary and partial differential equations
		Probability and statistics
		Different types of transformations
Computational Methods	MS2	Introduction to programming languages such as C# and Matlab
		Exposure to numerical techniques for solving partial differential equations
		Neural network for predictive applications
		Basics of atomis modelling, molecular dynamics and introduction to Monte-carlo simulation
		Introduction to FEM and current trends in modelling and imulation

Materials and Metallurgy	MS3	To develop a basic understanding on the classification of materials
		Mechanical property based selection of materials for nuclear application and standards
		Various fabrication related issues in material including welding and corrosion
		Non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Reactor Physics and Fuel Design	MS4	Introduction to basic nuclear and neutron physics concepts
		Nuclear reactors and fuel design concepts
		Reactor kinetics
Health Physics	MS5	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Metallurgical Thermodynamics	MS6	Introduction to Classical thermodynamics: 1st and 2nd laws and their applications
		Thermodynamic properties of pure substances and mixtures Solution thermodynamics
		Phased equilibria in multicomponent systems and stability
		Chemical reactor equilibria Exposure to experimental methods for determining thermodynamic properties
Experimental Methods for Materials Research	MS7	Exposure to various experimental techniques for materials characterization, including X-ray techniques, electron microscopies, ion-beam techniques, electron spectroscopies nuclear spectroscopies, vibrational spectroscopy and resonance absorption spectroscopies
		Basic understanding of underlying physics
Structural Materials for Nuclear Reactors	MS8	Exposure to the three stage nuclear power programme
		Concept of selection of structural materials for different applications
		Materials for thermal reactors, fast breeder reactors and reprocessing applications
		Materials processing and fabrication of components
NDE Science and Technology	MS9	Introduction to various non-destructive evaluation techniques for safe and reliable operation of structures and components
		Surface, volumetric and Dynamic NDE
Physical Metallurgy	MS10	Basic understanding of crystal structure and microstructure
		Knowledge of origin, construction and classifications of metallurgical phase diagrams

		Understanding of different types of metallurgical phase transformations and underlying principles
		Introduction to microstructural characterization techniques and tools
Fuel Cycle Physics and Introduction to Fuel Cycle	MS11	Introduction of nuclear fuel cycles
		Introduction to exploration, recovery and enrichment and uranium and other nuclear fuel materials
		Different types of nuclear fuels and fuel fabrication
		Recycling the spent fuel, fission products and actinides
Introduction to Materials Science and Engineering	MS12	Introduction to basic structures, bonding and defects in solids and techniques for their characterization
		Physcial properties of materials
		Basics of phase diagram and phase transformations
		Techniques for synthesis of materials
Corrosion Science and Engineering	MS13	Basic understanding of corrosion process, monitoring and preventation
		Introduction to thermodynamics and kinetics of corrosion
		Forms of corrosion and corrosion in nuclear reactor and reprocessing plants
Mechanical Behavior of Engineering Materials	MS14	Introduction to engineering materials
		Elastic and plastic deformation in polycrystalline materials
		Strengthening mechanisms in polycrystalline structural materials
		Exposure to damage mechanisms such as creep, fatigue and also exposure to fracture mechanics
Manufacturing Technology	MS15	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles of plastic deformation, processes like rolling, forging, extrusion etc. in the case of metal forming module.
		Arc welding process, welding metallurgy, defects, inspection, quality control aspects are covered in welding module. Extraction of Uranium and Zirconium from ore to final product form is covered in the material processing module.

(E) FAST REACTOR ENGINEERING – I

(E1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(E2) CORE ENGINEERING

Sr. No.	**Name of the Course**	**Course code**
1	Code Design for pressure vessel and piping	FRE1
2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2
3	Transport Phenomena	FRE3
4	Reliability Engineering	FRE4
5	Process Design and Control	FRE5
6	Vibration Engineering and Condition Monitoring	FRE6
7	Seismic Design of Nuclear Reactors and Facilities	FRE7
8	Emergency Preparedness and Disaster Management	FRE8

(E3) OPERATIONS

Sr. No.	**Name of the Course**	**Course code**
1	Plant Dynamics and Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical’s	FRE14
7		Viva Voce

Course Outcomes:

(E1) FUNDAMENTALS

Name of the Course	**Course code**	**Course Outcome**
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(E2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for pressure vessel and piping	FRE1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tube sheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.

Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2	Advanced knowledge in heat and mass transfer
		Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
		Heat transfer in porous media and heat transfer with phase change
		Radiation heat transfer
Transport Phenomena	FRE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyse transport problems
		Analyse transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyse transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Vibration Engineering and Condition Monitoring	FRE6	Basic concepts in vibrations analysis
		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	FRE7	Introduction to earthquakes, design basis ground motion and IS 1893 spectra
		Introduction of earthquake engineering and analysis for multi degree freedom systems
		Analysis and design of structures, equipment and piping
		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(E3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine
		Turbine troubles
Mechanical and Electrical Equipment	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(F) FAST REACTOR ENGINEERING – II

(F1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(F2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	FRE15
2	Nuclear Instrumentation	FRE16
3	Reliability Engineering	FRE4
4	Process Design and Control	FRE5
5	Embedded System Design & Human Machine Interface	FRE17
6	Process Instrumentation	FRE18
7	Emergency Preparedness and Disaster Management	FRE8

(F3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical’s	FRE14
7		Viva-Voce

Course Outcomes:

(F1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(F2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	FRE15	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	FRE16	Students learn about basics of interaction of radiation with matter.
		Principle & Techniques to detect and measure ionizing radiation.
		Basics of radiation counting statistics
		Introduction to Neutron Flux Measurement in FBTR and PFBR.
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Embedded System Design & Human Machine Interface	FRE17	Introduction to Microprocessor Based Hardware Design
		Computer Communication and Networks
		Fault Tolerant and Distributed Architectures
		Programmable Logic Controller Design
		Overview of plant automation and Human Machine Interface (HMI)

Process Instrumentation	FRE18	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of various process variables
		Reliability principles, Fail safe design principles
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(F3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine Turbine troubles
Mechanical and Electrical Equipments	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	Assessment of the understanding in the subject area by the students.

BACK TO MAIN

INTEGRATED Ph.D. (Dual Degree) LIFE SCIENCES (Program Code: LIFE05)

I. Courses at IMSc

Program Code : LIFE05	Programme Specific Outcome	To understand biological data and the means by which they are acquired
		To communicate and collaborate with biologists
		To understand and apply quantitative techniques from mathematics, physics and data science to biological phenomena
		To comprehend, express and present scientific data
		To understand and interpret model calculations

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Biology-1	10-LIFE05-001-C
2	Protein Structure	10-LIFE05-002-C
3	Mathematics and statistics for biologists	10-LIFE05-003-C
4	Physical Methods for Biologists	10-LIFE05-004-C
5	Biology-2	10-LIFE05-005-C
6	Biological sequence analysis	10-LIFE05-006-C
7	Systems Biology	10-LIFE05-007-C

(B) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Biophysics of Macromolecular Structures	10-LIFE05-001-E
2	Simulation Techniques in Biology	10-LIFE05-002-E
3	Population Biology, Ecology and Evolution	10-LIFE05-003-E
4	Computational Neuroscience	10-LIFE05-004-E
5	Modeling of Infectious Diseases	10-LIFE05-005-E

Course Outcomes:

(A) Core Courses

Name of the Core Courses	Course code	Course Outcome
Biology-1	10-LIFE05-001-C	Learn basics of genetics, biochemistry, molecular biology and cell biology
		Learn about foundational experiments contributing to key developments in molecular biology over the last century
		Learn basics of developmental biology and molecular evolution
		Learn about biological systems where computational modelling has already made an impact
Protein Structure	10-LIFE05-002-C	Learn basics of biochemistry and protein structure (including globular, membrane proteins)
		Learn computational tools required to understand and address structural aspects of proteins
Mathematics and statistics for biologists	10-LIFE05-003-C	Learn to frame and solve simple problems in dynamics using differential equations, and understand some classic applications
		Learn basic concepts and applications of linear algebra
		Learn essentials of probability theory and statistics and applications to biological problems
		Have a basic competence in numerical methods, machine learning methods and tools, and related topics
Physical Methods for Biologists	10-LIFE05-004-C	Learn how to make biophysical estimates
		Learn about the random walk and diffusion, Ficks law and how to make related estimates
		Learn to make statistical mechanics calculations in biology, involving cooperativity, entropy and self-assembly
		Learn about biological polymers and their properties and perform force extension calculations
		Understand biological fluids, Reynolds number and the Stokes limit
Biology-2	10-LIFE05-005-C	Learn basics of DNA packaging, Chromatin structure and Epigenetics

		Learn basics of neuroscience, ecology and evolution
		Learn basic experimental techniques in biology
		Learn basics of intercellular communication, physiology, epidemiology and immunology
Biological sequence analysis	10-LIFE05-006-C	Have a basic understanding of computer science algorithms, especially related to strings and pattern-matching
		Understanding of sequence alignment algorithms, generative models, hidden Markov models
		Basic understanding of phylogenetics and related principles and algorithms
		Basics of next-generation-sequencing methods and analysis, including essential algorithms
		Ability to frame and implement algorithms for real-world bioinformatic tasks
Systems Biology	10-LIFE05-007-C	Understand the role of networks across different scales in biology
		Mathematically model the dynamics of simple networks of interacting biological entities
		Understand the basic physical mechanisms explaining how spatial patterns can emerge spontaneously
		Learn the functional role of waves in biology for transport, communication and coordination

(B) Elective Courses

Name of the Elective Courses	Course code	Course Outcome
Biophysics of Macromolecular Structures	10-LIFE05-001-E	Understand the basics of biological macromolecular structure and functions
		Understand different biophysical approaches for probing the biological macromolecular structures and the environment in which they function.
Simulation Techniques in Biology	10-LIFE05-002-E	Learn basic statistical mechanics tools for simulation methodologies probing different length and time scales
		Apply simulation technologies to understand protein structure and function in-silico

Population Biology, Ecology and Evolution	10-LIFE05-003-E	To understand the time evolution of single species population using different types of mathematical models
		Learn basic aspects of game theory to understand how cooperation can emerge
		To model trophic (predator-prey) interactions in multiple species communities
		To understand basic aspects of the mathematical theory of evolution through natural selection
Computational Neuroscience	10-LIFE05-004-E	Understand how information is processed by the nervous system
		Learn how neurons communicate with each other and with sensory, as well as, effector organs
		Derive the Hodgkin-Huxley model of action potential transmission along a nerve
		Able to simulate in computers the electrical activity in neurons and small neuronal networks
Modeling of Infectious Diseases	10-LIFE05-005-E	Understand disease, disease spread and modeling approaches
		Learn the basics of epidemiology and epidemiological methods
		Derive and solve ordinary dufferential equation based models of disease spreading
		Understand basic concepts of immunology

INTEGRATED Ph.D. (Dual Degree) MATHEMATICAL SCIENCES (Program Code: MATH05)

Course Structure:

I. Courses at IMSc

Core Subjects

Sr. No.	Name of the Course	Course code
1	ALGEBRA I	10MATH04-001-C
2	ALGEBRA II	10MATH04-002-C
3	ANALYSIS I	10MATH04-003-C
4	ANALYSIS II	10MATH04-004-C
5	TOPOLOGY I	10MATH04-005-C
6	TOPOLOGY II	10MATH04-006-C
7	COMPLEX ANALYSIS	10MATH04-007-C
8	CREDIT SEMINAR	10MATH04-008-C
9	RESEARCH METHODOLOGY	10MATH04-009-C

Electives

Sr. No.	Name of the Course	Course code
1	TOPICS IN ANALYTIC NUMBER THEORY	10MATH04-001-E
2	TOPICS IN ALGEBRAIC NUMBER THEORY	10MATH04-002-E
3	TOPICS IN COMMUTATIVE ALGEBRA	10MATH04-003-E
4	TOPICS IN MODULAR FORMS	10MATH04-004-E

5	TOPICS IN ELLIPTIC CURVES	10MATH04-005-E
6	TOPICS IN ALGEBRAIC CURVES	10MATH04-006-E
7	TOPICS IN DIOPHANTINE GEOMETRY	10MATH04-007-E
8	TOPICS IN TRANSCENDENTAL NUMBER THEORY	10MATH04-008-E
9	TOPICS IN ALGEBRAIC GROUPS	10MATH04-009-E
10	TOPICS IN INFINITE DIMENSIONAL LIE ALGEBRAS	10MATH04-010-E
11	TOPICS IN FUNCTIONAL ANALYSIS	10MATH04-011-E
12	TOPICS IN NON-COMMUTATIVE GEOMETRY	10MATH04-012-E
13	TOPICS IN LIE GROUPS	10MATH04-013-E
14	TOPICS IN ALGEBRAIC GEOMETRY	10MATH04-014-E
15	TOPICS IN DIFFERENTIAL GEOMETRY	10MATH04-015-E
16	TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS	10MATH04-016-E
17	TOPICS IN MATHEMATICAL PHYSICS	10MATH04-017-E
18	TOPICS IN ALGEBRA	10MATH04-018-E
19	TOPICS IN OPERATOR ALGEBRAS	10MATH04-019-E
20	TOPICS IN REPRESENTATION THEORY	10MATH04-020-E
21	TOPICS IN ALGEBRAIC COMBINATORICS	10MATH04-021-E
22	TOPICS IN TOPOLOGY	10MATH04-022-E
23	TOPICS IN SYMPLECTIC GEOMETRY	10MATH04-023-E
24	PROGRAMMING FOR MATHEMATICIANS	10MATH04-024-E

Course Outcomes:

Core subjects

Name of the Course	**Course code**	**Course Outcome**
ALGEBRA I	10MATH04-001-C	Understanding of basic group theory in the language of group actions
		Ability to apply linear algebra, in particular, canonical forms and spectral theory
		Understanding of basic category theory and tensor products
ALGEBRA II	10MATH04-002-C	Understanding the fundamentals of Galois theory
		Familiarity with semi simplicity and its applications
		Good understanding of the representation theory of finite groups
		Knowledge of basic commutative algebra
ANALYSIS I	10MATH04-003-C	Knowledge of measure theory
		Understanding of L^p spaces
		Familiarity with product measures and Fubini's theorem
		Understanding of the Radon-Nikodym theorem and the Lebesgue decomposition theorem
ANALYSIS II	10MATH04-004-C	Good understanding of the basic theorems of functional analysis
		Familiarity with various kinds of topologies on function spaces
		Knowledge of Banach algebras
		Understanding of basic Hilbert space theory and C^*-algebras

		Familiarity with applications of fundamental groups and homology groups
Topology II	10MATH04-006-C	Knowledge of advanced topics in homology theory
		Familiarity with cohomology theory and homotopy
		Understanding of basic notions of differential topology
		Knowledge of topics such as differential geometry, characteristic classes and Morse theory
Complex Analysis	10MATH04-007-C	Familiarity with analytic functions
		Knowledge of Cauchy's theorem, maximum modulus principle, Schwarz lemma
		Ability to apply conformal mappings and Mobius transformations
		Understanding of the Dirichlet problem and harmonic functions
Credit Seminar	10MATH04-008-C	Appreciation of current research in chosen sub-area
Research Methodology	10MATH04-009-C	An introduction to the methods and techniques of academic research through a project and presentations - both oral and written.

Electives

Name of the Course	Course Code	Course Outcome
TOPICS IN ANALYTIC NUMBER THEORY	10MATH04-001-E	Possibilities for topics are: introduction to arithmetic functions, convolution and Mobius inversion formula, basic asymptotic formulas for arithmetic functions, characters and Fourier analysis on finite abelian groups, theory of Dirichlet series, primes in arithmetic progression, Riemann zeta function, Poisson summation and functional equation, The prime number theorem, error term in prime number theorem, its oscillation and the Riemann hypothesis, equivalent formulations of Riemann hypothesis, zero-free regions, explicit formula and Siegel’s theorem, introduction to sieve methods, Brun and Selberg sieve, large sieve and the Bombieri-Vinogradov theorem and Vinogradov’s three prime Theorem.
TOPICS IN ALGEBRAIC NUMBER THEORY	10MATH04-002-E	Possibilities for topics are: Dedekind domains, ramification, different and discriminants, decomposition and inertia groups, quadratic fields and genus theory, classification of primitive quadratic characters, Gauss sums and quadratic reciprocity, geometry of numbers, finiteness of class number and explicit computations, regulators and Dirichlet’s unit theorem, cyclotomic fields and inverse Galois problem for abelian number fields, Artin symbol and splitting in cyclotomic fields, Dedekind zeta function, the analytic class number formula and introduction to the Chebotarev density theorem
TOPICS IN COMMUTATIVE ALGEBRA	10MATH04-003-E	One possibility is a course covering the second half of Matsumura’s text including topics such as: regular sequences, Koszul complex, Cohen-Macaulay rings, Gorenstein rings, regular rings, UFDs, complete intersections, local flatness criterion, generic freeness, derivations and differentials, separability, I-smoothness, Cohen’s structure theorems and applications of complete local rings.
TOPICS IN MODULAR FORMS	10MATH04-004-E	Possibilities include: Introduction to SL2(R) and its action on the Poincare upper half-plane H, discrete subgroups Γ of SL2(R) and their cusps, the modular group SL2(Z), Topology,

		measure theory and complex structure on H/Γ and its compactification, Modular functions, modular forms and cusp forms on SL2(Z), examples : Eisenstein Series and the delta Function, finite dimensionality of space of modular forms, the Miller basis and the Z-structure on the space of modular forms, growth of Fourier co-efficients of cusp forms, introduction to Ramanujan’s conjectures, theory of Hecke operators and Petersson inner-product on the space of cusp forms, application to Ramanujan’s conjectures, the L-function of modular forms, congruence subgroups, modular forms and cusp forms on congruence subgroups, spectral theory of automorphic forms, introduction to Galois representations and Deligne’s theorem, Lehmer’s conjecture and the Atkin-Serre Conjecture.
TOPICS IN ELLIPTIC CURVES	10MATH04-005-E	Possibilities for material to be covered include selected topics from Elliptic functions by Lang, The arith-metic of Elliptic curves by Silverman, Elliptic curves by Milne or Elliptic curves by Husemoller. Another possibility would be to prove Mazur’s theorem which is a well-known and important result covering elliptic curves and abelian varieties, and the moduli of elliptic curves.
TOPICS IN ALGEBRAIC CURVES	10MATH04-006-E	Possibilities for material to be covered include selected topics from An invitation to arithmetic geometry by Lorenzini, Algebraic Curves by Fulton or lectures notes of Joseph Oesterle. Topics such as the basics of algebraic varieties over the complex numbers (with focus on dimension 1), singularities of curves (what are they and when is a curve nonsingular), desingularization of curves by normalization, the relationship between nonsingular algebraic curves and complex manifolds of dimension 1, nonsingular projective algebraic curves and function fields, the Riemann-Roch theorem, and also some of its applications.
TOPICS IN DIOPHANTINE GEOMETRY	10MATH04-007-E	Some possibilities are: introduction to Global fields, absolute values on global fields, theory of heights, rational points on conics. local-global principle and application to quadratic forms, affine and projective varieties, morphisms and rational

		maps, explicit arithmetic on function fields and their zeta-functions, divisors on curves, The Riemann-Roch theorem, elliptic curves over global fields, endomorphism rings of Elliptic curves, CM and non-CM curves, ehe Mordell-Weil group and rank of an elliptic curve and local-global principle on elliptic curves and the Tate-Shaferevich group.
TOPICS IN TRANSCENDENTAL NUMBER THEORY	10MATH04-008-E	Possibilities are: Liouville's theorem and Liouville Numbers, elements of rational approximation, transcendence of e and π, irrationality of $\zeta(3)$, introduction to algebraic independence, Lindemann-Weierstrass theorem, Schanuel's conjecture and Ax's theorem for for-mal power series, the Schneider-Lang Theorem, Hilbert's seventh problem and the Gelfond-Schneider theorem, Baker's Theorem and applications, six exponential theorem, introduction to heights and Roth's Theorem, the padic Baker theorem (by Brumer) and introduction to Leopoldt's conjecture and the padic subspace theorem and applications.
TOPICS IN ALGEBRAIC GROUPS	10MATH04-009-E	One possibility is to cover the basic theory of linear algebraic groups over an algebraically closed field up to the classification of the reductive groups by means of root data, developing the necessary background from algebraic geometry as and when needed. Thus covering preliminaries from algebraic geometry, linear algebraic groups: definition and first properties, commutative algebraic groups, derivations, differentials, and Lie algebras, topological properties of morphisms applied to this context, Parabolic subgroups, Borel subgroups, and solvable subgroups, Weyl group, roots, and root datum and reductive groups and their classification: isomorphism and existence theorems.
TOPICS IN INFINITE DIMENSIONAL LIE ALGEBRAS	10MATH04-010-E	Some possibilities are: generalized Cartan matrices and their associated Lie algebras, symmetrizability, the invariant bilinear form, the Weyl group, classification of indecomposable GCMs, finite, affine and indefinite types, affine Kac-Moody algebras, roots, the affine Weyl group, realizations of untwisted and twisted affine Kac-Moody algebras in terms of loop algebras, representation theory: integrable

		representations, category O, proof of the Weyl-Kac character formula, highest weight integrable representations, weights, representations of affine Kac-Moody algebras.
TOPICS IN FUNCTIONAL ANALYSIS	10MATH04-011-E	Some possibilities are: analytic Fredholm theory, compact and Fredholm operators, Atkinson's theorem, Gelfand duality, properties of the analytic index, Toeplitz operators on Hardy spaces, Pseudo-differential operators and Elliptic regularity, Fourier transforms and Sobolev spaces on Rn, Symbol calculus and Pseudo-differential operators, Elliptic-ity and Pseudo-differential operators on smooth manifolds, construction of para-metrices, Elliptic regularity theorem, Ellipticity and Fredholm property of Dirac operators on closed manifolds.
TOPICS IN NON-COMMUTATIVE GEOMETRY	10MATH04-012-E	Some possibilities are: Vector bundles, K-theory for topological spaces, Serre Swan theorem, K0 and K1for a C*-algebra, homotopy invariance, split exactness, half-exactness, stability of K-theory, inductive limits and K-theory, Bott periodicity, Six term exact sequences, computations with them, Pimsner-Voiculescu exact sequence, Thom isomorphism, Hilbert C*-modules, KK groups, Geometric index theory, Vector bundles, connec-tions and curvature on Riemannian manifolds, structure equations of Cartan, invari-ant forms and characteristic classes in de Rham cohomology, Chern-Gauss-Bonnet theorem and idea of proof, topological index and statement of the Atiyah-Singer index theorem
TOPICS IN LIE GROUPS	10MATH04-013-E	Some possibilities are: Introduction to Lie algebras, definitions, examples, abelian, nilpotent, solvable lie algebras, semisimple lie algebras, representation of Lie algebras, structure of general Lie algebras over characteristic zero field : statement of the Levi decomposition, statement of Ado's theorem, Introduction to real differentiable manifolds, and various standard objects associated with it, statement of the Frobenius theorem on integrability, definition of real Lie groups, examples, associated Lie algebra, the exponential map and its properties, closed subgroup theorem, continuous homomorphisms, definition of Lie subgroups and

		examples, association of lie subgroups and lie subalgebras, covering Lie groups, simply connected lie groups and association with real Lie algebras, the adjoint representation, the manifold structure of the left or right coset space with respect to a closed subgroup and the (subgroup)-principal bundle structure of the Lie group with respect to the projection to the coset space, Construction of left invariant Haar measure using left invariant differential forms, formula for modular function, compact Lie groups, Peter-Weyl theorem, embedding compact groups in linear Lie groups, Weyl group, conjugacy of maximal tori in connected compact Lie groups, Centralizers of tori, basic structure of semisimple Lie groups, existence of compact real forms of complex semi-simple Lie algebras, Cartan decomposition both at the Lie algebra and Lie group level, Iwasawa decomposition.
TOPICS IN ALGEBRAIC GEOMETRY	10MATH04-014-E	One possibility is an introduction to the language of schemes, properties of morphisms, and sheaf co-homology. So that the students gain an understanding of the basic notions and techniques of modern algebraic geometry.
TOPICS IN DIFFERENTIAL GEOMETRY	10MATH04-015-E	Some possibilities are: Definition of smooth manifolds, atlas, examples, tangent spaces, inverse and im-plicit functon theorems for manifolds, vector fields, flow, completeness of the flow function, integrability and Frobenius theorem, differential forms, pullback by func-tions, exterior derivative, orientations, manifolds with boundary, Stokes theorem, DeRham cohomology, computations using Mayer Vietoris, Riemannian metrics and geodesics.
TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS	10MATH04-016-E	Some possibilities are: Examples of partial differential equations, Strategies for studying PDE., Well posed problem, Brief introduction to classical solutions, weak solution and regularity, Transport equation, Laplace's equation, Heat equation and wave equation, Problems associated to these equations, notion of fundamental solution etc., Non-linear first order PDE, Hamilton Jacobi equations, calculus of variations, Hamilton's ode, Legendre transforms, etc., Theory of linear partial differential

		equations: Sobolev spaces, weak derivative, Sobolev inequalities, Elliptic equations, Weak solutions, the existence of weak solutions, regularity, maximum principles, eigenvalues and eigenfunctions of elliptic operators, compactness, etc.
TOPICS IN MATHEMATICAL PHYSICS	10MATH04-017-E	One possibility is to cover classical and quantum mechanics covering topics such as: review of Galilean group, mechanical system with one degree of freedom, mechanical system consisting of motion of a point in three dimensional space and motion of system of n points, review of calculus of variation, Lagrange's equation, Hamilton's equations, Liouville's theorem, Symplectic structures on phase spaces and Noether's theorem, D'Alembert's principle, Symplectic manifolds, Hamiltonian mechanics on symplectic manifolds, moment map, postulates of quantum mechanics, mathematical aspects of Schrödinger's equation, review of Lie group, Lie algebra and their representations with main focus on groups like U(1), SO(3), SU(2), Spin groups in 3 and 4 dimensions, Spin 1/2 particle in magnetic field, review of Fourier transforms, position and momentum space, Dirac notation, Heisenberg's uncertainty principle, Hydrogen atom, quantization, canonical quantization, The Groenewold-van Hove no-go theorem, canonical quantization in n–dimensions, quantization and symmetries.
TOPICS IN ALGEBRA	10MATH04-018-E	One possibility is a course in commutative algebra covering prime ideals and maximal ideals, nilradical and jacobson radical, prime avoidance and the Chinese remainder theorem, extension and contraction of ideals, modules, submodules and quotient modules, direct sum and direct product, finitely generated modules and Nakayama lemma, exact sequences, tensor products, restriction and extension of scalars, exactness properties of the tensor product, algebras, tensor product of algebras, localization, local properties, extended and contracted ideals in rings of fractions, primary decomposition,

		integral extensions, lying over, going-up theorems, integrally closed domains and the going-down theorem, valuation rings, Noetherian and Artinian modules, Noetherian rings, Hilbert basis theorem, primary decomposition in Noetherian rings, Artinian rings and their structure, discrete valuation rings and Dedekind domains, fractional ideals, completions, filtrations, topologies, and completions, graded rings and modules, associated graded ring, dimension theory, Hilbert functions, dimension theory of Noetherian local rings, regular local rings, transcendental dimension, relation to algebraic varieties and algebraic geometry.
TOPICS IN OPERATOR ALGEBRAS	10MATH04-019-E	Some possibilities are: Banach algebras, spectrum, spectral radius formula, C*-algebras, Gelfand Naimark theorem, continuous functional calculus, GNS construction, positivity, measurable functional calculus, von Neumann algebras, Kaplansky density theorem, double commutant theorem, finite-dimensional C*-algebras, representation theory of the C*-algebra of compact operators, Toeplitz algebra, Coburn's theorem, group C*-algebras, crossed products, amenability, groupoid C*-algebras.
TOPICS IN REPRESENTATION THEORY	10MATH04-020-E	Some possibilities are: Lie algebras: definition and basic properties, ideals, subalgebras, homomorphisms, nilpotent and solvable Lie algebras, Lie's and Engel's theorems, semisimple Lie algebras, the Killing form, Cartan's criterion, abstract Jordan decomposition, classification of finite dimensional semisimple Lie algebras, Dynkin diagrams, the Weyl group, isomorphism and conjugacy theorems, representations, Verma modules, category O, irreducible highest weight modules, complete reducibility, Weyl character formula, Freudenthal weight multiplicity formula, Kostant and Steinberg formulas.
TOPICS IN ALGEBRAIC COMBINATORICS	10MATH04-021-E	Some possibilities are: Partially ordered sets and Mobius inversion, generating functions, permutations and statistics, Robinson-Schensted correspondence, partitions, Young's lattice, hook-length formula, Representation theory of symmetric groups, similarity classes of

		matrices and orthogonal polynomials.
TOPICS IN TOPOLOGY	10MATH04-022-E	Definitions and basic construction of homotopy groups, Whitehead's theorem, Hurewicz's theorem, stable homotopy groups, fibrations and obstruction theory, Bott's periodicity theorem, H-cobordism theorem, construction and applications of characteristic classes.
TOPICS IN SYMPLECTIC GEOMETRY	10MATH04-023-E	Possibilities include: Motivations of sympletic Geometry from Hamiltonian mechanics, neighbourhood theorems, compatible almost complex structure, and the contractibility of the space of almost complex structures, integrability of almost complex structures, Newlander-Nirenberg theorem, Hamiltonian circle actions on symplectic manifolds, moment maps, Fubini-Studi form on projective space, Kähler forms as Hessians of plurisubharmonic function on complex manifolds, introduction to pseudoholomorphic curves, outline of proof of Gromov's non-squeezing theorem.
PROGRAMMING FOR MATHEMATICIANS	10MATH04-024-E	Some possibilities are: Basic python syntax, Iterables and generators, Object oriented programming, introduction to Sage, the Numpy library, the Networkx library, graphics with Sage and Matplotlib and a Programming project.

BACK TO MAIN

INTEGRATED Ph.D. in PHYSICAL SCIENCES (Program Code: PHYS05)

I. Courses at HRI

Program Code : PHYS05	Programme Specific Outcome	Understanding and knowledge of physics in the classical and quantum domain.
		Understanding of mathematical methods in their applications in diverse settings.
		Understanding and application of statistical methods in physics
		Provide exposure to various specialised areas such as condensed matter, atomic physics, particle physics, astrophysics, and quantum information.
		Learning many body techniques as well as quantum field theoretic methods and applying them to solve problems.

(A) Core Courses

SEMISTER – I

Sr. No.	Name of the Course	Course code
1	Classical Mechanics	08PHYS05-001-C
2	Quantum Mechanics I	08PHYS05-002-C
3	Electrodynamics	08PHYS05-003-C
4	Mathematical Methods I	08PHYS05-004-C
5	Laboratory I	08PHYS05-005-C

SEMISTER – II

Sr. No.	Name of the Course	Course code
1	Numerical Methods	08PHYS05-006-C
2	Quantum Mechanics II	08PHYS05-007-C
3	Statistical Mechanics	08PHYS05-008-C
4	Electronics	08PHYS05-009-C
5	Laboratory II	08PHYS05-010-C

SEMISTER – III

Sr. No.	Name of the Course	Course code
1	Condensed Matter I	08PHYS05-011-C
2	Quantum Mechanics III	08PHYS05-012-C
3	Quantum Field Theory I	08PHYS05-013-C
4	Mathematical Methods II	08PHYS05-014-C
5	Elective I	08PHYS05-015-C

SEMISTER – IV

Sr. No.	Name of the Course	Course code
1	Particle Physics	08PHYS05-016-C
2	Elective II	08PHYS05-017-C
3	Elective III	08PHYS05-018-C
4	Project	08PHYS05-019-C
5	Laboratory III	08PHYS05-020-C

(B) Electives I (choose any one)

Sr. No.	Name of the Course	Course code
1	Advanced Statistical Mechanics	08PHYS05-001-E
2	Fluid Mechanics,	08PHYS05-002-E
3	General Relativity	08PHYS05-003-E
4	Non-linear Dynamics	08PHYS05-004-E
5	Quantum Information and Computation I.	08PHYS05-005-E

(C) Electives II & III (choose any two)

Sr. No.	Name of the Course	Course code
1	Astrophysics	08PHYS05-006-E
2	Condensed Matter Physics II	08PHYS05-007-E

3	Cosmology	08PHYS05-008-E
4	Introduction to Electronic Structure	08PHYS05-009-E
5	Quantum Field Theory II	08PHYS05-010-E
6	Quantum Information and Computation II	08PHYS05-011-E
7	Quantum Optics	08PHYS05-012-E
8	Soft Matter	08PHYS05-013-E
9	Ultra Cold Atoms	08PHYS05-014-E

SEMISTER V

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Quantum Field Theory I	08PHYS05-021-C
2	Mathematical Methods II	08PHYS05-022-C
3	Project	08PHYS05-023-C

(B) Electives (choose any one)

Sr. No.	Name of the Course	Course code
1	Fluid Mechanics	08PHYS05-015-E
2	General Theory of Relativity	08PHYS05-016-E
3	Nonlinear Dynamics	08PHYS05-017-E
4	Quantum Information and Computation I	08PHYS05-018-E
5	Quantum Mechanics III	08PHYS05-019-E

SEMISTER VI

(A) Core Courses

Sr. No.	Name of the Course	Course code
1	Statistical Mechanics	08PHYS05-024-C
2	Research Methodology and Numerical Methods	08PHYS05-025-C

(B) Electives (choose any two)

Sr. No.	Name of the Course	Course code
1	**Astrophysics**	08PHYS05-020-E
2	Condensed Matter Physics II	08PHYS05-021-E
3	Cosmology	08PHYS05-022-E
4	Introduction to Electronic Structure Calculations	08PHYS05-023-E
5	Particle Physics	08PHYS05-024-E
6	Quantum Field Theory II	08PHYS05-025-E
7	Quantum Information and Computation II	08PHYS05-026-E
8	Quantum Optics	08PHYS05-027-E
9	Soft Matter	08PHYS05-028-E
10	Ultra cold Atoms	08PHYS05-029-E

Course Outcomes:

(A) Core Courses

SEMISTER I

Name of the Course	Course code	Course Outcome
Classical Mechanics	08PHYS05-001-C	Acquiring knowledge of Lagrangian and Hamiltonian formulations of classical dynamics.
		Acquiring knowledge of basic concepts of classical mechanics such as general theory of conservation laws, phase space and Poisson brackets.
		Understanding the theory of rigid body motion.
		Acquiring knowledge of applications such as the central force problem, small oscillations, non-linear dynamics.
Quantum Mechanics I	08PHYS05-002-C	Acquiring working knowledge of the basic concepts of quantum mechanics: states, operators and time evolution.
		Understanding of the role of symmetries in quantum mechanics.

		Understanding of the theory of angular momentum in quantum mechanics.
		Acquiring knowledge of applications such as the hydrogen atom, charged particle in a magnetic field and a particle in a periodic potential.
		Acquiring knowledge of perturbation theory in quantum mechanics and applications such as Stark and Zeeman effect.
Electrodynamics	08PHYS05-003-C	Acquiring knowledge of special theory of relativity and its role in electromagnetism.
		Acquiring knowledge of electrostatics and magnetostatics.
		Acquiring knowledge of the theory of electromagnetic radiation.
		Acquiring knowledge of scattering of electromagnetic waves.
Mathematical Methods I	08PHYS05-004-C	Acquiring knowledge of vector spaces and it applications to various physical problems.
		Acquiring knowledge of complex analysis and it applications to various physical problems.
		Acquiring knowledge of the theory of ordinary differential equations and it applications in various physical problems.
		Acquiring basic knowledge of the theory of statistics and its applications in interpretation of data
Laboratory I	08PHYS05-005-C	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment

SEMISTER II

Name of the Course	Course code	Course Outcome
Numerical Methods	08PHYS05-006-C	Ability to write codes using programming languages: F77, F90 or C.
		Acquiring knowledge of numerical linear algebra, interpolation techniques, generation and use of random numbers.

		Acquiring knowledge of numerical differentiation and integration (including Monte Carlo techniques).
		Acquiring knowledge of numerical methods to treat ODEs and PDEs: including FFT and finite difference methods, integral equations
Quantum Mechanics II	08PHYS05-007-C	Understanding of the theory and applications of scattering in quantum mechanics.
		Acquiring knowledge of the method of path integrals in quantum mechanics.
		Acquiring knowledge of the concept of entanglement in quantum mechanics and it applications such as Bell's inequalities.
		Acquiring knowledge of relativistic quantum mechanics and its applications.
Statistical Mechanics	08PHYS05-008-C	Acquiring knowledge of basics concepts such as phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.
		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Electronics	08PHYS05-009-C	Acquiring basic knowledge of circuit theory: lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive networks.
		Acquiring knowledge of basics of analog electronics, including that of diodes and LEDs.
		Acquiring knowledge basic knowledge of amplifiers.
		Acquiring knowledge of the basics digital electronics: logic gates, truth table,

		multiplexer, combinatorial circuits, flip-flop, and microprocessors.
Laboratory II	08PHYS05-010-C	Laboratory Experience with Coupled Oscillator Circuits:
		Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors
		Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
		Laboratory Experience with Flip-flops and Microcontrollers.

SEMISTER III

Name of the Course	Course code	Course Outcome
Condensed Matter I	08PHYS05-011-C	Understanding of the basic building blocks of matter and methods to probe structure of materials.
		Acquiring knowledge of the physics of metals.
		Acquiring knowledge of the physics of phonons.
		Acquiring knowledge of the physics of superconductors.
		Acquiring knowledge of the physics of magnetism.
Quantum Mechanics III	08PHYS05-012-C	Acquiring knowledge of the basics of atomic spectra in single electron atoms.
		Acquiring knowledge of atomic spectra in many electron atoms and molecules.
		Acquiring knowledge of the interaction of light and matter.
		Understanding of the basic theory involved in the study of cold atoms.
Quantum Field Theory I	08PHYS05-013-C	Acquiring knowledge of the method of second quantization for the study of many particle non-relativistic systems.
		Acquiring knowledge of the Lorentz group and its role in relativistic quantum field theory.
		Acquiring knowledge of the quantization of the Klein Gordon, Dirac and Maxwell fields.
		Acquiring knowledge of the basics of quantum electrodynamics and the study of various processes at tree level.

		Understanding of the role of gauge invariance in quantum electrodynamics.
Mathematical Methods II	08PHYS05-014-C	Ability to analyse phenomena using Fourier and Laplace transformation
		Ability to construct and solve higher order differential equation
		Understanding to apply Laplace and Poisson equation to electrostatics, Heat equation, Wave equation
		Understanding Group theory concepts and its application in Lie algebras
Elective I	08PHYS05-015-C	Application of Advanced Statistical Mechanics/ Fluid Dynamics/General Theory of Relativity/Techniques in Nonlinear Dynamics/Quantum Information and Computation I. in solving the problems related to the study.

SEMISTER IV

Name of the Course	Course code	Course Outcome
Particle Physics	08PHYS05-016-C	Understanding physics of elementary particles.
		Learning about fundamental interactions in terms of gauge principle.
		Acquiring skills to carry out computation in Strong, Weak and Electromagnetic theory.
		Learning various techniques useful for particle physics phenomenology.
		Learning methods to compute physical observables which can tested in the laboratory.
Elective II	08PHYS05-017-C	Application of Advanced Statistical Mechanics/ Fluid Dynamics/General Theory of Relativity/Techniques in Nonlinear Dynamics/Quantum Information and Computation I. in solving the problems related to the study.
Elective III	08PHYS05-018-C	Application of Advanced Statistical Mechanics/ Fluid Dynamics/General Theory of Relativity/Techniques in Nonlinear Dynamics/Quantum Information and Computation I. in solving the problems related to the study.
Project	08PHYS05-019-C	Ability to formulate a research problem
		Developing scientific skills to solve the problem

		Acquiring knowledge to interpret, discuss and communicate scientific results in written and oral form
Laboratory III	08PHYS05-020-C	Learning about the magnetic phase transition
		Learning Raman spectroscopy using lasers.
		Carry out the experiments with radioactive samples using the GM counter and gamma-ray spectrometer.
		Studying the Bragg diffraction using microwaves, and measuring the speed of light using laser source.
		Studying the Hall effect, Electron spin resonance, and measuring earth's magnetic field using NMR.

(B) Electives I (choose any one)

Name of the Course	Course code	Course Outcome
Advanced Statistical Mechanics	08PHYS05-001-E	Acquiring knowledge of the basics of Critical phenomena.
		Understanding of the notion of Renormalization in statistical mechanics.
		Understanding of the basics of Equilibrium dynamics: Conserved and broken symmetry variables, Hydrodynamic approach, Dynamical critical phenomena.
		Acquiring basic knowledge of Non-equilibrium phenomena and stochastic thermodynamics.
Fluid Mechanics	08PHYS05-002-E	Acquiring knowledge of the basic concepts in the study of ideal fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity.
		Study of viscous fluids.
		Acquiring knowledge of the basic topics in the theory of turbulence.
		Understanding of Thermal Conduction in fluids.
		Acquiring basic knowledge of Relativistic Fluid dynamics.
General Relativity	08PHYS05-003-E	Acquiring basic knowledge of differential geometry.
		Understanding of the equivalence principle and its applications.

		Acquiring knowledge of Einstein equation
		Acquiring knowledge of Schwarzschild solution along with applications.
		Acquiring knowledge of the theory of gravitational waves.
		Acquiring knowledge of the basics of Friedman-Robertson-Walker cosmology.
Non-linear Dynamics	08PHYS05-004-E	Acquiring knowledge of long time behavior of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.
		Acquiring knowledge of the nature of orbits for conservative and non-conservative systems.
		Understanding of maps, fixed points, cycles and stability, bifurcations.
		Basic understanding of chaos.
		Understanding of different kinds of perturbation theory for calculating orbits.
Quantum Information and Computation I.	08PHYS05-005-E	Understanding of the concept of entanglement: quantification and detection in bipartite and multipartite systems.
		Acquiring knowledge of the basics of quantum communication.
		Acquiring knowledge of the basics of quantum cryptography and quantum computation.
		Acquiring knowledge of the basics of the interface of quantum information with other sciences and experimental realizations.

(C) Electives II & III (choose any two)

Name of the Course	Course code	Course Outcome
Astrophysics	08PHYS05-006-E	Learning about magneto hydrodynamics with applications to Astrophysical systems.
		Study of stellar structure and developing detailed understanding of structure of stars.
		Developing understanding of the models of galaxies.
		Acquiring knowledge of the accretion of matter due to a point mass.

		Developing introductory understanding of cosmology.
Condensed Matter Physics II	08PHYS05-007-E	Learning the skill to study low dimensional systems.
		Understanding theories which describe charge transport in mesoscopic systems.
		Acquiring knowledge of the electronic structure in low dimensional systems.
		Learning about the effects of phonons in metals and dielectric properties of insulators.
		Acquiring knowledge of correlated electron systems.
		Learning about the Mott transition, the Kondo systems, Superconductivity and magnetism.
		Learning formalism necessary to study Quantum Hall systems, quantum wires and dots.
Cosmology	08PHYS05-008-E	Learning about the cosmological model, the cosmological constant and the dark matter.
		Developing the understanding of the thermal history of the universe and its imprints on CMB.
		Understanding the horizon problem and its resolution by inflation.
		Acquiring the knowledge of the theory of cosmological perturbations.
		Studying the implications of the cosmological perturbation on the structure formation.
Introduction to Electronic Structure	08PHYS05-009-E	Acquiring the knowledge of the first principle computation, methods like the H-F approximation.
		Learning the Density Functional theory, and various approximations within the formulation
		Learning the pseudo potential method and its applications.
		Application of these methods to study the band structure of various materials.
Quantum Field Theory II	08PHYS05-010-E	Understanding the Path Integral formulation of quantum field theory.
		Acquiring the knowledge of the regularisation methods and the renormalisation.

		Developing the understanding of spontaneous symmetry breaking and its implications
		Learning the non-abelian gauge theories and their quantisation.
		Learning the renormalisation of the non-abelian gauge theories both in the symmetric and symmetry broken phase
Quantum Information and Computation II	08PHYS05-011-E	Learning the concept of decoherence.
		Understanding the Markovian vs non-Markovian processes and their master equations.
		Learning about the resource theory.
		Developing the understanding of quantum thermodynamics.
		Relating the quantum information systems with the condensed matter systems.
		Acquiring the knowledge of the entanglement theory, and quantum correlations.
Quantum Optics	08PHYS05-012-E	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.
		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.
Soft Matter	08PHYS05-013-E	Learning about what scales are involved in soft matter.
		Studying the phase transition using various techniques.
		Understanding the colloidal systems.
		Developing the intuition about polymers and membranes.
		Learning about the experimental methods.
Ultra Cold Atoms	08PHYS05-014-E	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.

		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.

SEMISTER V

(A) Core Courses

Name of the Course	Course code	Course Outcome
Quantum Field Theory I	08PHYS05-021-C	Acquiring knowledge of the method of second quantization for the study of many particle non-relativistic systems.
		Acquiring knowledge of the Lorentz group and its role in relativistic quantum field theory.
		Acquiring knowledge of the quantization of the Klein Gordon, Dirac and Maxwell fields.
		Acquiring knowledge of the basics of quantum electrodynamics and the study of various processes at tree level.
		Understanding of the role of gauge invariance in quantum electrodynamics.
Mathematical Methods II	08PHYS05-022-C	Ability to analyse phenomena using Fourier and Laplace transformation
		Ability to construct and solve higher order differential equation
		Understanding to apply Laplace and Poisson equation to electrostatics, Heat equation, Wave equation
		Understanding Group theory concepts and its application in Lie algebras
Project	08PHYS05-023-C	Ability to formulate a research problem
		Developing scientific skills to solve the problem
		Acquiring knowledge to interpret, discuss and communicate scientific results in written and oral form

(B) Electives

Name of the Course	Course code	Course Outcome
Fluid Mechanics	08PHYS05-015-E	Acquiring knowledge of the basic concepts in the study of ideal fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity.
		Study of viscous fluids.

		Acquiring knowledge of the basic topics in the theory of turbulence.
		Understanding of Thermal Conduction in fluids.
		Acquiring basic knowledge of Relativistic Fluid dynamics
General Theory of Relativity	08PHYS05-016-E	Acquiring basic knowledge of differential geometry.
		Understanding of the equivalence principle and its applications.
		Acquiring knowledge of Einstein equation,
		Acquiring knowledge of Schwarzschild solution along with applications.
		Acquiring knowledge of the theory of gravitational waves.
		Acquiring knowledge of the basics of Friedman-Robertson-Walker cosmology.
Nonlinear Dynamics	08PHYS05-017-E	Acquiring knowledge of long time behavior of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.
		Acquiring knowledge of the nature of orbits for conservative and non-conservative systems.
		Understanding of different kinds of perturbation theory for calculating orbits
		Understanding of maps, fixed points, cycles and stability, bifurcations.
		Basic understanding of chaos.
Quantum Information and Computation I	08PHYS05-018-E	Learning the concept of decoherence.
		Understanding the Markovian vs non-Markovian processes and their master equations.
		Acquiring the knowledge of the entanglement theory, and quantum correlations.
		Learning about the resource theory.
		Developing the understanding of quantum thermodynamics.
		Relating the quantum information systems with the condensed matter systems.
Quantum Mechanics III	08PHYS05-019-E	Acquiring knowledge of the basics of atomic spectra in single electron atoms.
		Acquiring knowledge of atomic spectra in many electron atoms and molecules.

		Acquiring knowledge of the interaction of light and matter.
		Understanding of the basic theory involved in the study of cold atoms.
		Acquiring knowledge of the basics of atomic spectra in single electron atoms.
		Acquiring knowledge of atomic spectra in many electron atoms and molecules.

SEMISTER VI

(A) Core Courses

Name of the Course	Course code	Course Outcome
Statistical Mechanics	08PHYS05-024-C	Acquiring knowledge of basics concepts such as phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.
		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Research Methodology and Numerical Methods	08PHYS05-025-C	Acquiring knowledge of research Methodology including quantitative methods, communication skills, seminar presentation and review of research papers.
		Introduction to programming languages: F77, F90 or C.
		Acquiring knowledge of numerical linear algebra, interpolation techniques, generation and use of random numbers.
		Acquiring knowledge of numerical differentiation and integration (including Monte Carlo techniques).
		Acquiring knowledge of numerical methods to treat ODEs and PDEs:

		including FFT and finite difference methods, integral equations.

(B) Electives

Name of the Course	Course code	Course Outcome
Astrophysics	08PHYS05-020-E	Learning about magnetohydrodynamics with applications to Astrophysical systems.
		Study of stellar structure and developing detailed understanding of structure of stars.
		Developing understanding of the models of galaxies.
		Acquiring knowledge of the accretion of matter due to a point mass.
		Developing introductory understanding of cosmology.
Condensed Matter Physics II	08PHYS05-021-E	Learning the skill to study low dimensional systems.
		Understanding theories which describe charge transport in mesoscopic systems.
		Acquiring knowledge of the electronic structure in low dimensional systems.
		Learning about the effects of phonons in metals and dielectric properties of insulators.
		Learning formalism necessary to study Quantum Hall systems, quantum wires and dots.
		Acquiring knowledge of correlated electron systems.
		Learning about the Mott transition, the Kondo systems, Superconductivity and magnetism.
Cosmology	08PHYS05-022-E	Learning about the cosmological model, the cosmological constant and the dark matter.
		Developing the understanding of the thermal history of the universe and its imprints on CMB.
		Understanding the horizon problem and its resolution by inflation.
		Acquiring the knowledge of the theory of cosmological perturbations.
		Studying the implications of the cosmological perturbation on the structure formation.

Introduction to Electronic Structure Calculations	08PHYS05-023-E	Acquiring the knowledge of the first principle computation, methods like the H-F approximation.
		Learning the Density Functional theory, and various approximations within the formulation.
		Learning the pseudo potential method and its applications.
		Application of these methods to study the band structure of various materials.
Particle Physics	08PHYS05-024-E	Understanding physics of elementary particles.
		Learning about fundamental interactions in terms of gauge principle.
		Acquiring skills to carry out computation in Strong, Weak and Electromagnetic theory.
		Learning various techniques useful for particle physics phenomenology.
		Learning methods to compute physical observables which can tested in the laboratory
Quantum Field Theory II	08PHYS05-025-E	Understanding the Path Integral formulation of quantum field theory.
		Acquiring the knowledge of the regularisation methods and the renormalisation.
		Developing the understanding of spontaneous symmetry breaking and its implications.
		Learning the non-abelian gauge theories and their quantisation.
		Learning the renormalisation of the non-abelian gauge theories both in the symmetric and symmetry broken phase.
Quantum Information and Computation II	08PHYS05-026-E	Learning the concept of decoherence.
		Understanding the Markovian vs non-Markovian processes and their master equations.
		Acquiring the knowledge of the entanglement theory, and quantum correlations.
		Learning about the resource theory.
		Developing the understanding of quantum thermodynamics.
		Relating the quantum information systems with the condensed matter systems.

Quantum Optics	08PHYS05-027-E	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.
		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.
Soft Matter	08PHYS05-028-E	Learning about what scales are involved in soft matter.
		Studying the phase transition using various techniques.
		Understanding the colloidal systems.
		Developing the intuition about polymers and membranes.
		Learning about the experimental methods.
Ultra cold Atoms	08PHYS05-029-E	Learning about the scales involved in the system.
		Understanding the experimental background, like trapping, optical lattices, Feshbach resonance, etc.
		Using many body methods to study phase transition, perturbation theory.
		Learning about the Bose condensation and its theoretical aspects.
		Developing the understanding of the BCS instability in sermonic system.
		Studying the quantum spin systems.

II. Courses at IMSc

Program Code : PHYS05	Programme Specific Outcome	Physics at IMSc need to do 1st two semesters of course work in standard Master Degree level courses in Classical Mechanics, Quantum Mechanics I & II, Classical Electromagnetism, Mathematical Methods, Statistical Mechanics, Classical Field Theory, and Condensed Matter Physics I.
		The 3rd and 4th semester courses for Integrated Ph.D. students in IMSc are respectively same as the 1st and 2nd semester courses for the Ph.D. students in Physics at IMSc.
		In their 3rd semester, the students are being taught advanced level courses (aiming to take up research problems) in Statistical Mechanics, Mathematical Methods, as well as introductory courses on Particle Physics and Quantum Field Theory (which includes a part on Many-Body Field Theory, used for advanced courses in Condensed Matter Physics).
		In their 4th semester, the students need to credit two research-level courses either in High Energy Physics (Quantum Field Theory II, Cosmology and Gravitation, Particle Physics II) or in Low Energy Physics (Advanced Condensed Matter Physics, Non- linear Dynamics, Quantum Information and Computation, Statistical Field Theory) as well as a research project, which is, generally taken up by the student towards pursuing his/her Ph.D. research work here at IMSc.
		The students do have the freedom to shift their choice of topics for Ph.D. even if they do their 4th semester courses entirely in High Energy Physics or Low Energy Physics – provided the students are confident enough and they can find suitable Ph.D. guides at IMSc in that directions.

(A) Semester I:

Sr. No.	Name of the Course	Course code
1	Classical Mechanics	11

2	Quantum Mechanics I	12
3	Electromagnetic Theory	13
4	Mathematical methods	14

(B) Semester II:

Sr. No.	Name of the Course	Course code
1	Quantum Mechanics II	21
2	Classical Field Theory	22
3	Condensed Matter Physics I	23
4	Statistical Mechanics	24

(C) Semester III:

Sr. No.	Name of the Course	Course code
1	Quantum Field Theory I	31
2	Mathematical Methods II	32
3	Statistical Mechanics II	33
4	Particle Physics I	34

(D) Semester III:

1. High Energy Physics (HEP):

Sr. No.	Name of the Course	Course code
1	Quantum Field Theory II	41
2	Cosmology-and-Gravitation Or Particle Physics	42a 42b

2. Low Energy Physics (LEP):

Sr. No.	Name of the Course	Course code
1	Advanced Condensed Matter Physics	43
2	Nonlinear Dynamics Or Quantum Information-and-Computation Or Statistical Field Theory	44a 44b 44c

Course Outcomes:

(A) Semester I

Name of the Course	Course code	Course Outcome
Classical Mechanics	11	After successfully completing the course, the students should have mastery over Lagrangian and Hamiltonian formulations, Hamilton-Jacobi formalism, methods of dealing with constrained classical systems, canonical transformations, symmetries in the classical world, relativistic mechanics, rudiments of non-linear dynamics.
		The students should acquire the knowledge of dealing with generic dynamical systems (be it classical or quantum) using the language of Lagrangian and Hamiltonian.
		Students should develop analytical as well as numerical powers to solve problems in Mechanics – both for theoretical purpose as well as for problems of practical interests.
Quantum Mechanics I	12	Students should learn and internalize the formalism required to describe principles of Quantum Mechanics: Hilbert space formalism involving states, observables, dynamics, and measurement.
		After internalizing and maneuvering principles of Quantum Mechanics, the students should master the techniques of solving exactly (and thereafter, approximately) one, two, and three dimensional potential problems.
		They should also learn how to deal with different symmetries.
Electromagnetic Theory	13	Techniques of Electrostatics and Magnetostatics should be learnt properly.
		Students should learn, understand, and internalize Mawell's equations, their interpretations, and applications, particularly in Radiation Theory, Antenna Theory, etc.
		Students should also learn the four-vector formalism to treat Maxwell's equations in terms of Electromagnetic field.
Mathematical methods	14	Students should learn the theory of Complex Analysis as well as its applications in different problems in Physics.
		Students should develop mastery over different aspects of Linear Algebra and its applications in different branches of Physics.
		Students should develop adequate working

		knowledge (together with thorow knowledge in the corresponding theory) in solutions of ordinary differential and integral equations, different integral transforms, etc.

(B) Semester II

Name of the Course	Course code	Course Outcome
Quantum Mechanics II	21	Students should learn and thereby apply the method of second quantization – required to treat system of indistinguishable particles – while dealing with many-body quantum systems.
		WKB approximation, various variation methods, etc. Should be learnt and internalized by the students. Moreover, the students should develop clear idea about rudiments of scattering in the quantum world.
		Students should develop mastery over Path Integral Approach to Quantum Mechanics and its applications.
		Students should also develop skills to deal with the phase-space description of Quantum Mechanical systems – particularly useful to deal with the continuous-variable case.
Classical Field Theory	22	Students should develop working level understanding (together with thorough knowledge in its theoretical part also) in Continuum Mechanics, Hydrodynamics, Electrodynamics, Gravitation, and Landau-Ginzburg theory.
		The idea behind teaching this course is to bring together different classical fields into one platform.
Condensed Matter Physics I	23	Students should develop concrete ideas about length, time, and energy scales while dealing with many-body systems – both soft and hard condensed matter.
		Particularly, the students should develop mastery over different properties of crystals, electronic properties of many- body systems, lattice vibrations, rudiments of semi-conductor physics, optical properties of different materials, the notion of super-fluidity and different magnetism properties.
Statistical Mechanics	24	Students should develop thorough knowledge in fundamental principles of Statistical Mechanics: Probability Theory, Ergodicity, Mixing, etc.
		Students should have prior familiarity with

		the laws of Thermodynamics, so that they can apply their knowledge of Statistical Mechanics of the present course to derive different laws of Thermodynamics.
		The notion of Gibbs distribution should be thoroughly understood and internalized.
		Students should also develop clear understanding regarding how to deal with system of non-interacting/interacting particles.

(C) Semester III:

Name of the Course	Course code	Course Outcome
Quantum Field Theory I	31	Students should develop a mastery over elementary processes in Quantum Electrodynamics (QED): electron-positron annihilation, Compton scattering, Bhabha scattering, etc.
		Students should learn and internalize different radiative corrections for scalar field theory. They also learn techniques of scalar field quantization, as well as the techniques of dealing with non-interacting electrons from field theoretic perspectives.
		In the remaining one-third of the QFT-I course, LSZ formalism, Path integral formalism, and renormalization techniques are being taught for HEP-oriented students in order that they can use these techniques for their research in HEP.
		Similarly, in the other remaining one-third of the QFT-I course, operator techniques of second quantization, Kubo formula, system of interacting bosons, techniques mean- field theory, etc. Are being taught for LEP- oriented students in order that they can use these techniques for their research in LEP.
Mathematical Methods II	32	Students are supposed to learn and thereby apply different numerical techniques : interpolation methods, numerical solutions of ordinary and partial differential equations, Monte-Carlo method, numerical optimization, numerical techniques of dealing with fast Fourier transforms, etc.
		Students should develop a thorough working knowledge (together with the corresponding theoretical development) in the representation theories of discrete as well as continuous groups used in Classical and Quantum Mechanics.

		Students should develop working knowledge (as well as theoretical understanding) in topics of advanced Complex Analysis: analytic continuation, branch cuts, Riemann surfaces, conformal mapping, etc.
		Students should develop working knowledge in rudiments of Probability Theory.
Statistical Mechanics II	33	Students should develop a working knowledge about critical phenomena: scaling hypothesis, self-similarity, and fractals. Moreover, they should develop a thorough knowledge regarding criticality in spin systems, classical field theory, etc.
		Students should understand, internalize, and thereby, apply techniques of renormalization group – including both perturbative as well as non-perturbative cases.
		Students should develop a very good understanding about broken symmetry, how deal with disorders in systems, and dynamics of fluctuations (including the fluctuation-dissipation theorem).
Particle Physics I	34	Students should develop a thorow knowledge on standard model in Particle Physics, including symmetries & quarks, Parton model & QCD, etc.
		Moreover, students should develop concrete ideas about different decay processes, V-A theory of weak interactions, CP violation, etc.
		They should have a very good working knowledge in the unification of electromagnetic and weak interactions.
		Working knowledge about neutrinos.

(D) Semester IV:

1. **Electives- HEP**

Name of the Course	Course code	Course Outcome
Quantum Field Theory II	41	This advanced-level course in Quantum Field Theory (QFT) aims at training the students to the extent where they can initiate some research project in High Energy Physics.
		In this course, students are supposed to develope working expertise in topics like: functional methods in QFT, funtional integral quantization of non-Abelian gauge fields, applications of renormalization group, anomalies in abelian as well as non-abelian gauge theories, etc.
Cosmology and Gravitation	42a	This advanced-level course in Cosmology & Gravitation aims at training the students to the extent where they can initiate some research project in Astrophysics, Cosmology, etc.
		In this course, students are supposed to develope working expertise in topics like: Einstein's field equations and their different solutions, Hamiltonian formulation of Gravity, Cosmology, singularity theorems, etc.
Particle Physics-II	42b	This advanced-level course in Particle Physics aims at training the students to the extent where they can initiate some research project in Particle Physics.
		In this course, students are supposed to develope working expertise in topics like: basics of the Standard Model, Electroweak interaction, Quantum Chromodynamics, Neutrino Physics, CP violation, Supersymmetry, Grand unified theory, etc.

2. **Electives- LEP**

Name of the Course	Course code	Course Outcome
Advanced Condensed Matter Physics	43	This advanced-level course in Condensed Matter Physics aims at training the students to the extent where they can initiate some research project in Hard/Soft Condensed Matter Physics.
		In this course, students are supposed to develope working expertise in: Correlated Electron Physics and Soft Condensed Matter Physics.

Nonlinear Dynamics	44a	This advanced-level course in Nonlinear Dynamics (NLD) aims at training the students to the extent where they can initiate some research project in different branches of Physics where Nonlinear Dynamics plays a vital role – apart from Nonlinear Dynamics itself. In this course, students are supposed to develope working expertise in: Hamiltonian formulation of NLD, Deterministic NLD, Integrability of Hamiltonian Dynamics, Chaos, Semiclassical Analysis of NLD, Quantum Aspects of NLD, etc.
Quantum Information-and-Computation	44b	This advanced-level course aims at training the students to the extent where they can initiate some research project in different branches of Physics where Information Theory plays a vital role – apart from Quantum Information & Computation itself. In this course, students are supposed to develope working expertise in: Entanglement Theory and its applications, Shannon's Theory of Classical Information & its Quantum generalizations, Quantum Cryptography, Quantum Computation, physical implementaions, etc.
Statistical Field Theory	44c	This advanced-level course aims at training the students to the extent where they can initiate some research project in Statistical Mechanics or its applications in fields like Condensed Matter Physics, Particle Physics, etc. In this course, students are supposed to develope working expertise in: Bose-Einstein condensation, Fermions, diagrammatic techniques, self-coupled scaler field theory, Yukawa theory, spontaneous symmetry breaking & Higgs model of Quantum Chromodynamics, deconfinement phase transition, Salam-Weinberg model and symmetry restoration, early universe, nuclear matter & pion condensation, neutron stras, etc.

III. Courses at NISER

Program Code : PHYS05	Programme Specific Outcome	Doctoral program at School of Physical Sciences, NISER, in general, leads to critical thinking, effective scientific communication, scientific ethics, social interactions and ability to solve complex problems in nature.
		The Core courses of the program provide comprehensive grounding in all the basic areas of Physics which consolidate student understanding and provide foundation for future research. This set of courses which aim both at recapitulation of known concepts and an emphasis on advanced problem solving techniques help to bring students from diverse kinds of training at the Master's level up to the uniform high standards required at NISER. The Comprehensive exam at the end of the course work makes sure that students are well prepared to start their research.
		Elective courses provide advanced knowledge of specialized topics which broaden student horizon. Research projects under the guidance of faculty members give students exposure to current research areas in the department. By the end of the first year students have a clear idea of the research they want to do based on the elective courses and the projects they have done.
		Students work under our experienced faculty and use world class research labs and computational facilities to do their doctoral work. They are trained to identify, formulate and execute projects based on important problems in their chosen research field. An active group of postdoctoral fellows and several national and international collaborations are available for students to develop collaborative skills and mature into independent researchers. Most students are expected to have published work in good quality journals to get a PhD degree.
		A doctoral committee (monitoring committee in the first year) constantly monitors student progress. Students are required to give annual talks on the progress made by them in the previous year. This gives them training in

		giving academic talks and they also get regular feedback on their progress.
		Regular seminars and conferences on topics of current research interests are regularly organized in the department to expose students to cutting edge topics. Students are required to attend outside conferences and become trained in publicizing their research work through research talks or poster presentations to the community

(A) Core Courses:

Sr. No.	Name of the Course	Course code
1	Classical Mechanics	P601
2	Mathematical Methods	P602
3	Electromagnetism	P603
4	Self-Study/Mini project/credit seminar	P698
5	Statistical Mechanics	P614
6	Quantum Mechanics	P615
7	Mini Project	P699

(B) Elective Courses:

Sr. No.	Name of the Course	Course code
1	Nuclei and Particle Physics	P648
2	Atoms Molecules and Radiation	P649
3	Introduction to Condensed Matter Physics	P650
4	Advanced Solid State Physics	P651
5	Computational Physics	P652
6	Quantum Field Theory I	P653
7	Particle Physics	P654
8	Introduction to Phase transitions and Critical phenomena	P655
9	Nonlinear Optics and Lasers	P656
10	General Relativity and Cosmology	P657
11	Soft Condensed Matter	P658

12	Applied Nuclear Physics	P659
13	Many Particle Physics	P660
14	Physics of Mesoscopic Systems	P661
15	Introduction to Quantum Optics	P662
16	Astronomy and Astrophysics	P663
17	Plasma Physics and Magnetohydrodynamics	P664
18	Biophysics	P665
19	Quantum Nanoelectronics	P666
20	Nonlinear Physics, Chaos and Turbulence	P667
21	Magnetism and Superconductivity	P668
22	Density Functional Theory of Atoms, Molecules and Solids	P669
23	Quantum Field Theory II	P670
24	Quantum Information and Quantum computation	P671
25	Experimental High Energy Physics	P672
26	Experimental Techniques	P673
27	Introduction to Cosmology	P674

Course Outcomes:

(A) Core Courses

Name of the Course	**Course code**	**Course Outcome**
Classical Mechanics	P601	This course reviews the concepts of Masters level classical mechanics with more emphasis on the applied/problem solving aspects.
		This course is meant to prepare the students for more rigorous analytical treatment of the subject required for research.
Mathematical Methods	P602	This course reviews the important mathematical tools required for physicists for implementation in research work in all specialization of physical sciences.
Electromagnetism	P603	This course reviews masters level electricity and magnetism with more emphasis on problem solving and applications.

		This course is meant to prepare students for taking up realistic research challenges involving one of the most important class of interactions in Physics.
Self-Study/Mini project/credit seminar	P698	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Statistical Mechanics	P614	This course reviews masters level statistical mechanics and thermodynamics and prepares students for analyzing research problems/results in a wide variety of situations involving statistical mechanics.
Quantum Mechanics	P615	This course reviews masters level quantum mechanics and prepares students for analyzing research problems/results in a wide variety of situations involving quantum mechanics.
Mini Project	P699	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) Elective Courses:

Name of the Course	Course code	Course Outcome
Nuclei and Particle Physics	P648	Provides training in basic concepts and methods in nuclear physics, stability of nucleons and classification of interactions.
		The course prepares the student to begin working in experimental and theoretical high energy physics.
Atoms Molecules and Radiation	P649	Important topics in atomic physics, selection rules, atomic and molecular spectroscopy is taught.
		The training is imperative to work in the area of applied solid state physics and optics.
Introduction to Condensed Matter Physics	P650	This is the first course in condensed matter physics and draws on quantum and statistical mechanics to provide a foundation in basic concepts and techniques required to tackle advanced courses in the area of solid state physics.

Advanced Solid State Physics	P651	This is a course which aims to prepare students with advanced concepts, techniques and knowledge of solid state physics that allows them to start working on basic research problems in the broad area of condensed matter theory, materials theory or solid state experiments.
Computational Physics	P652	This course provides training in computation tools required in research across a wide variety of fields including condensed matter, high energy phenomenology and lattice field theories.
Quantum Field Theory I	P653	This first course on quantum field theory prepares the student for tackling future advanced courses in the area of high energy physics.
Particle Physics	P654	This course teaches the basics of particle physics and allows the student to start beginning research work in high energy phenomenology.
Introduction to Phase transitions and Critical phenomena	P655	This course teaches the students advanced concepts and methods in statistical mechanics crucial for the student to take up basic research work.
Nonlinear Optics and Lasers	P656	This course teaches the students advanced concepts and methods in modern topics in laser optics and non-linear optics necessary for the student to take up basic research work in optics.
General Relativity and Cosmology	P657	This course teaches the students, advanced concepts and methods in general relativity crucial for the student for building their background for research work in general relativity and cosmology.
Soft Condensed Matter	P658	This course teaches the students advanced concepts and methods in soft matter physics, with the aim to build their background for future research work in this area.
Applied Nuclear Physics	P659	This course teaches the students advanced concepts and methods in applied nuclear physics, with the aim to build their background for future research work in this area.
Many Particle Physics	P660	This course teaches the students advanced concepts and methods in many particle physics, with the aim to build their background for future research work in this area.
Physics of Mesoscopic Systems	P661	This course teaches the students advanced concepts and methods in mesoscopic physics,

		with the aim to build their background for future research work in this area.
Introduction to Quantum Optics	P662	This course teaches the students important concepts and methods in quantum optics, with the aim to build their background for future research work in this area.
Astronomy and Astrophysics	P663	This course teaches the students important concepts and methods in Astronomy and Astrophysics, with the aim to build their background for future research work in this area.
Plasma Physics and Magnetohydrodynamics	P664	This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.
Biophysics	P665	This course teaches the students important concepts and methods in biophysics, with the aim to build their background for future research work in this area.
Quantum Nanoelectronics	P666	This course teaches the students important concepts and methods in nanoelectronics, with the aim to build their background for future research work in this area.
Nonlinear Physics, Chaos and Turbulence	P667	This course teaches the students important concepts and methods in classical nonlinear dynamics, with the aim to build their background for future research work in this area.
Magnetism and Superconductivity	P668	This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.
Density Functional Theory of Atoms, Molecules and Solids	P669	This course teaches the students important concepts and methods in density functional theory, with the aim to build their background for future research work in this area.
Quantum Field Theory II	P670	This course teaches the students important concepts and methods in advanced quantum field theory, with the aim to build their background for future research work in this area.

Quantum Information and Quantum computation	P671	This course teaches the students important concepts and methods in quantum information and computation, with the aim to build their background for future research work in this area.
Experimental High Energy Physics	P672	This course teaches the students important concepts and methods in experimental high energy physics, with the aim to build their background for future research work in this area.
Experimental Techniques	P673	This course teaches the students important concepts and methods in experimental techniques, with the aim to build their background for future research work in this area.
Introduction to Cosmology	P674	This course teaches the students important concepts and methods in introductory cosmology, with the aim to build their background for future research work in this area.

DIPLOMA in MEDICAL RADIOISOTOPE TECHNIQUES (DMRIT)
(Program Code: HLTH07)

Course Structure:

I. Courses at BARC

Program Code :HLTH07	Programme Specific Outcome	To learn and strengthen knowledge related to basic sciences applied in nuclear medicine. To learn and apply principles of radiation protection in nuclear medicine laboratories.
		To be able to understand and apply knowledge of radiation detectors and various imaging and non imagingequipments like Uptake probe, Gamma Camera, SPECT, PET, Intraoperative Probes in a nuclear medicine laboratory. Role and application of complimentary imaging devices such as USG, CT & MRI.
		To introduce and train on concepts of radionuclide generators and medical cyclotron, radiopharmacy techniques and understand the in-vivo kinetics of radiopharmaceuticals used in imaging and therapy.
		To understand quality control of instruments and radiopharmaceuticals. To understand and adopt appropriate quality assurance practices in delivery of nuclear medicine services.
		To be able to assume responsibility as Nuclear Medicine Physicist, Imaging Technologist, Radiopharmacist and give orientation to function as Radiation Safety Officer.

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	Basic Sciences For Nuclear Medicine	01HLTH07-001-C
2	Radiation Physics, Radiation Biology & Radiation Protection	01HLTH07-002-C
3	Diagnostic Radiopharmaceuticals & In-Vitro Techniques	01HLTH07-003-C
4	Instrumentation & Imaging Technology	01HLTH07-004-C
5	Clinical Nuclear Medicine Techniques	01HLTH07-005-C

(B) PRACTICLAS

Sr. No.	Name of the Course	Course code
1	Physics of Nuclear Medicine	01HLTH07-001-P
2	Clinical Nuclear Medicine Techniques	01HLTH07-002-P
3	Apprentice Program	01HLTH07-003-P

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Basic Sciences For Nuclear Medicine	01HLTH07-001-C	Understand and strengthen concepts of human anatomy and physiology, basics of –cell biology, -immunlogy, -molecular biology, -biochemistry, chemistry, electronics, mathematicsand statistics related to nuclear medicine.
		Obtain concepts on medical terminology, common hospital practices and biomedical statistics.
Radiation Physics, Radiation Biology & Radiation Protection	01HLTH07-002-C	Understand and apply nuclear medicine-related concepts of nuclear physics, detectors viz.gas filled, liquid scintillation, organic and inorganic

		scintillation, & semiconductor, counting statistics, gamma ray spectrometry, radiation biology, personnel monitoring devices, radiation protection & dosimetry, radioactive material transport & waste management, radiation emergencies & preparedness in nuclear medicine setup.
Diagnostic Radiopharmaceuticals & In-Vitro Techniques	01HLTH07-003-C	Understand and apply knowledge of various radionuclides and radiopharmaceuticals in clinical NM including the fundamentals of radiolabelling procedures, quality control, bio-distribution and clinical translation.
		Understand fundamental concepts of compartmental analysis, biomedical application of nanotechnology, and design of radiopharmacy laboratory.
		Acquire knowledge of diagnostic in-vitro techniques for detection of various drugs, hormones, or microbes using RIA, IRMA, Radiorespirometry, Radioreceptor assay, and other Immunoassays and quality control of these procedures.
Instrumentation & Imaging Technology	01HLTH07-004-C	Understand functioning of imaging & non-imaging Nuclear Medicine instruments, their quality control, and application, viz. rectilinear scanner, gamma camera, SPECT, PET-CT, uptake probe, gamma probe, whole body counter, dose calibrator and radiation monitoring instruments.
		Principle and functioning of Medical Cyclotron and complimentary imaging devices such as USG, CT & MRI. Recent advances in SPECT, PET, developments in detector systems including hybrid systems such as PET-MRI.
		Understand the role and application of Computer and Medical informatics in Nuclear Medicine.
Clinical Nuclear Medicine Techniques	01HLTH07-005-C	Understand and apply knowledge about non-imaging techniques using radionuclides.
		Understand and apply knowledge in patient preparation & instruction, interventional approaches, selection/choice of -radiopharmaceuticals and its dose, equipment, -imaging techniques, &imaging parameters for various nuclear medicine procedures. Learn specific techniques applied for various organ imaging, tumour imaging, lymphoscintigraphy, sentinel node scintigraphy, infection and inflammation.

		Learn and apply techniques in Image processing and recording, image display & report generation. To enable skillfull application of gained knowledge in performing quantitative data analysis.
		Learn and understand techniques applied in therapeutic nuclear medicine for choice of radionuclide and radiopharmaceuticals for therapy, pre therapy workup, and post therapy imaging.
		Learn and apply radiation protection measures in diagnostic and therapeutic Nuclear Medicine. Learn protection of patient, regulatory aspects like layout of laboratory, patient discharge limits, AERB directives for dose limits, Safety Code, Duties of RSO.

(B) PRACTICALS

Name of the Course	Course code	Course Outcome
Physics of Nuclear Medicine	01HLTH07-001-P	To study and perform practicals on basic aspects of instrumentsused in nuclear medicine, including performance evaluation and quality control.
		To study effect of counting statistics and errors in measurements.
		To prepare radiopharmaceuticals in a hospital radiopharmacy setup and to perform their Quality control tests (physicochemical & biological).
		To study characteristics of Geiger Mueller Counters for its application in monitoring and surveillance.
Clinical Nuclear Medicine Techniques	01HLTH07-002-P	To understand and perform nuclear medicine procedures including, -patient preparation, -radiopharmaceutical preparation & their quality control, -dose administration, -data acquisition, -data processing, -report generation, and evaluation of these techniques.
Apprentice Program	01HLTH07-003-P	To undergo one year programme that imparts extensive trainingon aspects of Scintigraphy, PET-CT, Health Physics, Radiation Monitoring and Clinical Nuclear Medicine Techniques. To learn and understand the practices adopted in a state-of-art diagnostic and therapeutic nuclear medicine setup through hands-on training.

BACK TO MAIN

M.Sc. in PHYSICAL SCIENCES

(Program Code: PHYS08)

Course Structure:

I. Courses at HRI

Program Code : PHYS08	Programme Specific Outcome	Understanding and knowledge of physics in the classical domain.
		Understanding and knowledge of physics in the quantum domain.
		Understanding and application of statistical methods in physics
		Laboratory experience so that students are exposed to modern experimental techniques.
		Understanding of mathematical methods in their applications in diverse settings.
		Provide exposure to various specialised areas such as condensed matter, nuclear physics, atomic physics, particle physics, astrophysics and quantum information
		Introduction to methods that will be lifelong assets for careers in research and development.

(A) Core Courses

SEMISTER – I

Sr. No.	Name of the Course	Course code
1	Classical Mechanics	08PHYS08-001-C
2	Quantum Mechanics I	08PHYS08-002-C
3	Electrodynamics	08PHYS08-003-C
4	Mathematical Methods I	08PHYS08-004-C
5	Laboratory I	08PHYS08-005-C

SEMISTER – II

Sr. No.	Name of the Course	Course code
1	Numerical Methods	08PHYS08-006-C
2	Quantum Mechanics II	08PHYS08-007-C
3	Statistical Mechanics	08PHYS08-008-C

4	Electronics	08PHYS08-009-C
5	Laboratory II	08PHYS08-010-C

SEMISTER – III

Sr. No.	Name of the Course	Course code
1	Condensed Matter I	08PHYS08-011-C
2	Quantum Mechanics III	08PHYS08-012-C
3	Quantum Field Theory I	08PHYS08-013-C
4	Mathematical Methods II	08PHYS08-014-C
5	Elective I	08PHYS08-015-C

SEMISTER – IV

Sr. No.	Name of the Course	Course code
1	Particle Physics	08PHYS08-016-C
2	Elective II	08PHYS08-017-C
3	Elective III	08PHYS08-018-C
4	Project	08PHYS08-019-C
5	Laboratory III	08PHYS08-020-C

(B) Electives I (choose any one)

Sr. No.	Name of the Course	Course code
1	Advanced Statistical Mechanics	08PHYS08-001-E
2	Fluid Mechanics	08PHYS08-002-E
3	General Relativity	08PHYS08-003-E
4	Non-linear Dynamics	08PHYS08-004-E
5	Quantum Information and Computation I.	08PHYS08-005-E

(C) Electives II & III (choose any two)

Sr. No.	Name of the Course	Course code
1	Astrophysics	08PHYS08-006-E
2	Condensed Matter Physics II	08PHYS08-007-E
3	Cosmology	08PHYS08-008-E
4	Introduction to Electronic Structure	08PHYS08-009-E
5	Quantum Field Theory II	08PHYS08-010-E
6	Quantum Information and Computation II	08PHYS08-011-E
7	Quantum Optics	08PHYS08-012-E
8	Soft Matter	08PHYS08-013-E
9	Ultra Cold Atoms	08PHYS08-014-E

Course Outcomes:

(A) Core Courses

SEMISTER I

Name of the Course	Course code	Course Outcome
Classical Mechanics	08PHYS08-001-C	Acquiring knowledge of Lagrangian and Hamiltonian formulations of classical dynamics.
		Acquiring knowledge of basic concepts of classical mechanics such as general theory of conservation laws, phase space and Poisson brackets.
		Understanding the theory of rigid body motion.
		Acquiring knowledge of applications such as the central force problem, small oscillations, non-linear dynamics.
Quantum Mechanics I	08PHYS08-002-C	Acquiring working knowledge of the basic concepts of quantum mechanics: states, operators and time evolution.
		Understanding of the role of symmetries in quantum mechanics.
		Understanding of the theory of angular momentum in quantum mechanics.
		Acquiring knowledge of applications such as the hydrogen atom, charged particle in a magnetic field and a particle in a periodic potential.

		Acquiring knowledge of perturbation theory in quantum mechanics and applications such as Stark and Zeeman effect.
Electrodynamics	08PHYS08-003-C	Acquiring knowledge of special theory of relativity and its role in electromagnetism.
		Acquiring knowledge of electrostatics and magnetostatics.
		Acquiring knowledge of the theory of electromagnetic radiation.
		Acquiring knowledge of scattering of electromagnetic waves.
Mathematical Methods I	08PHYS08-004-C	Acquiring knowledge of vector spaces and it applications to various physical problems.
		Acquiring knowledge of complex analysis and it applications to various physical problems.
		Acquiring knowledge of the theory of ordinary differential equations and it applications in various physical problems.
		Acquiring basic knowledge of the theory of statistics and its applications in interpretation of data
Laboratory I	08PHYS08-005-C	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment

SEMISTER II

Name of the Course	Course code	Course Outcome
Numerical Methods	08PHYS08-006-C	Ability to write codes using programming languages: F77, F90 or C.
		Acquiring knowledge of numerical linear algebra, interpolation techniques, generation and use of random numbers.
		Acquiring knowledge of numerical differentiation and integration (including Monte Carlo techniques).
		Acquiring knowledge of numerical methods to treat ODEs and PDEs: including FFT and finite difference methods, integral equations
Quantum Mechanics II	08PHYS08-007-C	Understanding of the theory and applications of scattering in quantum mechanics.
		Acquiring knowledge of the method of path integrals in quantum mechanics.

		Acquiring knowledge of the concept of entanglement in quantum mechanics and it applications such as Bell's inequalities.
		Acquiring knowledge of relativistic quantum mechanics and its applications.
Statistical Mechanics	08PHYS08-008-C	Acquiring knowledge of basics concepts such as phase space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.
		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Electronics	08PHYS08-009-C	Acquiring basic knowledge of circuit theory: lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive networks.
		Acquiring knowledge of basics of analog electronics, including that of diodes and LEDs.
		Acquiring knowledge basic knowledge of amplifiers.
		Acquiring knowledge of the basics digital electronics: logic gates, truth table, multiplexer, combinatorial circuits, flip-flop, and microprocessors.
Laboratory II	08PHYS08-010-C	Laboratory Experience with Coupled Oscillator Circuits:
		Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors
		Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator

		Laboratory Experience with Flip-flops and Microcontrollers.

SEMISTER III

Name of the Course	Course code	Course Outcome
Condensed Matter I	08PHYS08-011-C	Understanding of the basic building blocks of matter and methods to probe structure of materials.
		Acquiring knowledge of the physics of metals.
		Acquiring knowledge of the physics of phonons.
		Acquiring knowledge of the physics of superconductors.
		Acquiring knowledge of the physics of magnetism.
Quantum Mechanics III	08PHYS08-012-C	Acquiring knowledge of the basics of atomic spectra in single electron atoms.
		Acquiring knowledge of atomic spectra in many electron atoms and molecules.
		Acquiring knowledge of the interaction of light and matter.
		Understanding of the basic theory involved in the study of cold atoms.
Quantum Field Theory I	08PHYS08-013-C	Acquiring knowledge of the method of second quantization for the study of many particle non-relativistic systems.
		Acquiring knowledge of the Lorentz group and its role in relativistic quantum field theory.
		Acquiring knowledge of the quantization of the Klein Gordon, Dirac and Maxwell fields.
		Acquiring knowledge of the basics of quantum electrodynamics and the study of various processes at tree level.
		Understanding of the role of gauge invariance in quantum electrodynamics.
Mathematical Methods II	08PHYS08-014-C	Ability to analyse phenomena using Fourier and Laplace transformation
		Ability to construct and solve higher order differential equation
		Understanding to apply Laplace and Poisson equation to electrostatics, Heat equation, Wave equation
		Understanding Group theory concepts and its application in Lie algebras
Elective I	08PHYS08-015-C	Application of Advanced Statistical Mechanics/ Fluid Dynamics/General Theory of Relativity/Techniques in Nonlinear Dynamics/Quantum Information and Computation I. in solving the problems related to the study.

SEMISTER IV

Name of the Course	Course code	Course Outcome
Particle Physics	08PHYS08-016-C	Understanding physics of elementary particles.
		Learning about fundamental interactions in terms of gauge principle.
		Acquiring skills to carry out computation in Strong, Weak and Electromagnetic theory.
		Learning various techniques useful for particle physics phenomenology.
		Learning methods to compute physical observables which can tested in the laboratory.
Elective II	08PHYS08-017-C	Application of Astrophysics/Condensed Matter Physics / Cosmology/Electronic Structure Calculations/Quantum Field Theory/ Quantum Optics/ Soft Matter/ Ultra cold Atoms in solving the problems related to the study.
Elective III	08PHYS08-018-C	Application of Astrophysics/Condensed Matter Physics / Cosmology/Electronic Structure Calculations/Quantum Field Theory/ Quantum Optics/ Soft Matter/Ultra cold Atoms in solving the problems related to the study.
Project	08PHYS08-019-C	Ability to formulate a research problem
		Developing scientific skills to solve the problem
		Acquiring knowledge to interpret, discuss and communicate scientific results in written and oral form
Laboratory III	08PHYS08-020-C	Learning about the magnetic phase transition
		Learning Raman spectroscopy using lasers.
		Carry out the experiments with radioactive samples using the GM counter and gamma-ray spectrometer.
		Studying the Bragg diffraction using microwaves, and measuring the speed of light using laser source.
		Studying the Hall effect, Electron spin resonance, and measuring earth's magnetic field using NMR.

(B) Electives I (choose any one)

Name of the Course	Course code	Course Outcome
Advanced Statistical Mechanics	08PHYS08-001-E	Acquiring knowledge of the basics of Critical phenomena.
		Understanding of the notion of Renormalization in statistical mechanics.

		Understanding of the basics of Equilibrium dynamics: Conserved and broken symmetry variables, Hydrodynamic approach, Dynamical critical phenomena.
		Acquiring basic knowledge of Non-equilibrium phenomena and stochastic thermodynamics.
Fluid Mechanics	08PHYS08-002-E	Acquiring knowledge of the basic concepts in the study of ideal fluids: Euler equation, hydrostatics, Bernoulli equation, conservation laws, incompressible fluids, waves, irrotational flows, inviscid fluids and vorticity.
		Study of viscous fluids.
		Acquiring knowledge of the basic topics in the theory of turbulence.
		Understanding of Thermal Conduction in fluids.
		Acquiring basic knowledge of Relativistic Fluid dynamics.
General Relativity	08PHYS08-003-E	Acquiring basic knowledge of differential geometry.
		Understanding of the equivalence principle and its applications.
		Acquiring knowledge of Einstein equation
		Acquiring knowledge of Schwarzschild solution along with applications.
		Acquiring knowledge of the theory of gravitational waves.
		Acquiring knowledge of the basics of Friedman-Robertson-Walker cosmology.
Non-linear Dynamics	08PHYS08-004-E	Acquiring knowledge of long time behavior of the solutions of a system of ordinary nonlinear differential equations, fixed points and their classification according to stability.
		Acquiring knowledge of the nature of orbits for conservative and non-conservative systems.
		Understanding of maps, fixed points, cycles and stability, bifurcations.
		Basic understanding of chaos.
		Understanding of different kinds of perturbation theory for calculating orbits.

Quantum Information and Computation I.	08PHYS08-005-E	Understanding of the concept of entanglement: quantification and detection in bipartite and multipartite systems.
		Acquiring knowledge of the basics of quantum communication.
		Acquiring knowledge of the basics of quantum cryptography and quantum computation.
		Acquiring knowledge of the basics of the interface of quantum information with other sciences and experimental realizations.

(C) Electives II & III (choose any two)

Name of the Course	Course code	Course Outcome
Astrophysics	08PHYS08-006-E	Learning about magnetohydrodynamics with applications to Astrophysical systems.
		Study of stellar structure and developing detailed understanding of structure of stars.
		Developing understanding of the models of galaxies.
		Acquiring knowledge of the accretion of matter due to a point mass.
		Developing introductory understanding of cosmology.
Condensed Matter Physics II	08PHYS08-007-E	Learning the skill to study low dimensional systems.
		Understanding theories which describe charge transport in mesoscopic systems.
		Acquiring knowledge of the electronic structure in low dimensional systems.
		Learning about the effects of phonons in metals and dielectric properties of insulators.
		Acquiring knowledge of correlated electron systems.
		Learning about the Mott transition, the Kondo systems, Superconductivity and magnetism.
		Learning formalism necessary to study Quantum Hall systems, quantum wires and dots.
Cosmology	08PHYS08-008-E	Learning about the cosmological model, the cosmological constant and the dark matter.

		Developing the understanding of the thermal history of the universe and its imprints on CMB.
		Understanding the horizon problem and its resolution by inflation.
		Acquiring the knowledge of the theory of cosmological perturbations.
		Studying the implications of the cosmological perturbation on the structure formation.
Introduction to Electronic Structure	08PHYS08-009-E	Acquiring the knowledge of the first principle computation, methods like the H-F approximation.
		Learning the Density Functional theory, and various approximations within the formulation
		Learning the pseudo potential method and its applications.
		Application of these methods to study the band structure of various materials.
Quantum Field Theory II	08PHYS08-010-E	Understanding the Path Integral formulation of quantum field theory.
		Acquiring the knowledge of the regularisation methods and the renormalisation.
		Developing the understanding of spontaneous symmetry breaking and its implications
		Learning the non-abelian gauge theories and their quantisation.
		Learning the renormalisation of the non-abelian gauge theories both in the symmetric and symmetry broken phase
Quantum Information and Computation II	08PHYS08-011-E	Learning the concept of decoherence.
		Understanding the Markovian vs non-Markovian processes and their master equations.
		Learning about the resource theory.
		Developing the understanding of quantum thermodynamics.
		Relating the quantum information systems with the condensed matter systems.

		Acquiring the knowledge of the entanglement theory, and quantum correlations.
Quantum Optics	08PHYS08-012-E	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.
		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.
Soft Matter	08PHYS08-013-E	Learning about what scales are involved in soft matter.
		Studying the phase transition using various techniques.
		Understanding the colloidal systems.
		Developing the intuition about polymers and membranes.
		Learning about the experimental methods.
Ultra Cold Atoms	08PHYS08-014-E	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.
		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.

M.D. in PATHOLOGY
(Program Code: HLTH09A01)

Program Code : HLTH09A01	Programme Outcome	To produce a specialist who is competent to provide a high quality diagnostic opinion in a given clinical situation with an appropriate and relevant sample, able to teach undergraduate and post-graduate, capable of pursuing clinical and laboratory based research and is familiar with current developments and advances in the field of pathology.

Course Structure:

I. Courses at TMC

Program Code : HLTH09A01	Programme Specific Outcome	Experience of the diagnostic techniques required to become technically competent in Practical Laboratory Diagnostic Work
		Broad practical and theoretical knowledge of all aspects of routine surgical pathology and also specialist areas such as cytopathology, hematology, oncopathology and histopathology of specific systems in order to be able to provide specialist advice
		Experience of the practice of evidence based clinical medicine through attendance in joint clinics or multi-disciplinary teams.
		Inculcating a habit of literature searches, attendance at scientific meetings, and the presentation of scientific work
		Competency for planning, organizing and establishing pathology services / department in all types of medical establishments
		Competency to impart training to students at various levels including postgraduate level in the subject and carry out research

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	SURGICAL PATHOLOGY	09HLTH09A01-001-C
2	AUTOPSY PATHOLOGY	09HLTH09A01-002-C
3	CLINICAL PATHOLOGY and ROUTINE HEMATOLOGY	09HLTH09A01-003-C
4	HEMATOPATHOLOGY	09HLTH09A01-004-C
5	IMMUNOLOGY	09HLTH09A01-005-C
6	TRANSFUSION MEDICINE	09HLTH09A01-006-C
7	BIOCHEMISTRY / LABORATORY MEDICINE	09HLTH09A01-007-C
8	MOLECULAR PATHOLOGY	09HLTH09A01-008-C
9	CYTOGENETICS	09HLTH09A01-009-C
10	MEDICLA STATISTICS	09HLTH09A01-010-C
11	LIBRARY / INFORMATION RETRIEVAL/ WEB SEARCH ENGINES in MEDICINE	09HLTH09A01-011-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
SURGICAL PATHOLOGY	09HLTH09A01-001-C	Grossing of all surgical specimens in keeping with protocol or guidelines for handling various specimens
		Identifyand accurately describe the chief gross and microscopic alterations in the surgically removed specimens
		Correctly diagnose majority of the lesions received on an average day from the surgical service of a general hospital.
		Knowledge and incorporation of internationally approved terminology for classification of diseases e.g. WHO and TNM staging for tumors.
AUTOPSY PATHOLOGY	09HLTH09A01-002-C	To perform autopsies safely, eviscerate and dissect organs

		To liaise with clinician and identify issues to be addressed by autopsy examination
		Correctly identify all major lesions which have caused, or contributed to, the patient's death on macroscopic examination.
CLINICAL PATHOLOGY and ROUTINE HEMATOLOGY	09HLTH09A01-003-C	Establish and direct a hematopathology laboratory that includes clinical hematology, urine analysis, clinical microscopy, flow cytometry and diagnostic hematopathology
		To provide consultation to clinicians on patient problems related to hematopathology.
HEMATOPATHOLOGY	09HLTH09A01-004-C	Work up of an aspirate right from obtaining the peripheral blood smear, bone marrow aspirate smear, requesting relevant lab tests and obtaining history to microscopic examination.
		Learn normal aspirate cellular findings, approach to abnormal findings and integrate aspirate with trephine biopsy findings
		Recognize normal WBC, RBC and platelet maturation, as well as cellular dysplasia
		Diagnosis of all common hematological conditions including hemogloleukaemia and lymphomas.
		Recognize reactive bone marrow and abnormal infiltrates, effects of chemotherapy and growth factor stimulation on blood and bone marrow
		Evaluate and interpret results of flow cytometry in conjunction with morphology,cytochemistry, clinical presentation, and immunohistochemistry studies
IMMUNOLOGY	09HLTH09A01-005-C	Interpret lymphocyte subset by immunophenotyping on flow cytometry and use data to characterize leukocyte populations
		Interpret the protein electrophoresis patterns observed in normal serum, normal plasma, normal urine, and in large monoclonal gammopathies such as

		multiple myeloma and Waldenstrom'smacroglobulinemia
		Knowledge of the role of the complement system or proteins in health and disease, complement protein measurements to assess inherited and acquired deficiency states, Understand the acute phase response and acute phase proteins, such as C-reactive protein, to assess inflammatory conditions. Understand cytokines as mediators and markers of immune and inflammatory responses.
		Bone marrow and solid organ transplant – principles, GVHD types and diagnosis, chimerism
TRANSFUSION MEDICINE	09HLTH09A01-006-C	Good practice for collection of blood and bleeding donors, phlebotomy techniques.
		Procedure for correct identification of blood sample and to perform ABO and Rh Grouping (cell and reverse), cross match procedure, Direct Coombs(DCT)and Indirect Coombs Test (IAT)
		Recognize the symptoms and signs of hemolytic and non-hemolytic transfusion reactions,
		To be able to review requests for blood components and discuss with the requesting physician,
		Collect blood for component preparation and know how to store blood components
BIOCHEMISTRY / LABORATORY MEDICINE	09HLTH09A01-007-C	Plan and organize the work flow in a routine clinical pathology laboratory in keeping with good laboratory practices
		Be able to correctly interpret the laboratory data of such studies, and discuss their significance with a view to arrive at a diagnosis
MOLECULAR PATHOLOGY	09HLTH09A01-008-C	To know the basic structure of DNA / RNA, Various techniques used in molecular pathology, principles, scope and limitations
		Basics of PCR, FISH, Sequencing, NGS-Principle, steps in technique, role in diagnostic pathology and infectious

		diseases, advantages and disadvantages, modifications of technique
CYTOGENETICS	09HLTH09A01-009-C	Demonstrate familiarity with methods of tissue culture and karyotyping in medical cytogenetics and cancer cytogenetics on peripheral blood culture, amniotic fluid culture, bone marrow aspiration culture and basic cytogenetics nomenclature
		Advanced technologies of molecular cytogenetics such as FISH, CGH
		Role of cytogenetics in diagnostic pathology, hematological malignancies, solid tumors and patient management
MEDICAL STATISTICS	09HLTH09A01-010-C	Demonstrate familiarity with importance of statistical methods in assessing data from patient material and experimental studies e.g. correlation coefficients, expected versus observed, etc. and their interpretation.
		Use of SPSS program
LIBRARY / INFORMATION RETRIEVAL/ WEB SEARCH ENGINES in MEDICINE	09HLTH09A01-011-C	To get acquainted with digital library, its services and the effective use of e–resources information to further their knowledge and to supplement conventional reading

M.D. in RADIO-DIAGNOSIS
(Program Code: HLTH09A03)

Program Code : HLTH09A03	Programme Outcome	To train the residents for wholesome approach to clinical scenario and attaining the diagnosis. And to contribute in therapeutic management wherever indicated.
		Application of the knowledge gained, in service and research.
		To be able to participate and contribute in the disease management group discussion in approaching particular case.
		To understand the need to identify emergency scenario and prompt reporting to help in patient management.
		Encourage and guide the students for various paper and case presentations.

Course Structure:

I. Courses at TMC

Program Code : HLTH09A03	Programme Specific Outcome	The candidate should complete the necessary training and mandatory theory as specified in the syllabus of the MD course.
		To participate and excel in the appraisal exams held each year of both theory and practical.
		To learn the need and importance of multidisciplinary approach in patient management.
		To attend and participate in lectures, case discussions and contribute value adding points.
		Provide adequate exposure to interventional radiology and nuclear medicine to give wholesome training.

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	Basic Sciences Related To Radio-Diagnosis	09HLTH09A03-001-C
2	Respiratory System	09HLTH09A03-002-C
3	GASTROINTESTINAL(GIT) And HEPATO-BILIARY-PANCREATIC SYSTEM	09HLTH09A03-003-C

4	Genito-Urinary System	09HLTH09A03-004-C
5	Musculoskeletal System	09HLTH09A03-005-C
6	Cardiovascular Radiology/ Echo Cardiography	09HLTH09A03-006-C
7	Neuroradiology	09HLTH09A03-007-C
8	General Radiology	09HLTH09A03-008-C
9	Ultrasound	09HLTH09A03-009-C
10	Ct	09HLTH09A03-010-C
11	ANGIOGRAPHY And INTERVENTIONAL RADIOLOGY	09HLTH09A03-011-C
12	Paediatric Radiology	09HLTH09A03-012-C
13	RADIOLOGY In EMERGENCY MEDICINE	09HLTH09A03-013-C
14	Oncologic Radiology	09HLTH09A03-014-C
15	Nuclear Medicine	09HLTH09A03-015-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Basic Sciences Related To Radio-Diagnosis	09HLTH09A03-001-C	To understand the basic physics and mechanisms of the various modalities used in Radiodiagnosis and Interventional Radiology so as to plan and modify protocols on case to case basis.
		To be able to decide the modality which can be used in specific indication and execute it.
		To understand the principles and application of radiation protection to the working personnels, staffs as well as the patients. Regular monitoring of the same.
		To understand the pathogenesis and biology of various diseases so as to interpret the imaging findings and correlate with clinical scenario.
Respiratory System	09HLTH09A03-002-C	Understand the etiopathogenesis of the disease and to prioritise the differentials in accordance with the clinical presentation of the patient.
		To differentiate between oncologic and non-oncologic causes.
		To manage the diagnostic interventional procedures like biopsies with adequate pre procedure checklist and post procedure observation of the patient.
		To be able to identify the emergency findings like thromboembolism with prompt reporting and to coordinate with the parent unit for immediate management of the same.
GASTROINTESTINAL(GIT)	09HLTH09A03-003-C	To understand the etiopathogenesis to arrive in diagnosis and to suggest next line of action.
		Give adequate information in the reporting by

And HEPATO-BILIARY-PANCREATIC SYSTEM		discussing with respective parent unit in concordance with the plan of management as in curative or palliative.
		To discuss and plan drainage procedures like PTBD and stenting in necessary scenarios.
		Acquire skills in diagnosing acute conditions like GI bleed with necessary supervision if needed.
Genito-Urinary System	09HLTH09A03-004-C	To learn the anatomy and etiopathogenesis of various oncologic and non-oncologic diseases.
		Plan protocols and additional imaging sequences in required areas like 3D reconstruction images needed for surgical planning.
		To be able to advise follow ups in indeterminate lesions according to accredited guidelines.
Musculoskeletal System	09HLTH09A03-005-C	To interpret the radiographs and identify benign vs malignant conditions and advise the relevant next line of imaging like USG, CT or MRI and image guided biopsies.
		To be able to identify post trauma findings and plan adequate positioning and protocol for the same.
		To understand the mechanism, pathology and imaging findings for sports related injuries and to report the necessary points needed for management.
		To train regarding pain management techniques in patients for diagnostic imaging as well as therapeutic procedures like vertebroplasty.
Cardiovascular Radiology/ Echo Cardiography	09HLTH09A03-006-C	Learn the anatomy, etiopathogenesis and diagnostic approach of the cardiovascular diseases.
		To diagnose and inform the emergency findings in case of pericardial effusion and thrombus.
		To train in the drainage procedure with adequate supervision and necessary setup.
		To prioritise reporting and informing the findings regarding tubes and vascular lines especially in ICU setup.
Neuroradiology	09HLTH09A03-007-C	Understand the normal neuroanatomy and etiopathogenesis, molecular biology of the common conditions.
		To be able to provide prompt diagnosis and management of acute stroke patients.
		Form a diagnostic approach according to the clinical scenario and identify the oncologic, infectious and vascular pathologies. To participate and contribute in joint discussion groups to arrive at clinicoradiological diagnosis.
		Inclusion and knowledge of recent technologies like functional MRI and DTI which help in surgical planning.
General Radiology	09HLTH09A03-008-C	To learn the basic concepts and identification of emergency findings in radiograph reporting.
		To assist, learn and perform the basic

		fluoroscopic procedures. To be able to manage the complications during the same.
		Learn the concepts and reporting in preformed guidelines for mammography. To assign final category and advice the next line of management.
Ultrasound	09HLTH09A03-009-C	To understand the physics and its clinical application of ultrasound techniques.
		To learn and perform various additional techniques like Doppler study, elastography and contrast enhanced USG.
		To learn and acquire the skills of interventional procedures with adequate preparation of patient before procedure.
		Provide prompt portable ultrasound services wherever necessary in case of emergencies, especially ICU and Casualty
CT	09HLTH09A03-010-C	To understand physics and working of various generations of CT and its clinical application for adequate planning of protocols. To know the prerequisites and indication before performing CT.
		To learn about the contrast agents, its side effects and how to manage various reactions with adequate training and monitoring.
		To be able to perform CT guided interventions and learn the mechanism of action of various procedures.
ANGIOGRAPHY And INTERVENTIONAL RADIOLOGY	09HLTH09A03-011-C	To understand the indications and contraindications of a procedure. And on how to manage the complications and required follow up.
		To learn and follow specific checklists in preparation of patients with skills in attaining an informed consent.
		Observing, assisting and learning to do basic procedures routinely done in our institution and to learn the post procedure care to be given.
		Trained to follow the protocol in even emergency situations.
Paediatric Radiology	09HLTH09A03-012-C	Understand the difference in etiopathogenesis and diagnostic approach for common disease in pediatric age group as compared to adults.
		Learn to modify the imaging protocols in accordance with the age and weight of the child.
		Trained to organise and pre plan various imaging services for children under local/ general anesthesia by coordinating with anesthesia team.
		To participate and contribute in multidisciplinary approach in arriving to diagnosis and management plan.
RADIOLOGY In EMERGENCY MEDICINE	09HLTH09A03-013-C	Trained for round the clock services in case of emergencies.
		Trained to give prompt imaging, diagnosis and notifying the treating physician regarding the

		emergency findings.
		Provide prompt portable x ray and ultrasound services wherever necessary in case of emergencies, especially ICU and Casualty
Oncologic Radiology	09HLTH09A03-014-C	Pathogenesis and diagnostic approach in work up of neoplastic diseases of all specialties in oncoradiology. To form a multidisciplinary management group.
		To understand basic cell biology and molecular pathway of various cancers. To learn and follow preformed guidelines while reporting.
		To be able to identify and diagnose the emergency findings in oncologic setup as in tumour bleed, brain herniation due to mass effect.
		To learn and provide necessary image guided procedures to arrive at histopathology and subsequent management.
Nuclear Medicine	09HLTH09A03-015-C	To attain basic knowledge on the various modalities and working mechanism.
		To learn to correlate the radiologic and nuclear medicine scan findings, useful during diagnostic dilemmas and planning of interventional procedures.
		Special training with peripheral RMC posting and lectures on topics for the same are conducted.

M.D. in RADIATION ONCOLOGY
(Program Code: HLTH09)

Course Structure:

I. Courses at TMC

Program Code : HLTH09A04	Programme Specific Outcome	To acquire an understanding of the subject of clinical oncology in general and radiation oncology in particular
		After attending the course, the resident doctors should be able to carry out the diagnosis of the type of cancer
		Training in carrying out the staging of the cancer and its treatment philosophy
		Decision making with regard to the type of therapy to be imparted to the cancer patient.
		Learning practical aspects of all types of radio-therapy techniques

(A) CORE COURSE

SEMISTER I

Sr. No.	Name of the Course	Course code
1	CLINICAL ONCOLOGY–I	09HLTH09A04-001-C
2	PHYSICS–I	09HLTH09A04-002-C
3	MEDICAL STATISTICS & EPIDEMIOLOGY–I	09HLTH09A04-003-C
4	CANCER BIOLOGY–I	09HLTH09A04-004-C
5	RADIOBIOLOGY–I	09HLTH09A04-005-C

SEMISTER II

Sr. No.	Name of the Course	Course code
1	CLINICAL ONCOLOGY–II	09HLTH09A04-006-C
2	PHYSICS–II	09HLTH09A04-007-C
3	MEDICAL STATISTICS & EPIDEMIOLOGY–II	09HLTH09A04-008-C
4	CANCER BIOLOGY–II	09HLTH09A04-009-C
5	RADIOBIOLOGY–II	09HLTH09A04-010-C
6	CHEMOTHERAPY & CLINICAL PHARMACOLOGY–II	09HLTH09A04-011-C

SEMISTER III

Sr. No.	Name of the Course	Course code
1	CLINICAL ONCOLOGY–III	09HLTH09A04-012-C
2	PHYSICS–III	09HLTH09A04-013-C
3	MEDICAL STATISTICS & EPIDEMIOLOGY–III	09HLTH09A04-014-C
4	CANCER BIOLOGY–III	09HLTH09A04-015-C
5	RADIOBIOLOGY –III	09HLTH09A04-016-C
6	CHEMOTHERAPY & CLINICAL PHARMACOLOGY –III	09HLTH09A04-017-C

(B) PRACTICALS

SEMISTER I

Sr. No.	Name of the Course	Course code
1	CLINICAL ONCOLOGY–I	09HLTH09A04-001-P
2	PHYSICS–I	09HLTH09A04-002-P
3	MEDICAL STATISTICS & EPIDEMIOLOGY–I	09HLTH09A04-003-P

4	RADIOBIOLOGY–I	09HLTH09A04-004-P

SEMISTER II

Sr. No.	Name of the Course	Course code
1	CLINICAL ONCOLOGY–II	09HLTH09A04-005-P
2	PHYSICS–II	09HLTH09A04-006-P
3	MEDICAL STATISTICS & EPIDEMIOLOGY–II	09HLTH09A04-007-P
4	CANCER BIOLOGY–II	09HLTH09A04-008-P
5	RADIOBIOLOGY–II	09HLTH09A04-009-P

SEMISTER III

Sr. No.	Name of the Course	Course code
1	CLINICAL ONCOLOGY–III	09HLTH09A04-010-P
2	PHYSICS–III	09HLTH09A04-011-P
3	MEDICAL STATISTICS & EPIDEMIOLOGY–III	09HLTH09A04-012-P
4	CANCER BIOLOGY–III	09HLTH09A04-013-P

Course Outcomes:

(A) CORE COURSES

SEMESTER I

Name of the Course	Course code	Course Outcome
CLINICAL ONCOLOGY–I	09HLTH09A04-001-C	To gain an in-depth understanding of Clinical Oncology in being able to evaluate, diagnose, treat and follow-up a patient with cancer
		Understand the staging and evaluation of patients in the clinic
PHYSICS–I	09HLTH09A04-002-C	Gain an understanding of physics and its application in radiation oncology
		Be able to interpret and participate in basic experiments and other aspects of radiation

		physics necessary to practise radiation Oncology effectively
MEDICAL STATISTICS & EPIDEMIOLOGY–I	09HLTH09A04-003-C	To understand and apply the knowledge of biostatistics to clinical work
		To understand and interpret available literature relevant to the practice of oncology
CANCER BIOLOGY–I	09HLTH09A04-004-C	To understand the pathophysiology of cancer
		To understand the biology underlying the natural history of malignant and other neoplastic processes affecting different parts of the body
		To understand and be able to apply this knowledge in the clinic and research
		Utilise this information in utilising different treatment modalities to oncology
RADIOBIOLOGY–I	09HLTH09A04-005-C	Understand the interaction of radiation in the tissues, cells
		Radio sensitivity of various cells and its clinical implications

SEMESTER II

Name of the Course	Course code	Course Outcome
CLINICAL ONCOLOGY–II	09HLTH09A04-006-C	To gain an in-depth understanding of Clinical Oncology in being able to evaluate, diagnose, treat and follow-up a patient with cancer
		Be able to participate in the decision making process
		Identify the best treatment protocol to manage a patient
		Understand the interaction of radiation and matter and the application of this in the clinic
		To be able to apply the knowledge of medical physics in selection of the right radiotherapy technique and energy for effective and optimal radiotherapy
		Be able to participate in planning, execution, verification and follow-up of patients undergoing radiation therapy
PHYSICS–II	09HLTH09A04-002-C	Be able to interpret and participate in basic experiments and other aspects of radiation physics necessary to practise radiation Oncology effectively
		Be able to understand the application of Radiation Physics in Radiation Oncology
		Be able to choose the appropriate RT equipment for the optimal treatment in a case

		Be able to understand and plan the choice of RT equipment, both external beam and brachytherapy in establishing a RT centre
MEDICAL STATISTICS & EPIDEMIOLOGY–II	09HLTH09A04-008-C	To understand and apply the knowledge of biostatistics to clinical work
		To understand and interpret available literature relevant to the practice of oncology
		To be able to utilise this understanding/ knowledge while working on allocated dissertation/ thesis
		To be able to apply this understanding in the clinic
CANCER BIOLOGY–II	09HLTH09A04-009-C	To understand the biology underlying the natural history of malignant and other neoplastic processes affecting different parts of the body
		To understand and be able to apply this knowledge in the clinic and research
		Utilise this information in utilising different treatment modalities to oncology
RADIOBIOLOGY–II	09HLTH09A04-010-C	Radio sensitivity of various cells and its clinical implications
		Application of this knowledge to determine effective radiotherapy regimes for treatment
		Understand the impact of time, dose and fractionation in Radiotherapy
		Understand the interaction of radiation with other treatment modalities
CHEMOTHERAPY & CLINICAL PHARMACOLOGY–II	09HLTH09A04-011-C	Mechanism of action and groups of various agents used in the clinic
		Clinical application and various chemotherapy, targeted and immunotherapy protocols
		Interaction of radiotherapy and systemic agents
		Delivery of various chemotherapy protocols and managing their toxicity

SEMESTER III

Name of the Course	Course code	Course Outcome
CLINICAL ONCOLOGY–III	09HLTH09A04-012-C	To gain an in-depth understanding of Clinical Oncology in being able to evaluate, diagnose, treat and follow-up a patient with cancer
		Be able to participate in the decision making process
		Identify the best treatment protocol to manage a patient
		Understand the interaction of radiation and matter and the application of this in the clinic

		To be able to apply the knowledge of medical physics in selection of the right radiotherapy technique and energy for effective and optimal radiotherapy
		Be able to participate in planning, execution, verification and follow-up of patients undergoing radiation therapy
		Be able to carry out both external beam and brachytherapy procedures, review patients on treatment, manage radiotherapy/ treatment related toxicity
PHYSICS–III	09HLTH09A04-013-C	Be able to interpret and participate in basic experiments and other aspects of radiation physics necessary to practise radiation Oncology effectively
		Be able to understand the application of Radiation Physics in Radiation Oncology
		Be able to choose the appropriate RT equipment for the optimal treatment in a case
		Be able to understand and plan the choice of RT equipment, both external beam and brachytherapy in establishing a RT centre
		Principles and application of radiation protection and personnel monitoring
MEDICAL STATISTICS & EPIDEMIOLOGY–III	09HLTH09A04-014-C	To understand and apply the knowledge of biostatistics to clinical work
		To understand and interpret available literature relevant to the practice of oncology
		To be able to utilise this understanding/ knowledge while working on allocated dissertation/ thesis
		To be able to apply this understanding in the clinic
CANCER BIOLOGY–III	09HLTH09A04-015-C	To understand the biology underlying the natural history of malignant and other neoplastic processes affecting different parts of the body
		To understand and be able to apply this knowledge in the clinic and research
		Utilise this information in utilising different treatment modalities to oncology
		Apply the knowledge and understanding to apply to research
RADIOBIOLOGY – III	09HLTH09A04-016-C	Understand the impact of time, dose and fractionation in Radiotherapy
		Understand the interaction of radiation with other treatment modalities

<table>
<tr><td></td><td></td><td>Understand and manage any untoward radiation exposure, occupational and lay public radiation exposure</td></tr>
<tr><td rowspan="4">CHEMOTHERAPY & CLINICAL PHARMACOLOGY –III</td><td rowspan="4">09HLTH09A04-017-C</td><td>Mechanism of action and groups of various agents used in the clinic</td></tr>
<tr><td>Clinical application and various chemotherapy, targeted and immunotherapy protocols</td></tr>
<tr><td>Interaction of radiotherapy and systemic agents</td></tr>
<tr><td>Delivery of various chemotherapy protocols and managing their toxicity</td></tr>
</table>

(B) PRACTICALS

SEMESTER I

<table>
<tr><th>Name of the Course</th><th>Course code</th><th>Course Outcome</th></tr>
<tr><td rowspan="2">CLINICAL ONCOLOGY–I</td><td rowspan="2">09HLTH09A04-001-P</td><td>Evaluate patients in the outpatients’ clinics and in-patients’ wards</td></tr>
<tr><td>Attend multidisciplinary clinics</td></tr>
<tr><td rowspan="2">PHYSICS–I</td><td rowspan="2">09HLTH09A04-002-P</td><td>Carry out simple physics treatment calculations</td></tr>
<tr><td>Interpret and apply percentage depth dose charts</td></tr>
<tr><td rowspan="2">MEDICAL STATISTICS & EPIDEMIOLOGY–I</td><td rowspan="2">09HLTH09A04-003-P</td><td>Solve basic statistics problems</td></tr>
<tr><td>Evolve hypothesis</td></tr>
<tr><td>RADIOBIOLOGY–I</td><td>09HLTH09A04-004-P</td><td>Evaluate and monitor radiation induced toxicity</td></tr>
</table>

SEMESTER II

<table>
<tr><th>Name of the Course</th><th>Course code</th><th>Course Outcome</th></tr>
<tr><td rowspan="3">CLINICAL ONCOLOGY–II</td><td rowspan="3">09HLTH09A04-005-P</td><td>Participate and make treatment decisions</td></tr>
<tr><td>Be able to plan treatment protocols for patients</td></tr>
<tr><td>Execute all forms of radiotherapy: EBRT to brachytherapy, conventional to adaptive, using advanced RT techniques like IMRT, VMAT, etc</td></tr>
<tr><td rowspan="4">PHYSICS–II</td><td rowspan="4">09HLTH09A04-006-P</td><td>Treatment planning</td></tr>
<tr><td>Treatment time calculation</td></tr>
<tr><td>Plan evaluation</td></tr>
<tr><td>Execute, verify radiation treatment</td></tr>
<tr><td rowspan="4">MEDICAL STATISTICS & EPIDEMIOLOGY–II</td><td rowspan="4">09HLTH09A04-007-P</td><td>Formulation of thesis protocol</td></tr>
<tr><td>Designing of clinical trial</td></tr>
<tr><td>Interpretation of results</td></tr>
<tr><td>Application of knowledge to clinic</td></tr>
</table>

CANCER BIOLOGY–II	09HLTH09A04-008-P	Participating in simple experiments in translational research
RADIOBIOLOGY–II	09HLTH09A04-009-P	Decide/ choose optimal dose/ fractionation schedules
		Calculation of Biologically Effective Doses for tumour control, acute and late effects using the LQ model.
		Clonogenic assays and Survival Fraction (SF2)
		Using Radio-sensitizers or Radio-Protectors (e.g. Amifostine, 2-Deoxy-Glucose, Curcumin).

SEMESTER III

Name of the Course	Course code	Course Outcome
CLINICAL ONCOLOGY–III	09HLTH09A04-010-P	Complex Simulation and treatment techniques e.g. asymmetric beam, TSET, Craniospinal Irradiation, Paediatric tumours, TBI.
		Treatment Planning (mixed beam, matching fields, electrons, head and neck implants)
		Intracavitary, ILRT and simple implants
		Preparing Surface Moulds
		Assisting EBRT, Head/Neck Implant, Templates
		Cytotoxic drugs (Taxenes, BCNU, High dose Methotrexate, Interferon, G-CSF, Leuprolide etc.)
PHYSICS–III	09HLTH09A04-011-P	3-Dimensional conformal planning
		Electronic portal imaging
		Networking
		Quality assurance tests in radiotherapy
MEDICAL STATISTICS & EPIDEMIOLOGY–III	09HLTH09A04-012-P	Role and function of cancer registries
		Multivariate analysis
		Meta Analysis
		Writing research articles for journals
CANCER BIOLOGY–III	09HLTH09A04-013-P	Understanding micro-array technique

BACK TO MAIN

M.D. in MICROBIOLOGY
(Program Code: HLTH09A05)

Program Code : HLTH09A05	Programme Outcome	The purpose is to create specialists who would provide high quality health care and advance the cause of science through research and training

Course Structure:

I. Courses at TMC

Program Code : HLTH09A05	Programme Specific Outcome	Student should be able to: 1. Demonstrate competence as a clinical microbiologist
		2. Interact effectively with the allied department by rendering services in basic as well as advanced laboratory investigations
		3. Demonstrate application of microbiology in a variety of clinical settings to solve diagnostic and therapeutic problems along with preventive measures
		4. Play a pivotal role in hospital infection control, including formulation of antibiotic policy and management of biomedical waste
		5. Establish good clinical microbiological services in a hospital and in the community in the fields of bacteriology, virology, parasitology, immunology and mycology
		6. Plan, execute and evaluate teaching assignment in Medical Microbiology

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	GENERAL MICROBIOLOGY	09HLTH09A05-001-C
2	IMMUNOLOGY and APPLIED ASPECTS	09HLTH09A05-002-C
3	SYSTEMATIC BACTERIOLOGY	09HLTH09A05-003-C
4	VIROLOGY	09HLTH09A05-004-C
5	PARASITOLOGY	09HLTH09A05-005-C
6	MYCOLOGY	09HLTH09A05-006-C
7	APPLIED CLINICAL MICROBIOLOGY	09HLTH09A05-007-C

(B) PRACTICALS

Sr. No.	Name of the Course	Course code
1	BACTERIOLOGY	09HLTH09A05-001-P
2	IMMUNOLOGY / SEROLOGY	09HLTH09A05-002-P
3	MYCOLOGY	09HLTH09A05-003-P
4	PARASITOLOGY	09HLTH09A05-004-P
5	VIROLOGY	09HLTH09A05-005-P

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
GENERAL MICROBIOLOGY	09HLTH09A05-001-C	Student should have acquired knowledge in the following: 1. Important historical events and developments in Microbiology 2. Basic as well as advanced knowledge in various microscopes and microscopic techniques used in Diagnostic Microbiology 3. Various isolation precautions including standard and transmission based precaution 4. Nomenclature, classification and morphology of bacteria as well as other microorganisms 5. Various types and significance of normal flora of human body in health and disease states

		6. Various antimicrobial agents and mechanisms of drug resistance 7. Applications of quality assurance, quality control in Microbiology and accreditation of laboratories
IMMUNOLOGY and APPLIED ASPECTS	09HLTH09A05-002-C	1. Components of immune system, types of immunity and immune response 2. Describes and identifies uses of various antigens, immunoglobulins (antibodies) and antigen and antibody reactions 3. Complement system and Cytokines 4. Various disorders like hypersensitivity, immunodeficiency and auto-immunity involving immune system 5. Immunological techniques and their applications in Diagnostic Microbiology as well as research
SYSTEMATIC BACTERIOLOGY	09HLTH09A05-003-C	1. Demonstrate knowledge and skills in various techniques for isolation and identification of bacteria 2. Demonstrate knowledge about epidemiology, morphology, biochemical properties, antigenic nature, pathogenesis, complications, laboratory diagnosis treatment and prevention of major bacterial pathogens of medical importance
VIROLOGY	09HLTH09A05-004-C	1. Demonstrates knowledge about general properties, classification, morphology, virus replication and genetics of viruses 2. Explain pathogenesis of viral infections 3. Demonstrates knowledge about isolation and identification of viruses 4. Demonstrate knowledge about epidemiology, morphology, genetics, antigenic nature, pathogenesis, complications, laboratory diagnosis, treatment and prevention of major DNA and RNA viruses of medical importance
PARASITOLOGY	09HLTH09A05-005-C	1. Demonstrate knowledge about general characters, classification and method of identification of parasites 2. Demonstrate knowledge about epidemiology, morphology, antigenic nature, life cycle, pathogenesis, complications, laboratory diagnosis, treatment and prevention of Protozoan parasites of medical importance

MYCOLOGY	09HLTH09A05-006-C	1. Explain general characteristics including morphology, reproduction and classification of fungi 2. Demonstrate knowledge and skills for isolation and identification of fungi 3. Demonstrate knowledge about epidemiology, morphology, biochemical properties, antigenic nature, pathogenesis, complications, laboratory diagnosis treatment and prevention of major fungal pathogens of medical importance 4. Able to identify laboratory contaminant fungi
APPLIED CLINICAL MICROBIOLOGY	09HLTH09A05-007-C	1. Demonstrate knowledge about epidemiology of infectious diseases 2. Demonstrate knowledge about antimicrobial prophylaxis and therapy 3. Demonstrate knowledge about hospital acquired infections 4. Demonstrate knowledge about management of biomedical waste 5. Effectively investigate an infectious outbreak in hospital and community 6. Demonstrate knowledge about opportunistic infections 7. Demonstrate knowledge and applications about molecular techniques in the laboratory diagnosis of infectious diseases

(B) PRACTICALS

Name of the Course	Course code	Course Outcome
BACTERIOLOGY	09HLTH09A05-001-P	1. Collection/transportation of specimens for microbiological investigations 2. Preparation, examination and interpretation of direct smears from clinical specimens 3. Plating of clinical specimens on media for isolation, purification, identification and quantification purposes 4. Preparation of stains viz Gram, Albert's, ZiehlNeelsen (ZN), silver impregnation stain and special stains for capsule and spore etc.
IMMUNOLOGY / SEROLOGY	09HLTH09A05-002-P	Perform and interpret different immunological and serological tests and clinical co-relation of the results

MYCOLOGY	09HLTH09A05-003-P	Perform different stains in Mycology and interpret and co-relate the growth of fungus
PARASITOLOGY	09HLTH09A05-004-P	Identify the ova, cyst, trophozoites of different parasites and report
VIROLOGY	09HLTH09A05-005-P	Perform and interpret different virological methods and clinically co-relate with the results

M.D. in Nuclear Medicine
(Program Code: HLTH09A06)

Program Code : HLTH09A06	Programme Outcome	To develop Human Resource (Clinical Nuclear Medicine(NM) Physicians at the postgraduate level with MD qualification), possessing specialized knowledge in Theoretical, Experimental NM techniques and Clinical Nuclear Medicine, required for routine clinical practiceencompassing Oncology, Cardiology, Nephrology, Endocrine disorders, Neurology and Skeletal Systems.
		Teaching and Training of basic and applied principles of Nuclear Medicine to study body structure and functions and use this information to diagnose and treat medical conditions, through uses of Radioactive materials called radiotracers or radiopharmaceuticals (both diagnostic & therapeutic) and Nuclear Medicine Instruments (such as PET-CT, Gamma camera and SPECT systems, Dose calibrator, radiation monitoring instruments).
		To train and introduce interdisciplinary subjects/concepts/ideas (Radiology, Cardiology, Oncology and other systems) for interdisciplinary application of Nuclear Medicine in management of specific system disorders
		To introduce the advanced concepts and emerging techniques with its applications in area of Nuclear Medicine (newer Radiopharmaceuticals, imaging techniques, newer clinical methodologies).

Course Structure:

I. Courses at BARC

Program Code : HLTH09A06	Programme Specific Outcome	Clinical Nuclear Medicine: Understand and apply principles of Clinical Nuclear Medicine for diagnosis and treatment of various diseases encompassing Oncology, Cardiology, Nephrology, Endocrine disorders, Neurology and Skeletal Systems.

		Basic Science and Instrumentation: Understand and apply Nuclear Medicine instrumental knowledge such as gamma camera, gamma probe, SPECT/CT, PET/CT, dose calibrator, radiation monitoring instruments etc for understanding and day to day functioning of these instruments in Nuclear Medicine practices
		Hospital Radiopharmacy: Understand and apply various radiopharmaceuticalpreparation techniques, mechanism of action and clearance of from human body for the understanding of various patho-physiological conditions.
		Newer Advances: (a) Provide exposure to advanced experimental/theoretical methods and train in research and life-long learning to adapt to the changing environment. (b) Understand and apply various changing guidelines for diagnosing and treating various clinical conditions.

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Basic Sciences & Instrumentation	01HLTH09A06-001-C
2	Diagnostic Radiopharmaceuticals & In-vitro Techniques	01HLTH09A06-002-C
3	Clinical Nuclear Medicine Paper I	01HLTH09A06-003-C
4	Clinical Nuclear Medicine Paper II	01HLTH09A06-004-C

(B) PRACTICALS

Sr. No.	Name of the Course	Course code
1	Physics	01HLTH09A06-001-P
2	Radiopharmaceutical & In-vitro Techniques	01HLTH09A06-002-P

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Basic Sciences & Instrumentation	01HLTH09A06-001-C	Understand the concepts of Basic sciences of Nuclear Medicine for applying them in Clinical Nuclear Medicine.
		Understand and apply basic science of electronics, mathematics, chemistry and biostatistics
		Understand and apply knowledge of functioning of Nuclear Medicine instruments and their utility (gamma camera, gamma probe, SPECT/CT, PET/CT, dose calibrator, radiation monitoring instruments etc.)
Diagnostic Radiopharmaceuticals & In-vitro Techniques	01HLTH09A06-002-C	Understand and apply knowledge of various radionuclides and radiopharmaceuticals in clinical NM, including the fundamentals of radiolabelling procedure, bio-distribution and clinical applications
		Acquire knowledge of diagnostic in-vitro techniques such as RIA and IRMA and use it for T4, FT4, TSH, Tg measurement and assays for various drugs and hormones
		Understand and apply knowledge of Radiation Biology, Radiation Protection, Health Physics and radioactive waste management in Nuclear Medicine Departments
Clinical Nuclear Medicine Paper I	01HLTH09A06-003-C	**Diagnostic**: Understand all in-vivo techniques and get knowledge about applications of radiopharmaceuticals,dosimetry studies, choice of equipment, imaging protocol, patient preparation, imaging parameters, interventional methods, quality/quantitative analysis, display, filming and report generation of in-vivo technique and apply all these in clinical practices,; the procedures includePET-CT scan with various PET radiopharmaceuticals, Bone Scan, Thyroid

		scan, Brain Scan, Lung Scan, Cardiac scan and so on.
		Therapeutic: Acquire skill and knowledge onTherapeutic Nuclear Medicine (Patient selection, including the diagnostic procedures necessary to establish the need for radionuclide therapy- indications and contraindications for the use of Radionuclide. Dose administration in patient management including dosimetryofthe target organs, to the surrounding tissue and/or other organ systems and total-body exposure, special problems of patient care caused by radionuclide therapeutic procedures-potential early and late adverse reactions, Clinicalfollow-up of patients in terms of timing and parameters of assessment of response and toxicity. Apply this knowledge in clinical practices
Clinical Nuclear Medicine Paper II	01HLTH09A06-004-C	Gain knowledge about recent advances in Imaging techniques & image processing including fusion/hybrid techniques and radiological methodologiesimage guided for radiotherapy & stereotactic techniques, recent advances in SPECT, PET, recent developments in detector systems (e.g. solid state detectors) including hybrid systems such as PET-MRI

(B) PRACTICALS

Name of the Course	Course code	Course Outcome
Physics	01HLTH09A06-001-P	Learning practical knowledge on radiation, detection and measurments.
		Learning practical aspects of radiation protection.
Radiopharmaceutical & In-vitro Techniques	01HLTH09A06-002-P	Learning practical knowledge in In-vitro radiopharmaceutical techniques.

BACK TO MAIN

II. Courses at TMC

Program Code : HLTH09A06	Programme Specific Outcome	Attain MD degree in Nuclear Medicine
		Complete requisite training. Appraisal exams are held regularly to assess that the candidate attained knowledge in keeping with the objectives by year according to the syllabus of the course.

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Basic Science related to Nuclear Medicine	09HLTH09A06-001-C
2	Diagnostic Nuclear Medicine	09HLTH09A06-002-C
3	Therapeutic Nuclear Medicine	09HLTH09A06-003-C
4	Recent Advances in Nuclear Medicine	09HLTH09A06-004-C

(B) PRACTICALS

Sr. No.	Name of the Course	Course code
1	Basic Sciences Experiment	09HLTH09A06-001-P
2	Clinical Experiment	09HLTH09A06-002-P

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Basic Science related to Nuclear Medicine	09HLTH09A06-001-C	Attain requisite skills, proficiency in Basic sciences and applied basic sciences related to Nuclear Medicine

Diagnostic Nuclear Medicine	09HLTH09A06-002-C	Attain requisite skills, proficiency in Diagnostic Nuclear Medicine
Therapeutic Nuclear Medicine	09HLTH09A06-003-C	Attain requisite skills, proficiency in Therapeutic Nuclear Medicine
Recent Advances in Nuclear Medicine	09HLTH09A06-004-C	Attain requisite skills, proficiency in the recent advances in all branches of Nuclear medicine

(B) PRACTICALS

Name of the Course	Course code	Course Outcome
Basic Sciences Experiment	09HLTH09A06-001-P	To thoroughly understand and execute the entire process of quality assurance in nuclear medicine i.e. quality control of radiopharmaceuticals and various instrument used in nuclear medicine as well as interoperation of quality control reports
Clinical Experiment	09HLTH09A06-002-P	To examine the patient and relevant clinical and Laboratory and other materials and come to a logical conclusion to plan, execute and report the result of relevant nuclear medicine procedures for making a clinical impact on the patients disease.

M.D. in PALLIATIVE MEDICINE
(Program Code: HLTH09A07)

Course Structure:

I. Courses at TMC

Program Code : HLTH09A07	Programme Specific Outcome	The postgraduate trainee should be able to
		1.Explain pathophysiological basis of pain and other physical symptoms, assess comprehensively, use and select investigations and pharmacological and non-pharmacological approaches for relief of pain and other symptoms
		2.Explain the role of psychosocial and spiritual-existential issues in illness and suffering, assess comprehensively,use and select appropriate measures for addressing these issues in a multidisciplinary setting and judiciously refer to specialist teams as required
		3.Able to provide good supportive care and make clinical decisions and judgements in caring for patients with advanced life-limiting illnesses and their caregivers
		4.Able to understand illness trajectory and course and available disease management options and treatments appropriate for patients
		5.Able to communicate with and understand patients' and families' wishes, preferences and goals of care and respect their values and beliefs
		6.Able to recognise the dying process and provide appropriate end of life care
		7.Able to provide specialist palliative care in all settings of clinic, inpatient, home, hospice, respite care
		8.Able to work in a multidisciplinary team with respect and cordiality and professionalism and supervise and mentor junior colleagues

		9.Able to undertake research in palliative medicine
		10.Able to provide leadership and advocacy
		11.Able to efficiently organise human resource, finances, quality control issues and data management along with professional development and self-mangagment

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Cognitive Domain	09HLTH09A07-001-C
2	Psychomotor Domain	09HLTH09A07-002-C
3	Affective Domain	09HLTH09A07-003-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Cognitive Domain	09HLTH09A07-001-C	**To acquire in-depth knowledge of**
		Introduction to Palliative Medicine
		Palliative Pharmacology
		Symptom control in Palliative Medicine
		Palliative Medicine in oncology
		Palliative Medicine in non-oncology
		Supportive care in Palliative Medicine
		Psychosocial issues in Palliative Medicine
		Paediatric and Geriatric Palliative Medicine
		End of life care, ethics and special topics in Palliative Medicine
		Nursing and rehabilitation care in Palliative Medicine
Psychomotor Domain	09HLTH09A07-002-C	**To develop procedural and non-procedural skill in the following:**
		Communication
		Decision making
		Pain and symptom management
		Supportive care and disease management
		Psychosocial support
		Interdisciplinary care and team management
		End of life care
		Procedural
		Research and education

		Leadership, advocacy and good clinical practice and quality assurance
Affective Domain	09HLTH09A07-003-C	**To acquire attitudes and values as follows:**
		Palliative care principles
		Pain and symptom management
		Clinical expert
		Psychological, social, emotional and spiritual support
		Interdisciplinary care
		Decision making
		Communication
		Pediatric and elder care
		End of life care
		Professionalism and leadership

M.D. in IMMUNO - HEMATOLOGY & TRANSFUSION MEDICINE (Program Code: HLTH09A08)

Course Structure:

I. Courses at TMC

Program Code : HLTH09A08	Programme Specific Outcome	At the end of the course a candidate must be able to: i) Understand and explain about the scientific basis of blood transfusion. ii) Understand the processes of blood collection, processing and component preparation. iii) Understand and explain the basis of pre-transfusion testing. iv) Should be able to explain and diagnose the adverse effects of blood transfusion. v) Should be able to perform apheresis technique independently. vi) Should be able to carry out the antenatal and neonatal transfusion practice. vii) Should be able to plan, perform and report specific research projects. viii) Should be able to give advice on haemotherapy including stem cell transplantation and solve the immunohaematological discrepancies in blood transfusion ix) To understand and advise on the rationale and process of use of blood & blood products to the associated clinical faculty.

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	HISTORY OF TRANSFUSION MEDICINE	09HLTH09A08-001-C
2	SCIENTIFIC BASIS OF TRANSFUSION	09HLTH09A08-002-C
3	ANTIGEN SYSTEMS IN FORMED ELEMENTS OF BLOOD	09HLTH09A08-003-C

4	BLOOD COLLECTION, PROCESSING, COMPONENT	09HLTH09A08-004-C
5	PRE-TRANSFUSION TESTING	09HLTH09A08-005-C
6	ADVERSE EFFECTS OF BLOOD TRANSFUSION	09HLTH09A08-006-C
7	APHERESIS	09HLTH09A08-007-C
8	AUTOLOGOUS TRANSFUSION	09HLTH09A08-008-C
9	ANTINATAL & NEONATAL TRANSFUSION PRACTICE	09HLTH09A08-009-C
10	IMMUNOHEMATOLOGY	09HLTH09A08-010-C
11	HEMOTHERAPY	09HLTH09A08-011-C
12	TRANSPLANTATION	09HLTH09A08-012-C
13	BLOOD SUBSTITUTE & HEMOPOIETIC AGENTS	09HLTH09A08-013-C
14	MEDICOLEGAL CONSIDERATIONS IN TRANSFUSIUON	09HLTH09A08-014-C
15	TOTAL QUALITY MANAGEMENT	09HLTH09A08-015-C
16	ORGANISATION & MANAGEMENT OF TRANSFUSION SERVICES	09HLTH09A08-016-C
17	BLOOD SAFETY	09HLTH09A08-017-C
18	MODERN BIOLOGICAL TECHNIQUES	09HLTH09A08-018-C
19	AUTOMATION & COMPUTERIZATION	09HLTH09A08-019-C
20	RECENT ADVANCES IN IMMUNOHAEMATOLOGY & BLOOD TRANSFUSION	09HLTH09A08-020-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
HISTORY OF TRANSFUSION MEDICINE	09HLTH09A08-001-C	To understand historical aspects of Transfusion Medicine and evolution
SCIENTIFIC BASIS OF TRANSFUSION	09HLTH09A08-002-C	To understand basis of the cycle from Blood Collection to Transfusion to the recipient ensuring blood safety
ANTIGEN SYSTEMS IN FORMED ELEMENTS OF BLOOD	09HLTH09A08-003-C	To understand different Blood grouping systems covering Genetics, Biochemical and clinical importance
BLOOD COLLECTION, PROCESSING, COMPONENT	09HLTH09A08-004-C	Should be able to perform donor screening, blood collection and component preparation
PRE-TRANSFUSION TESTING	09HLTH09A08-005-C	To understand principles of pre-transfusion testing.
		To perform and solve different problem cases
ADVERSE EFFECTS OF BLOOD TRANSFUSION	09HLTH09A08-006-C	To classify different adverse effects of blood transfusion.
		To identify, perform, workupand advise about the management
APHERESIS	09HLTH09A08-007-C	To understand principles of Apheresis.
		To be able to perform routine Apheresis and therapeutic Apheresis Procedures
AUTOLOGOUS TRANSFUSION	09HLTH09A08-008-C	To know indications and contraindications of Autologous transfusion and perform the same
ANTINATAL & NEONATAL TRANSFUSION PRACTICE	09HLTH09A08-009-C	To know the pathophysiology of HDFN.
		To be able to perform antenatal workup and to decide the indication, dose, special requirements for intrauterine and neonatal transfusion
IMMUNOHEMATOLOGY	09HLTH09A08-010-C	To know the principle and basis of different method to perform Immunohenatology workup including Red Cells, Platelets and Granulocytes
HEMOTHERAPY	09HLTH09A08-011-C	Should be able to give advice on Hemotherapy decisions
TRANSPLANTATION	09HLTH09A08-012-C	To understand processing, storage, quality control of stem cells.

		To advise and support transfusion requirements in HSCT and solid organ transplant
BLOOD SUBSTITUTE & HEMOPOIETIC AGENTS	09HLTH09A08-013-C	To understand role and clinical application of blood substitutes and Hemopoietic agents
MEDICOLEGAL CONSIDERATIONS IN TRANSFUSIUON	09HLTH09A08-014-C	To understand the regulatory aspects and ensure the regulatory requirements of blood centres
TOTAL QUALITY MANAGEMENT	09HLTH09A08-015-C	To know principles and scope of Quality Management System and implement Good Laboratory Practices (GLP)
ORGANISATION & MANAGEMENT OF TRANSFUSION SERVICES	09HLTH09A08-016-C	To understand the administrative aspects of organisation and management of Blood Transfusion Services.
		To know the importance of National Hemovigilance Programme
BLOOD SAFETY	09HLTH09A08-017-C	To know and implement the National and International guidelines for blood safety
MODERN BIOLOGICAL TECHNIQUES	09HLTH09A08-018-C	To know and understand the principles and applications of molecular techniques related to Transfusion Medicine
AUTOMATION & COMPUTERIZATION	09HLTH09A08-019-C	To know the importance and applications of Automation and computerisation in daily functioning of Transfusion Services
RECENT ADVANCES IN IMMUNOHAEMATOLOGY & BLOOD TRANSFUSION	09HLTH09A08-020-C	To know principles and scope of newer techniques (e.g., Flow Cytometry, Cellular Therapies, Pathogen Reduction Technology, Gene Therapy, Proteomicsand Metabolomics etc.

M.D. in ANESTHESIA
(Program Code: HLTH09A02)

Program Code : HLTH09A02	Programme Outcome	To train the candidate in skills and knowledge in various aspects of Anaesthesia – service, training & research
		This will also enable the individual to practice anaesthesia discipline
		To be able to participate in the holistic management, including preoperative assessment, risk stratification, preoperative optimization for the anaesthesia, post anaesthesia and post-surgery care, care of the critically ill patient in the intensive care unit. To Be able to manage acute post-operative pain, chronic pain management, be a part of the multidisciplinary team delivering treatment and follow-up of a patient receiving anaesthesia. The candidate should be able to implement these skills and deliver the service to patients in all age groups including paediatric, geriatric patients.
		He/ she should be able to train other anaesthesia technicians, anaesthesia assistants and junior fellow colleagues.
		Candidate should also be well versed in giving life support efficiently in cardiac arrest situations
		The candidate should engage in effective, meaningful research

Course Structure:

I. Courses at TMC

Program Code : HLTH09A02	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms
		All the necessary training and mandatory theory are specified in the syllabus of the MD Anaestheisa Course
		The student is expected to participate in the regular academic programmes (Case discussions, students' seminars, CMEs) conducted in the Institute.
		The purpose would be to acquire an understanding of the subject of anaesthesia
		The candidate's progress through the 3 years will be assessed by appraisal examinations.

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Anesthesia Outside Operating Room	09HLTH09A02-001-C
2	Post Anesthesia Care Unit	09HLTH09A02-002-C
3	Intensive Care Unit	09HLTH09A02-003-C
4	Cardiovascular Anesthesia	09HLTH09A02-004-C
5	Neuroanesthesia	09HLTH09A02-005-C
6	Pain Management	09HLTH09A02-006-C
7	Pediatric	09HLTH09A02-007-C
8	Obstetric	09HLTH09A02-008-C
9	Regional Anesthesia	09HLTH09A02-009-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Anesthesia Outside Operating Room	09HLTH09A02-001-C	To gain knowledge and understanding of preoperative evaluation and optimization of patients, risk stratification and provide anaesthesia for diagnostic and therapeutic procedures at CT, MRI, Intervention radiology, cardiac cath lab, Digital Subtraction Angiography lab, Endoscopy, electroconvulsive therapy with understanding of day care anaesthesia.
Post Anesthesia Care Unit	09HLTH09A02-002-C	Candidate should be efficient in Monitoring patients recovery in post anaesthesia care unit, Detecting and diagnosing problems peculiar to PACU such as delayed recovery due to drug overdoses, haemodynamic instability, acute pain management, issues related to airway, triaging the patients as per need – to more intense monitoring, shift to floor etc.
		Management of patients who have undergone massive blood transfusion in OT, patients requiring postoperative mechanical ventilator (MV) support, setting correct ventilator parameters, diagnosing patient ventilator dyssynchrony, weaning patients from MV, getting appropriate referrals such as nutritionist reference, physiotherapy etc. Mobilisation of patient in postop care unit
		Should also understand principles of haemodynamic monitoring and efficiently manage patients with haemodynamic instability

Intensive Care Unit	09HLTH09A02-003-C	To gain knowledge of physiology of respiratory and cardiovascular system in details, acid base physiology, electrolyte disturbances and arrhythmias, basics of mechanical ventilation and management of types of shock
		To gain knowledge and skills for basic and Advanced haemodynamic monitoring
		To learn the care of unconscious patient
		To gain knowledge and skills for basic and Advanced cardiopulmonary resuscitation
		To understand basics of communications and learn how to effectively communicate with patients and their care givers
Cardiovascular Anesthesia	09HLTH09A02-004-C	To gain thorough understanding of cardiovascular and intrathoracic physiology and pathophysiology, preoperative evaluation and optimization of patients, risk stratification. Acquire skills and knowledge to provide anaesthesia for surgery for CABG, valvular heart diseases repair, congenital heart diseases and vascular repairs
Neuroanesthesia	09HLTH09A02-005-C	To gain thorough understanding of central nervous system physiology and pathophysiology, preoperative evaluation and optimization of patients, risk stratification and provide anaesthesia for elective and emergency surgeries of brain and spine in adult and children.
		To understand triaging of polytrauma patient, their neuroassessment and emergency management
		To understand basics of intracranial pressure monitoring
Pain Management	09HLTH09A02-006-C	To gain thorough understanding and knowledge of intraoperative and acute postoperative pain management.
		To acquire skills to perform techniques needed for regional pain management
		To gain thorough understanding and knowledge of pathophysiology of chronic pain and its management in brief
Pediatric	09HLTH09A02-007-C	To gain thorough understanding of neonatal, infant and children's physiology of all systems, preoperative evaluation and optimization of patients, risk stratification. Acquire skills and knowledge to provide anaesthesia and perioperative care for different surgeries and diagnostic procedures and emergencies in children
		To gain knowledge and proficiency in neonatal rescuscitation

Obstetric	09HLTH09A02-008-C	To gain thorough understanding and knowledge of physiology and pathologies of a parturient, and acquire skills needed to provide anaesthesia for conducting caesarean section., and also managing obstetric emergencies.
		To understand and learn management of massive haemorrhage and massive transfusion protocol
Regional Anesthesia	09HLTH09A02-009-C	To gain the knowledge of anatomy needed for understanding of pain management of various parts of human body
		To acquire skills to perform techniques needed for regional anaesthesia and pain management using ultrasound and nerve stimulators.
		To practice central neuraxial blockade in adults and children

BACK TO MAIN

D.M. in MEDICAL ONCOLOGY (Program Code: HLTH10A01)

Program Code : HLTH10A01	Programme Outcome	To train the candidates in training on the basics of all aspects of oncology.
		To understand the role of associated specialties, i.e., surgical and radiation oncologic principles, basics of pathology, basics of radiology and their role in the multidisciplinary management of cancer patients.
		To provide exposure to the comprehensive management, including diagnosis, planning treatment, being a part of the multidisciplinary team delivering treatment and follow-up of a patient with cancer.
		To understand and be able to practice relevant aspects of medical oncology in terms of patients selection for treatment, management of various treatment modalities including, chemotherapy, immunotherapy, targeted therapy and newer modalities
		To introduce aspects of clinical and translational research during the program
		To provide national and international platform for presentations of clinical/surgical research data
		The training should encourage trainees to become thought leaders in various aspects of practice in medical oncology across the country.

Course Structure:

I. Courses at TMC

Program Code : HLTH10A01	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms.
		All the necessary training and mandatory theory are specified in the syllabus of the DM Medical Oncology Course.
		The student is expected to participate in the regular appraisal examinations and academic programmes conducted in the institute.
		The purpose would be to acquire an understanding of the subject of medical oncology in specific and all aspects of oncology in general.
		The candidate’s progress through the 3 years will also be assessed with feedback from all stake holders, including the candidate and work-based assessment.

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	BASIC SCIENCE in ONCOLOGY	09HLTH10A01-001-C
2	CLINICAL ONCOLOGY	09HLTH10A01-002-C
3	RECENT ADVAMCES in ONCOLOGY	09HLTH10A01-003-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
BASIC SCIENCE in ONCOLOGY	09HLTH10A01-001-C	To be able to understand the basics of cancer biology and molecular pathology.
		To understand the pathophysiology of various neoplastic and pre-neoplastic processes.
		To understand the newer advances in molecular diagnostics
		To develop the insight and ability to apply this knowledge in the field of clinical and translational cancer research.
CLINICAL ONCOLOGY	09HLTH10A01-002-C	To understand the multidisciplinary management of cancers and basic principles of medical oncology so as to provide the best treatment option to patients.
		To be able to provide complete oncologic care in future practice.
		To be able to grasp the basics of biostatistics and conduct of clinical research and randomised controlled trials.
		To learn the approach to evidence based surgical oncological approaches as well as principles of radiotherapy protocols so as to help and guide patients with cancer to choose appropriate modality of treatment.
		To completely understand the basics of systemic therapy, including chemotherapy, immunotherapy, targeted therapy as well as newer molecules
		To understand the applications of all aspects of systemic therapy in patient management, clinical practice, with specific emphasis on evidence based guidelines as well as management of adverse events.

RECENT ADVAMCES in ONCOLOGY	09HLTH10A01-003-C	To understand newer modalities and advances in oncology, specifically with respect to phase I/II trials, laboratory pre-clinical work and translational studies
		To have a basic working knowledge of next generation molecular biology techniques.
		To be aware of recent advances in diagnostic imaging and adjuvant modalities in cancer

BACK TO MAIN

D.M. in Paediatric Oncology under TMC (Program Code: HLTH10A02)

Program Code : HLTH10A02	**Programme Outcome**	Outcome of childhood cancers is one of the most impressive among all cancers put together, provided these cancers are treated early, diagnosed properly and treated appropriately by trained Pediatric oncologists.
		The Pediatric Oncology Program is designed to provide a diversified, organized educational environment that will allow the post graduate student to develop both the clinical and research skills necessary to become an academic Pediatric Oncologist.
		The aim is for acquisition of a fundamental knowledge base in Pediatric Hematology, Oncology and BMT and development of clinical skills in Pediatric Hematology, Oncology and BMT along with development of skills in interpreting basic laboratory tests pertinent to Pediatric Hematology, Oncology and BMT

Course Structure:

I. Courses at TMC

Program Code : HLTH10A02	**Programme Specific Outcome**	The aim is to prepare the future Pediatric Oncologists who will represent the clinical work force, educators, investigators and researchers in the field of pediatric oncology.
		Development of skills in preparing clinical presentations, discussions of cases, and case reports.
		The programme would teach the student to facilitate learning of medical/nursing students, practicing physicians, para-medical health workers and other providers as a teacher-trainer;

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	General principles of paediatric oncology	09HLTH10A02-001-C
2	Hemato-oncology	09HLTH10A02-002-C
3	Extra cranial solid tumour	09HLTH10A02-003-C
4	CNS tumours	09HLTH10A02-004-C
5	Haematopoietic stem cell transplant[HSCT]	09HLTH10A02-005-C
6	Laboratory training	09HLTH10A02-006-C
7	Generic training in practical skills	09HLTH10A02-007-C
8	Other issues	09HLTH10A02-008-C
9	Research Activities	09HLTH10A02-001-RA

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
General principles of paediatric oncology	09HLTH10A02-001-C	To be able to understand the basics of cancer biology and molecular pathology.
		To understand the pathophysiology of various haematological and solid cancers in children
		To understand the newer advances in molecular diagnostics, risk-stratifications and potentially targetable mutations in various pediatric cancers (solid and haematological)
		To develop the insight and ability to apply this knowledge in the field of clinical and translational cancer research.
Hemato-oncology	09HLTH10A02-002-C	To understand the principles of management of pediatric hemato-lymphoid malignancies so as to be able to provide the best available treatment.
		To familiarise with the diagnostic modalities used for diagnosing and risk-stratifying pediatric haematological malignancies through conventional and advanced molecular modalities
		To be able to collaborate with other disciplines in a multi-disciplinary team setting

		to provide holistic care to children affected by haematological cancer
		To be able to follow-up children treated for heamtological cancers as regards to identifying long-term issues following cancer treatment and make appropriate referrals
Extra cranial solid tumour	09HLTH10A02-003-C	To understand the principles of management of pediatric solid tumours so as to be able to provide the best available treatment.
		To familiarise with the diagnostic modalities (imaging and pathology) as well as recent advances in diagnostics and risk-stratification of pediatric solid tumours
		To familiarise with the various modalities of local therapy including surgery and radiation for treatment of solid tumours in children; to be able to make appropriate recommendations for local therapy in these children
		To be able to collaborate with other disciplines in a multi-disciplinary team setting to provide holistic care to children affected by solid cancers
		To be able to follow-up children treated for solid tumours in order to identify long-term issues following cancer treatment and make appropriate referrals
CNS tumours	09HLTH10A02-004-C	To understand the principles of management of pediatric CNS tumours so as to be able to provide the best available treatment.
		To familiarise with the diagnostic modalities (imaging and pathology) as well as recent advances in molecular diagnostics and risk-stratification of pediatric CNS tumours
		To familiarise with the various modalities of local therapy including surgery and radiation for treatment of CNS tumours in children; to be able to make appropriate recommendations for local therapy in these children
		To be able to collaborate with other disciplines including diagnostics, surgery, radiation, rehabilitation etc. in a multi-disciplinary team setting to provide holistic care to children affected by CNS tumours

		To be able to follow-up children treated for CNS tumours in order to identify late effects of treatment and make appropriate referrals
Haematopoietic stem cell transplant[HSCT]	09HLTH10A02-005-C	To gain basic knowledge on- indications for HSCT/Tissue typing/ Principles of Donor selection/Donor and recipient counselling
		To get primed to common conditioning regimens/stem sell manipulation techniques/ immuno-suppression and transplant immunology
		To be conversant with the management of graft versus host disease and other complications during peri-transplant period along with relevant supportive care.
		To be able to follow-up children undergoing HSCT in order to identify late effects of treatment and make appropriate referrals
Laboratory training	09HLTH10A02-006-C	To familiarise with basic laboratory diagnostic techniques including microscopy, flowcytometry, cytogenetics, immunohistochemistry and molecular pathology
		To be aware of the basics of high throughtput techniques in genomics
Generic training in practical skills	09HLTH10A02-007-C	To be well trained in core oncology procedures like bone marrow aspiration/biopsy, lumbar puncture and administration of intrathecal chemotherapy
		To be conversant in managing critically ill children needing intensive care and life-support
		To be familiar with techniques of chemotherapy handling and administration including handling of central venous access devices
		To get primed to pain-management and palliative care in pediatric oncology
Other issues	09HLTH10A02-008-C	To be conversant with the principles of blood transfusion and component therapy
		To be familiar with infection control practice, nutritional assessment/interventions and supportive care
		To be proficient in effective counselling

		strategies for the patient and parents
		To acquire organisational, managerial and leadership skills
		To know about advocacy, survivorship issues including pediatric oncology programmes in developing countries
Research Activities	09HLTH10A02-001-RA	To be conversant in basic research methodology, statistics and principles of good clinical practice
		To be able to independently conduct prospective studies and retrospective audits
		To be able to present, publish and evaluate research findings

BACK TO MAIN

D.M. in GASTROENTEROLOGY (Program Code: HLTH10A03)

Program Code : HLTH10A03	**Programme Outcome**	At the end of the DM course in Gastroenterology, the student should be able to: Practice the specialty of gastroenterology in keeping with the principles of professional ethics;
		The student should be able to identify social, economic, environmental, biological and emotional determinants of adult gastroenterology diseases and know the therapeutic, rehabilitative, preventive and promotion measures to provide holistic care to all patients;
		The student should be able to take detailed history, perform full physical examination and make a clinical diagnosis; Perform and interpret relevant investigations (Imaging and Laboratory); Perform and interpret important diagnostic procedures; Diagnose gastroenterological illnesses in adults based on the analysis of history, physical examination and investigative work up;
		The student should be able to plan and deliver comprehensive treatment for illness in adults using principles of rational drug therapy; Manage gastroenterological emergencies efficiently;
		The student should be able to plan and advise measures for the prevention of gastroenterological diseases;
		The student should be able to demonstrate empathy and humane approach towards patients and their families and respect their sensibilities; Demonstrate communication skills of a high order in explaining management and prognosis, providing counselling and giving health education messages to patients, families and communities.

Course Structure:

I. Courses at TMC

Program Code : HLTH10A03	**Programme Specific Outcome**	The aim is to teach the student to develop skills as a self-directed learner, recognize continuing educational needs; use appropriate learning resources, and critically analyze relevant published literature in order to practice evidence-based medicine;
		Demonstrate competence in basic concepts of research methodology and epidemiology;
		The programme would teach the student to facilitate learning of medical/nursing students, practicing physicians, para-medical health workers and other providers as a teacher-trainer;
		The programme would teach the student to function as a productive member of a team engaged in health care, research and education.

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Luminal Gastroenterology	09HLTH10A03-001-C
2	Hepatology	09HLTH10A03-002-C
3	Biliary and Pancreatic diseases	09HLTH10A03-003-C
4	Basic Endoscopy	09HLTH10A03-004-C

(B) Sub-specialty: Basic training to prepare to future sub-specialty tracks

Sr. No.	Name of the Course	Course code
1	Liver transplant	09HLTH10A03-001-SS
2	Gastrointestinal Oncology	09HLTH10A03-002-SS
3	Pediatric and Geriatric Gastroenterology	09HLTH10A03-003-SS
4	Advanced Endoscopy	09HLTH10A03-004-SS

(C) ANCILLARY COURSES

Sr. No.	Name of the Course	Course code
1	GI and liver pathology	09HLTH10A03-001-A
2	GI imaging	09HLTH10A03-002-A
3	Clinical Nutrition	09HLTH10A03-003-A
4	Allied Clinical Experience: Catheter care, stoma care, consequences of abdominal surgery, management of end-stage digestive diseases.	09HLTH10A03-004-A
5	Clinical Research Methodology	09HLTH10A03-005-A
6	Epidemiology and Public health related to digestive diseases	09HLTH10A03-006-A
7	Basic Sciences: Genetics, Molecular biology	09HLTH10A03-007-A

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Luminal Gastroenterology	09HLTH10A03-001-C	To be able to understand the basics of luminal gastrointestinal anatomy and physiology
		To understand the pathophysiology of various disease processes affecting the luminal GI tract.
		To understand the principles and basis of current treatments of the same as well as newer advances
		To develop the insight and ability to apply this knowledge in the field of clinical and translational research.
Hepatology	09HLTH10A03-002-C	To be able to understand the basics of anatomy and physiology of the liver
		To understand the pathophysiology of various disease processes affecting the liver
		To understand the principles and basis of current treatments of liver disease and newer advances
		To develop the insight and ability to apply this knowledge in the field of clinical and translational research.

Biliary and Pancreatic diseases	09HLTH10A03-003-C	To be able to understand the basics of anatomy and physiology of the bilio-pancreatic system
		To understand the pathophysiology of various disease processes affecting the bile ducts and the pancreas
		To understand the principles and basis of current treatments of liver disease and newer advances
		To develop the insight and ability to apply this knowledge in the field of clinical and translational research.
Basic Endoscopy	09HLTH10A03-004-C	To understand the principles and basis of endoscopic imaging including white light endoscopy, chromoendoscopy and endoscopic ultrasound
		To understand the common indications and contraindications for endoscopic procedures
		To learn the safe and appropriate practise of endoscopy including management of emergencies
		To have thorough knowledge of the various types of endoscopes, accessories and scope reprocessing
		To learn the basic skills well that would enable the student to move on to advanced/ therapeutic endoscopy eventually

(B) Sub-specialty: Basic training to prepare to future sub-specialty tracks

Name of the Course	Course code	Course Outcome
Liver transplant	09HLTH10A03-001-SS	To learn the basic principle of liver transplantation
		To understand the common indications and contraindications for liver transplantation, drugs used in the peri-transplant period and management of post- transplant complications
		To be aware of recent updates in the field off liver transplantation
Gastrointestinal Oncology	09HLTH10A03-002-SS	To understand the multidisciplinary management of GI cancers with a focus on diagnosis, management and palliation of symptoms

		To be aware of cancer pathways and precancerous lesions of the GI tract
		To understand screening and surveillance protocols and their rationale
Pediatric and Geriatric Gastroenterology	09HLTH10A03-003-SS	To learn the basic differences in management of gastrointestinal disorders in these extreme age groups
		To be aware of common disorders in pediatric and geriatric gastroenterologic practise
Advanced Endoscopy	09HLTH10A03-004-SS	To understand the principles and basis of endoscopic imaging including chromoendoscopy and endoscopic ultrasound
		To understand the common indications and contraindications for advanced endoscopic procedures
		To learn the safe and appropriate practise of advanced endoscopic procedures like ERCP, EUS and resections including management of emergencies
		To have thorough knowledge of the various types of endoscopes, instruments, accessories and scope reprocessing
		To be aware of recent advances in therapeutic endoscopy

(C) ANCILLARY COURSES

Name of the Course	Course code	Course Outcome
GI and liver pathology	09HLTH10A03-001-A	To be aware about the normal histopathological features of different parts of the GI system/ liver
		To know the histopathological features of common disorders of the GI system/ liver
GI imaging	09HLTH10A03-002-A	To be aware about the different imaging modalities available and their principles
		To know the indications and contraindications of various imaging modalities so as to be able to prescribe them rationally
		To be aware of the standard guidelines for various diseases with the use of appropriate imaging for each
		To be able to interpret the common GI imaging modalities that are used in the clinic
Clinical Nutrition	09HLTH10A03-003-A	To have knowledge about malnutrition and

		basics of nutritional support
		To be aware of the various nutritional screening tools
		To be able to rationally prescribe nutritional supplements and TPN where needed
Allied Clinical Experience: Catheter care, stoma care, consequences of abdominal surgery, management of end-stage digestive diseases.	09HLTH10A03-004-A	To be aware of the types, indications and care of various catheters used in routine practise and the management of complications associated with the same
		To know about the types of stomas, their indications, management and complications associated with the same
		To know the basic principles of GI surgery, the common surgeries done and the short term and long term complications associated with them
		To know the management options for end stage liver disease including symptom control, palliative care and nutritional support
Clinical Research Methodology	09HLTH10A03-005-A	To be able to grasp the basics of biostatistics and conduct of clinical research and randomised controlled trials.
		To learn the approach to evidence based gastroenterology so as to help and guide patients to choose appropriate modality of treatment.
		To have knowledge about ethics of clinical research and good clinical practise
Epidemiology and Public health related to digestive diseases	09HLTH10A03-006-A	To understand basics of epidemiology and public health
		To understand the common GI disorders and their public health impact
Basic Sciences: Genetics, Molecular biology	09HLTH10A03-007-A	To develop an understanding about basic sciences including genetics and molecular biology
		To understand the basics of genetic disorders of the GI tract
		To understand the applied aspects of basic sciences

D.M. in Critical Care
(Program Code: HLTH10A04)

Program Code : HLTH10A04	Programme Outcome	To train the DM candidates in basics of clinical critical care.
		To understand underlying principles of critical illness in various patient categories, the pathophysiologic basis of mechanisms of disease, the pharmacologic principles guiding various therapies, appropriate monitoring, organ support therapies and end of life support when required.
		To provide holistic management for critically ill patients, including diagnosis, planning treatment, anticipate likelihood of development of organ failure and be a part of the multidisciplinary team delivering treatment in the role of team leader.
		To build clinical skills, obtain technical expertise in various procedures to be performed for providing oran support therapies.
		To create an understanding regarding basic principles of clinical research, and translating application to bedside management of the critically ill patients.
		To provide national and international platform for presentations of research data in the field of critical care.
		The training should produce consultants to practice all over the country, and teachers to propagate training to future generations of trainees in the field of critical care medicine.

Course Structure:

I. Courses at TMC

Program Code : HLTH10A04	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms.
		All the necessary training and mandatory theory are specified in the syllabus of the DM Critical Care Medicine Course.
		The student is expected to participate in the regular appraisal examinations and academic programmes conducted in the institute.
		The purpose would be to acquire an understanding of the subject of Critical Care Medicine
		The candidate’s progress through the 3 years will also be assessed with feedback from all stake holders, including the candidate and work-based assessment.

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	Resuscitation and Initial Management of the Acutely Ill Patients	CCM 1
2	Diagnosis : Assessment, Investigation, Monitoring and Data Interpretation	CCM 2
3	Disease Management	CCM 3
4	Therapeutic interventions/organ system support in single or multiple organ failure	CCM 4
5	Practical procedures	CCM 5
6	Peri-operative care	CCM 6
7	Comfort and Recovery	CCM 7
8	End of life care	CCM 8
9	Pediatric Care	CCM 9
10	Transport	CCM 10
11	Patient safety and health systems management	CCM 11
12	Professionalism	CCM 12
13	Physics & Clinical Measurement Mathematical Concepts	CCM 13
14	Research Methods	CCM 14
15	Applied Anatomy	CCM 15
16	Physiology & Biochemistry	CCM 16
17	Pharmacology	CCM 17

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Resuscitation and Initial Management of the Acutely Ill Patients	CCM 1	Learn and Develop clinical skills for emergent resuscitation and acute care of critically ill, obtain technical expertise in various procedures to be performed for providing organ support therapies.
Diagnosis : Assessment, Investigation, Monitoring and Data Interpretation	CCM 2	To understand principles of disease in various patient categories, the pathophysiologic basis of mechanisms of disease, the pharmacologic principles guiding various therapies, institution and interpretation of appropriate monitoring modalities and devices

Disease Management	CCM 3	To provide comprehensive management of critically ill patients, including diagnosis, planning treatment and interventions , anticipate likelihood of development of organ failure and take and develop leadership skills while managing care by multidisciplinary team
Therapeutic interventions/organ system support in single or multiple organ failure	CCM 4	Develop core skills and expertise in various procedures required in critically ill and provide multiple organ support therapies
Practical procedures	CCM 5	Develop core competencies and skills in various procedures required in critically ill Develop expertise in conducting diagnostic and therapeutic procedures for treatment in critically ill
Peri-operative care	CCM 6	Develop understanding in managing routine perioperative and postoperative care and develop competence and expertise in diagnosing and treating complications
Comfort and Recovery	CCM 7	Understanding the core concepts of values and ethics in providing Comfort care to patients while undergoing disease treatment
End of life care	CCM 8	Develop and understand key principles of Compassionate care while providing End of life Care and comfort care of terminally ill
Paediatric Care	CCM 9	To understand principles of diseases in paediatric patient, the pathophysiologic basis of mechanisms of disease, the pharmacologic principles guiding therapies, institution and interpretation of appropriate monitoring modalities and devices
Transport	CCM 10	Develop proficiency in transport medicine with key understanding of the risks and the nuances of transporting critically ill from one care giving location to other, with special understanding about intra-hospital and inter-hospital transports. Develop leadership qualities for orchestrating a safe transport with optimum use of logistics
Patient safety and health systems management	CCM 11	Develop and dissipate knowledge and practices regarding maintaining high safety standards to patients and care givers
Professionalism	CCM 12	Develop and practice professional and ethical care to all the critically ill as well as conducting oneself morally and ethically

Physics & Clinical Measurement Mathematical Concepts	CCM 13	Thorough knowledge of Medicine, physiology and the clinical course of disease process. To Develop knowledge regarding the working principles and key concepts of various monitoring devices
Research Methods	CCM 14	To create an understanding regarding basic principles of clinical research ,statistics and emphasis on Good Clinical Practice guidelines (GCP) and translating this knowledge application to bedside management of the critically ill patients.
Applied Anatomy	CCM 15	Develop knowledge of the anatomy and applied anatomy basics
Physiology & Biochemistry	CCM 16	Develop knowledge about basics and alteration of Physiology and Biochemistry and its use in Care of critically ill patients
Pharmacology	CCM 17	Acquire knowledge about pharmacology principles and various drugs and application of this knowledge for Care of critically ill patients

D.M. in ONCOPATHOLOGY
(Program Code: HLTH10A05)

Course Structure:

I. Courses at TMC

Program Code : HLTH10A05	Programme Specific Outcome	Understand and apply principles of oncopathology(grossing, immunohistochemistry) for rendering a meaningful oncopathology report
		Understand importance of multi-disciplinary management of patients and contribute to same effectively
		Provide exposure in various branches of oncopathology including solid tumors, cytology, fluid hematopathology and molecular diagnostics
		Engage in research and life long learning to adapt to changing needs of oncology

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	Theoretical knowledge	09HLTH10A05-001-C
2	Practical and clinical skills	09HLTH10A05-001-P
3	Writing project/ Research articles	09HLTH10A05-001-R
4	Inter-personal relationship and communication skills.	09HLTH10A05-002-C
5	Training in Research Methodology, Medical Ethics and Medicolegal aspects	09HLTH10A05-003-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Theoretical knowledge	09HLTH10A05-001-C	Pathogenesis and diagnostic approach and work up od benign and neoplastic diseases of all specialties in oncopathology

		Immunohistochemistry principle, basics, methods, [manual automated], trouble shooting and quality assurance
		Research methodology and Quality management system including quality control, quality assurance and quality indicators in laboratory medicine
		Basic cell biology, carcinogenesis and molecular pathways
Practical and clinical skills	09HLTH10A05-001-P	Grossing protocols of all common oncology surgical specimens and guidelines for handling all other specimens. Protocols for Obtaining tissues for ancillary methods
		Order and Interpret immunohistochemistry results in all cancers including flow cytomtery immunophenotyping, Be able to participate in Standardization and validation of newer antibodies and quality assurance in IHC lab
		Teaching oncopathology to postgraduates, nurses and paramedical staff including laboratory personnel
		Initiate research questions and systematically write or present a paper and publish in a journal
		Be aware of quality control and bio-safety and waste disposal issues in a laboratory
		Constantly update knowledge of recent advances in oncopathology and allied subjects
Writing project/ Research articles	09HLTH10A05-001-R	Identification of important peer reviewed journals. Demonstrate ability to search literature for information
		Evaluate levels of evidence in literature
		Demonstrate ability to critically evaluate published studies
		Demonstrate ability to design, plan and do a research study/ audit as part of curriculum
		Demonstrate ability to take informed consent before procedures
Inter-personal relationship and communication skills.	09HLTH10A05-002-C	Understanding of importance and criticality of the laboratory tests and reports

		Demonstrate objectivity in interpretation of morphology
		Understand ones limitation in interpretation of tests and knowledge and to communicate the same to patients and colleagues
		Demonstrate skills in teaching junior staff, laboratory workers and medical colleagues
		Demonstrate effective communication skills in explaining reports to patients, delay in reports and counseling them if necessary including disclosure of laboratory errors
		Demonstrate effective communication skills in interacting with clinical and multidisciplinary teams in difficult cases
Training in Research Methodology, Medical Ethics and Medicolegal aspects	09HLTH10A05-003-C	Participate and present in Slides Meetings by faculty including MAPCON
		Participate and present Multidisciplinary joint meeting and Tumour boards and Journal Clubs
		Participate and present in Gross Specimen meetings
		Acquire training in Good Clinical practice
		understand Institutional IEC protocols be able to write a study protocol for thesis
		Be able to analyse SPSS based survival analysis

D.M. in INTERVENTIONAL RADIOLOGY (Program Code: HLTH10A06)

Program Code : HLTH10A06	Programme Outcome	To train the residents in skills in various aspects vascular and non-vascular Intervention.
		To be able to participate in holistic management including diagnosis, planning treatment and performing vascular and non-vascular procedure. To contribute in multi-disciplinary team discussion in approaching particular case.
		To understand the need to identify emergency scenario and prompt reporting to help in patient management.
		Encourage and guide the residents for various paper and case presentations at national and International level.

Course Structure:

I. Courses at TMC

Program Code : HLTH10A06	Programme Specific Outcome	The candidate should complete the necessary training and mandatory theory as specified in the syllabus of the DM Interventional Radiology course.
		To participate and excel in the appraisal exams held each year of both theory and practical.
		To learn the need and importance of multidisciplinary approach in patient management.
		To attend and participate in lectures, case discussions and contribute value adding points.
		Provide adequate exposure to interventional non oncology cases in Interventional Radiology to give wholesome training.

(A) CORE COURSE

1ST YEAR

Sr. No.	Name of the Course	Course code
1	Basics of Clinical aspects	09HLTH10A06-001-C
2	Basics of interventional vascular/non-vascular catheterization laboratory	09HLTH10A06-002-C

2^{ND} YEAR

Sr. No.	Name of the Course	Course code
1	Imaging of the vascular & non-vascular system: general principles	09HLTH10A06-003-C

3^{RD} YEAR

Sr. No.	Name of the Course	Course code
1	Vascular Intervention: General	09HLTH10A06-004-C
2	Vascular Intervention: Specific territories	09HLTH10A06-005-C

Course Outcomes:

(A) CORE COURSES

1^{ST} YEAR

Name of the Course	Course code	Course Outcome
Basics of Clinical aspects	09HLTH10A06-001-C	To gain an in-depth understanding of Image Guided Intervention in being able to evaluate, diagnose, treat and follow-up a patient.
		To understand the pathogenesis and biology of various diseases so as to interpret the imaging findings and correlate with clinical scenario.
		To Understand Epidemiology including expected outcomes.
		To understand pathophysiology including aetiology – risk factors.
		To understand the relevant anatomy for all the various organ systems in the body relevant to IR practice including embryology and normal variants.
		To understand the complementary roles of the various imaging modalities in the assessment planning, treatment and overall management of patient.
		To understand the basic physics and mechanisms of the various modalities and equipment used in Interventional Radiology so as to plan and modify protocols on case to case basis. To be able to decide the modality which can be used in a specific indication.
		To understand the principles and application of radiation protection to the working personnel's, staffs as well as the patients. Regular monitoring of the same.

		The candidate's progress through the 3 years will also be assessed with feedback from all stake holders, including the candidate.
Basics of interventional vascular/non-vascular catheterization laboratory	09HLTH10A06-002-C	The candidate should know the indications, contraindications and understand the range of treatment strategies including, endovascular/interventional and alternatives treatment to a level sufficient to be able to discuss management with patients and formulate appropriate treatment plans within an MDT.
		The candidate should be able to select appropriate laboratory and imaging investigations pertinent to treatment for all the relevant organ systems.
		The candidate should know the outcomes of interventional procedures including complications, how to avoid them and their management.
		The candidate should be understanding pre-, peri- and post-procedural drug requirements including the use of chemotherapeutic drugs used in oncology and embolization.
		The resident should also understand the main characteristics, advantages and limitations of a given procedure and devices to be used: – Needle for biopsy: size and tip characteristics – Ablation devices: different energies used for achieving tissue ablation in different organs and structures (microwave ablation (MWA), radiofrequency ablation (RFA), laser ablation, cryoablation (CRYO), high-intensity focussed ultrasound (HIFU)) – Vascular and drainage catheter shapes and characteristics to be chosen according the anatomical region.
		The resident should be competent to perform following procedures: **1) Image guided biopsy:** •Demonstrate competence in safely performing percutaneous biopsy of lesions in the chest, abdomen and pelvis, bone soft tissue. • Be familiar with a variety of biopsy needles (histology, cytology) and techniques. • Be able to treat patients with post-biopsy pneumothorax including conservative management or placement of a chest drain if necessary. • Be familiar with how to treat patients with significant haemorrhage following biopsy.
		2) Image guided drainage: • Identify the safest and most expeditious route of drainage for abscess collections in various anatomic locations throughout the chest, abdomen and pelvis.

		• Demonstrate skill at image-guided puncture and drainage of a range of target lesions in common sites and conditions. • Demonstrate understanding of dilatation of established drainage tracks for placement of larger bore catheters. • Identify potentially difficult cases such as multiloculated abscess cavities that may require placement of multiple catheters for adequate drainage or instillation of fibrinolytic agents to aid in drainage. • Be familiar with a wide variety of coaxial needles drainage catheters and guide wires for the purposes of percutaneous abscess drainage.
		3) Hepato-Pancreatico-Biliary (HPB) Intervention: • Demonstrate familiarity with a wide array of percutaneous biliary access systems, and all equipment available for HPB interventional procedures including access and drainage systems, balloons, stents and stent grafts. • Demonstrate skills in percutaneous transhepatic cholangiography and biliary drainage under a combination of fluoroscopic and ultrasound guidance. • Demostrate skills in percutaneous biliary duct occlusion using a variety of embolic materials. • Organise appropriate post-procedural management following drainage procedures to assess response to the intervention and recognise and manage complications including haemorrhage, infection, drain displacement. • Arrange post-drainage procedures and interventions including, as appropriate, check cholangiography, conversion to internal drainage, biliary stenting by percutaneous or combined radiological – endoscopic methods. • Identify patients who will benefit from an expanding metal stent. • Describe the major complications associated with percutaneous transhepatic cholangiography and biliary drainage and management of them. • Recognise patients at high risk of sepsis following biliary interventions and understand how to treat post-procedural sepsis. • Manage patients with arterio-biliary fistulae or bleeding following percutaneous biliary drainage. • Demonstrate skills in treating complications of pancreatitis including recognising and treating further complications such as haemorrhage. • Demonstrate skills in treating focal liver diseases such as liver abscess.
		4) Percutaneous Nephrostomy Insertion:

		• Understand the technical aspects for diagnostic evaluation of pelvicalyceal and ureteric obstruction. • Describe the various imaging techniques for accessing the upper tracts safely and successfully: – Ultrasound (freehand and guided techniques) – Fluoroscopy – Computed tomography (freehand and guided techniques) – Blind puncture. • Demonstrate knowledge and understanding of planning access intervention. • List the relative risks related to a different choice of calyceal access. • Describe the various puncture techniques to access the upper tracts safely and successfully. • Describe the use of contrast, air and CO2 to identify appropriate calyx for puncture. • Describe and demonstrate knowledge of parallax fluoroscopy to access the upper tracts. • Understand the correct technique for placement of external drainage nephrostomy catheter. • Understand the various catheter fixation techniques available. • Describe the maintenance of long-term nephrostomy drainage, catheter exchange replacement of dislodged catheters antegrade and placement of ureteric stents.
		5) Vascular access: • Understand the standard groin anatomy, including the position of the inguinal ligament and the femoral nerve, artery and vein. • The Seldinger technique of arterial and venous puncture. • Ultrasound-guided vessel puncture. • Mechanisms for guidewire, sheath and catheter insertions into the groin. • Mechanisms of puncture site haemostasis including manual compression and the use of common closure devices. • Alternative sites of arterial puncture, such as brachial, axillary, popliteal, tibial, pedal, radial and ulnar. • Understand the roles and the advantages and disadvantages of each access.

2ND YEAR

Name of the Course	Course code	Course Outcome
Imaging of the vascular & non-	09HLTH10A06-003-C	The resident should be competent in carrying out imaging and integrating the different range of

vascular system: general principles		imaging modalities for the relevant organ systems for diagnosis, staging, follow-up and directing therapies including Ultrasound, MR Angiography, CT, PET CT and Scintigraphy.
		The resident should be able to understand the mechanisms, complementary roles and limitations of the different imaging techniques including ultrasonography, magnetic resonance angiography, computed tomography angiography, catheter angiography (including Digital Subtraction Angiography and 3-D Rotational Angiography) cone beam CT and image fusion in the investigation and treatment guidance of the different organ systems. The residents should develop understanding of different imaging with respect to the following: • Be able to interpret pre-treatment images • Be able to stage disease with reference to images • Be able to interpret post-treatment images and follow-up images with reference to posttreatment sequelae • Be able to identify local post-treatment recurrences • Be able to interpret imaging changes in post-operative patients • Be able to interpret imaging changes in patients on antiangiogenics
		The resident should be familiar with: • Guidewires, sheaths and catheters (pigtail and selective) used for common diagnostic angiographic procedures. • Digital subtraction angiographic techniques, bolus chase techniques, road mapping, smart mask and pixel shift techniques. • Standard arterial and venous anatomy and variations in anatomy throughout the body. • Peripheral vascular angiography. • Mesenteric and renal angiography. • Abdominal aortography. • Thoracic aortography. • Carotid, vertebral and subclavian angiography. • Diagnosis of atherosclerotic disease, vasculitis, aneurysmal disease, thrombosis, embolism and other vascular pathology. • Post-procedural care regimens for standard diagnostic vascular procedures.
		Resident should understand the risks associated with the different imaging modalities including: • Contrast medium related: Iodinated contrast.

		• The risk factors for developing nephrogenic systemic fibrosis (NSF) with differing Gadolinium agents. • The complication rates for common diagnostic catheter procedures. • Exposure to ionising radiation, both for the patient and the IR team. • Magnetic resonance imaging including the effects of and on implanted materials, e.g. pacemakers, vascular stents and implants, prosthetic joints. • Physical injury during/as a result of arterial catheterisation.
		The resident should have image interpretation skills to be able to understand: • Normal vascular anatomy • Organ anatomy and system anatomy • Correlations between the real anatomy (surgical anatomy) and imaging anatomy (CT, magnetic resonance (MR), ultrasound (US), angiography and X-rays) • Most common distortions and changes in anatomy occurring after surgery • Most common anatomical variations • Liver segmentation and its relationship with surrounding structures • Liver parenchymal structure (the concept of “liver’s functional unit”) • Liver vascular anatomy, including arterial, portal, and venous anatomy • Biliary anatomy • Most common liver anatomical variations in vascular and biliary anatomy • Common post-operative modifications of liver anatomy and biliary route (e.g. biliary diversions) • Renal anatomy and its relationship with surrounding structures • Arterial and venous renal distribution • Anatomy of the collecting system • Most common anatomical variations of the vascular and collecting system • Post-operative anatomical variations of the vascular and collecting system (e.g. urinary diversions) • Anatomy of lungs (lobes/segments) and their relationships with surrounding structures • Vascular anatomy of the lungs (pulmonary arteries and veins, bronchial arteries) • Airways anatomy • Most common post-surgical vascular anatomy and airways variations

		• Anatomy, parenchymal structure, relationships with surrounding structures, vascular anatomy, most common anatomical variations and possible post-surgical changes of any other organs including the pancreas, adrenal glands, thyroid, lymph nodes and bones

3[RD] YEAR

Name of the Course	Course code	Course Outcome
Vascular Intervention: General	09HLTH10A06-004-C	The resident should acquire clinical, pathological and radiological understanding of diseases and conditions requiring vascular treatments. • Perform vascular treatments in emergency or elective settings. • Recognition and management of complications. • Know how to perform and handle imaging workup before and after vascular treatments. • Clinical assessment of patients before and after the treatment. • Understand the changes that will occur in different organs parenchyma after vascular treatments. • Know different agents that may be injected (delivery, side effects). • Accurately report key findings and treatment steps.
		Vascular Intervention: • Plan the vascular procedure depending on the indication. • Understand the material used for procedures, and know which one to use with reference to the indication. • Know basic and advanced guidance techniques (digital subtraction angiography (DSA), 3D imaging). • Perform diagnostic angiography. • Perform angioplasty and stent placement. • Perform embolisation (arterial and venous). • Perform basic and advanced chemoembolisation. • Perform radioembolisation. • Perform arterial or venous thrombolysis and thrombectomy. • Place access lines. • Place and retrieve superior and inferior vena cava filters. • Perform dialysis fistula interventions. • Perform foreign body retrieval. • Place closure devices

		Non-vascular Intervention: • Plan optimal procedural access, patient positioning and relevant/optional image guidance methods • Demonstrate competence in using the current technologies • Plan the procedure depending on the indication • Understand the material used for procedures (balloons, stents, drains, etc.) and know which one to use with reference to the indication • Be able to use adjunctive procedures such as hydro-dissection, CO2 dissection, ureteral stenting, etc. in order to optimise the procedural outcome • Know basic and advanced guidance techniques • Perform drainage (collection, bile, urinary, etc.) • Perform nutritional procedures (gastro and jejunostomies) • Perform conversion from drain to stent (urinary and biliary)
Vascular Intervention: Specific territories	09HLTH10A06-005-C	**Venous Intervention** **The resident should develop technical skills in the following Venous Intervention:** 1) Central venous access 2) Venous Thrombosis and Insufficiency 3) Pulmonary thromboembolic disease 4) Superior and inferior vena cava disease 5) Portal and hepatic venous interventions 6) Gonadal venous interventions 7) Venous sampling **1) Central venous access:** •Demonstrate proficiency in Doppler US for demonstrating and assessing venous anatomy • Demonstrate competence in US-guided puncture of the internal jugular, external jugular, axillary, subclavian, upper limb and femoral veins • Be competent in insertion of temporary and tunnelled lines via the jugular, subclavian and femoral approaches • Be competent in placement of arm and chest wall ports • Recognise when a central catheter is in an abnormal position on post-procedural imaging • Be aware of alternative strategies where standard routes of access are unavailable, including tunnelled femoral lines, translumbar IVC lines, transhepatic lines, US-guided puncture of the innominate veins and recanalisation of occluded central veins to facilitate access Management of complications, i.e.: • Be competent in insertion of chest drains for pneumothorax

		• Be competent in management of massive air embolus • Be competent in snare retrieval of intra-vascular catheter fragments • Know techniques for repositioning malpositioned lines • Be able to perform fibrin sheath stripping • Know the range of central venous catheters, ports, PICCs, dialysis and apheresis lines • Know maximum flow rates achievable with different catheters • Know the maximum pressures to which lines may be subjected **2) Venous Thrombosis and Insufficiency:** • Demonstrate competence in percutaneous therapies such as laser, radiofrequency ablation and foam sclerotherapy and avoidance of complications • Recognise the relative risks and benefits associated with treatment of varicose veins including DVT, infection, skin slough, etc. • Demonstrate competence in mechanical and pharmacological thrombolysis and its complications • Demonstrate knowledge of various venous stents and appropriate placement of venous stents **3) Pulmonary thromboembolic disease:** • Be familiar with a wide range of interventional equipment including guidewires, catheters, aspiration and mechanical thrombectomy catheters and permanent and optional IVC filters • Understand the potential advantages and limitations of various types of filters including the maximal caval diameter in which each type of device may be placed • Demonstrate technical competence in the performance of femoral and jugular venous access using ultrasound guidance, pulmonary angiography, pulmonary thrombolysis and mechanical thrombectomy, inferior vena cavography, IVC filter placement and retrieval • Integrate the use of intraprocedural pressure monitoring in performing pulmonary angiography • Ensure post-procedural protocols are in place, including date for retrieval of optional filters **4) Superior and inferior vena cava disease:** • Demonstrate technical competence in the performance of SVC and IVCO recanalisation, including venous access using ultrasound guidance, catheter-directed thrombolysis, balloon dilatation and stent placement

		• Be familiar with the interventional equipment including guidewires, sheaths, catheters, balloons and various types of stents/stent-grafts • Be familiar with the use of re-entry devices **5) Portal and hepatic venous interventions:** • Recognise the patterns of portal vein occlusion including cavernous transformation of the portal vein and the important collateral pathways • Be familiar with the equipment used in the TIPS procedure including guidewires, sheaths, catheters, balloons, stents, embolic materials, and transhepatic cannulation kits • Discuss the benefits of using covered stents versus bare stents • Know the normal ranges for portal venous pressures, central venous pressures, and portosystemic pressure gradients, including target ranges for post-TIPS portosystemic pressure gradients • Demonstrate knowledge of the anatomical relationship between portal vein and systemic intrahepatic veins and their impact for TIPS • Demonstrate technical competence in the performance of all procedural aspects of TIPS using fluoroscopic and ultrasound guidance • Recognise and manage intra- and post-procedural complications of TIPS, including haemoperitoneum, haemobilia, biliary-shunt fistula formation, progressive liver failure, shunt thrombosis or occlusion, right heart failure, and hepatic encephalopathy • Demonstrate competence in the performance of TIPS revision procedures, including the management of shunt stenosis or occlusion • Demonstrate competence in the performance of variceal embolisation using a variety of agents including coils, plugs, glue, Onyx, etc. • Demonstrate competence in the performance of BRTO **6) Gonadal venous interventions:** • Demonstrate technical competence in performing venous access from different routes (jugular, antecubital, femoral) under ultrasound guidance and performing venography • Be familiar with different embolic agents used in embolisation of gonadal veins and internal iliac veins in women • Be aware of complications and their management **7) Venous sampling:**

		• Demonstrate competence in performing venous sampling and peripheral venous or arterial stimulation • Be familiar with the catheters and wires used in venous sampling • Recognise and manage complications
		Neurointervention **Carotid:** **The resident should develop technical skills in carotid intervention as follows:** • Demonstrate technical competence performing carotid and supra-aortic interventions including but not limited to balloon angioplasty, stent placement and use of cerebral protection devices • Know the types and rates of expected complications of percutaneous interventions and how to manage them • Manage acute embolic complications during percutaneous carotid interventions with catheter directed thrombolysis and other techniques **Stroke:** **The resident should develop technical skills in stroke management as follows:** • Demonstrate competence in performing a mechanical thrombectomy procedure • Be familiar with the materials needed for Transarterial thrombectomy (i.e. guiding catheters, micro catheters, micro guide wires) • Know the most commonly used thrombectomy devices (stent-retrievers, hydrodynamic devices) • Know the potential risks and complications (dissection, perforation, thrombus dislodgement) and their management • Demonstrate competence in performing intra-arterial thrombolysis
		Peripheral Intervention **Aorta:** **The resident should develop technical skills in aortic intervention as follows:** • Demonstrate competence in planning stent-graft repair using cross sectional imaging on a high-quality workstation • Demonstrate competence in the techniques of endovascular repair of aortic aneurysms or dissections, including:

		– Pre-/peri-procedural transcatheter occlusion of significant branch vessels – Preparation, insertion and deployment of the current aortic stent-graft devices – Post-deployment manoeuvres required to safely remove the device introducer and close the access site • Recognise patients with anatomy unsuitable for conventional access for endovascular repair and suggest alternative methods of stent-graft placement • Recognise the complications that may arise during endovascular repair and their appropriate management: – Dissection, occlusion or rupture of the access vessels, the aorta or the aneurysm sac – Coverage of important branch vessels, e.g. the carotid, subclavian, spinal, renal or internal iliac arteries – Distal embolisation of the arch vessels or the mesenteric, renal or lower limb vessels – Contrast reactions and contrast induced nephropathy (CIN) – Cardio-respiratory complications related to prolonged general anaesthesia in patients with poor cardiovascular reserve • Demonstrate competence in the techniques for the management of endoleaks. **Peripheral Arteries:** **The resident should develop technical skills in management of peripheral arterial disease.** • Demonstrate ability to plan optimal vascular access and vascular closure • Demonstrate technical competence of puncture site management • Be able to categorise arterial lesions according to the expected outcome, e.g.: – Technical success – Complications – Clinical outcome – Restenosis • Demonstrate technical competence in the performance of peripheral vascular interventions including: – Crossing stenosis with selective catheters and guidewires – Recanalisation techniques of total occlusions including subintimal recanalisation and use of re-entry devices

		– Balloon angioplasty and stent placement – Catheter-directed thrombolysis and Percutaneous Aspiration and Mechanical Thrombectomy – Management of complications • Demonstrate correct selection and use of equipment including: – Guidewires – Catheters – Sheaths – Balloons • Atherectomy devices – Stents and stent-grafts • Understand the role of intravascular pressure gradients including the use of vasodilators to assess the outcome of vascular interventions • Differentiate between embolic occlusion and in situ thrombosis in cases of acute limb ischaemia and tailor therapy accordingly • Demonstrate ability to recognise and manage the potential complications of endovascular procedures such as balloon angioplasty, stenting, stent grafting and catheter-directed thrombolysis/percutaneous aspiration and mechanical thrombectomy • Understand the indications, contraindications and limitations of puncture site closure devices • Recognise the role of emerging treatments for restenosis including: – Local drug delivery • Percutaneous atherectomy – Endovascular brachytherapy **Visceral Arteries:** **The resident should develop technical skills in visceral arterial intervention:** **Mesenteric artery:** • Demonstrate competence in superselective catheterisation and selection of wires, catheters, stents and suitable embolic materials according to anatomical site • Demonstrate technical competence in performing angioplasty, stenting, stent-grafting and embolisation in these vascular territories • Demonstrate competence in the techniques and equipment used in embolisation for acute and chronic gastrointestinal blood loss. • Demonstrate competence in the techniques and the range of equipment used in embolisation and exclusion of visceral artery aneurysms • Demonstrate knowledge of potential complications and preventative strategies in the treatment of visceral artery aneurysms

		• Demonstrate competence in the angiographic techniques for the assessment of acute and chronic mesenteric ischaemia • Understand and evaluate suitability for endovascular treatment • Demonstrate competence in the techniques and equipment used in the endovascular management • Demonstrate competence in performing angiography in a patient with vasculitis • Demonstrate competence in the endovascular treatment of vasculitis **Renal artery:** •Demonstrate competence with the equipment and techniques used in the treatment of renal artery stenosis • Integrate the use of intra-procedural intra-arterial pressure measurements in assessing the results of renovascular interventions • Know the types and rates of complications of renovascular interventions and demonstrate competence in the management of those • Demonstrate competence in the techniques and equipment used in the treatment of renal haemorrhage secondary to iatrogenic or direct trauma. **Bronchial & Pulmonary artery:** •Demonstrate competence in catheterising and embolising the bronchial and pulmonary arteries. • Demonstrate competence and understanding in the management of complications of various visceral arterial interventions. **Uterine artery:** •Demonstrate technical competence in pelvic angiography and uterine artery catheterisation and embolisation • Know potential complications of uterine artery embolisation and their management. **Prostatic artery:** • Acquire the necessary competence to carry out prostate artery embolisation. • Understand the complications of prostate artery embolisation and how to manage them.
		Interventional Oncology:

		The resident should develop technical skills in organ specific image guided interventions: **1) Lung (Primary & Metastatic)** **The residents should develop technical skills in the treatment of primary and metastatic lung disease.** • Plan optimal procedural access, patient positioning and relevant/optional image guidance methods in accordance to the ALARA principle • Be able to use separation techniques to help create a buffer zone between the tumour and neighbouring vital structures such as pleura, mediastinum and diaphragm (e.g. artificial pneumothorax/hydrothorax, pneumomediastinum) 44 Upper GI: Stomach and Oesophagus • Be able to decide which kind of ablative technology (MWA, RFA, CRYO, IRE) to use for treatment depending on the type and location of tumour, its size and its imaging, pathology characteristics and adjacent structures (vascular, bronchi, mediastinal structures, nerves and heart) • Plan the correct positioning of the electrodes in the tumour to achieve optimal results with the least possible complications • Plan the size of the electrode to use and the number required to receive acquired ablation effect • Know when and how to avoid pleural burns • Know when to do a prophylactic infiltration of long acting local anaesthetic to prevent pain due to pleural burns • Decide when to treat bilateral disease in the same setting or in a second setting • Recognise the differences between the lung and parenchymal organs such as liver and kidney in terms of thermal and electrical conductivity which result in differences in ablation times and protocols • Be able to recognise intra-procedural pneumothorax or haemorrhage as soon as possible and be able to establish appropriate management by aspiration, placement of a chest tube, embolisation or consultation of surgical colleague for adequate treatment
		2) Upper GI (Stomach & Oesophagus): **The residents should develop technical skills to treat patients with Stomach and Oesophageal cancer requiring image guided interventions.**

		• Have knowledge on the vascular anatomy and the various anastomoses in the upper GI tract • Know the use of microcatheters and micro-guidewires for superselective embolisation • Know which size of particles can be used for tumour embolisation to diffuse gastric cancer bleeding in order to optimise bleeding control and to minimise ischemic complications • Know how to embolise macroscopic bleedings in the upper GI tract (due to vessel erosion, pseudoaneurysms) with the use of microcoils. Have knowledge on the importance to embolise distal and proximal to the bleeding due to possible retrograde distal perfusion through collaterals • Be familiar with techniques of image-guided gastrostomy and be familiar with the different available systems • Be able to place a gastrostomy with and without assistance of a nasogastric tube • Understand the role of peri-interventional antibiotics in gastrostomy placement. **3) Hepatic: Primary and Metastatic.** **The residents should develop technical skills to treat patients with primary and metastatic liver disease requiring vascular and non-vascular interventions.** **3.a) Technical skills in vascular hepatic arterial interventions:** • Know the indications and absolute and relative contraindications to chemo/radioembolisation • Demonstrate technical competence in performing lobar, segmental and targeted embolisation therapy • Know the different types of catheters, guide wires and sheaths available to make access easier • Know the use of micro catheters and micro-guide wires for super selective treatments (especially chemoembolisation) • Know when to use TACE and when to use drug-eluting Beads (DEB) TACE. • Know which size of beads to use in which size of tumours • Know which chemotherapy to charge the beads with depending upon the tumour • Understand the difference between conventional TACE (cTACE) and DEB TACE • Know how to protect adjacent structures (duodenum, stomach, skin, etc.) during radioembolisation

		• Know the differences between radioembolic microsphere in terms of size, materials and isotope • Understand how to plan a dose for radioembolisation • Know when a single lobar treatment needs to be done and when both lobes can be treated simultaneously • Understand the concept of radiation segmentectomy • Understand the concept of bland embolisation for neuroendocrine metastases • Be able to manage tumour bleeds (intra- and extratumoural) **3.b) Technical skills in portal Vein interventions:** • Recognise the anatomy of intrahepatic portal vein branches and their relationships with tumour bearing liver segments. • Know the differences and indications for ipsilateral and contralateral transhepatic approaches in PVE. • Be familiar with the equipment used in PVE including guidewires, sheaths, catheters, embolic materials and transhepatic cannulation kits. • Be competent at US-guided transhepatic puncture of intrahepatic portal vein branches. • Demonstrate technical competence in the performance of all procedural aspects of PVE, for ipsilateral and controlateral transhepatic approaches. **3.c) Technical skills in non-vascular hepatic interventions:** • Demonstrate competence in the current technologies available in IGA therapy including ethanol, radiofrequency and MWA • Understand the evolving technologies in this area including cryotherapy and irreversible electroporation (IRE) • Recognise the limitations of current ablation technologies and have knowledge of techniques used to achieve larger volumes of ablation (e.g. overlapping ablations, perfused devices and adjunctive techniques) • Recognise that energy-based IGA therapy in specific locations may cause injury to non-target areas such as the diaphragm, bowel, stomach and major bile ducts and know strategies to reduce these risks and to perform IGA therapy with greater safety, better patient tolerance and a reduced risk of treatment failures (e.g. technique of artificial ascites, bile duct cooling, artificial pneumothorax and separation of organs with CO2)

		• Be able to recognise intraoperative and post-operative complications of IGA therapy and undertake the appropriate investigation and management of complications such as haemorrhage, infection and GI perforation **3.d) Technical skills in biliary intervention:** • Demonstrate knowledge and understanding of safe biliary puncture • Show competence in decision-making in which lobar duct to access in order to achieve the best drainage • Be competent at ultrasound-guided puncture of intrahepatic biliary radicals (dilated or non-dilated) • Know how to access an intrahepatic biliary radical under fluoroscopic guidance • Have an understanding and knowledge of sheaths, guidewires, catheters, endobiliary biopsy forceps (cardiotomy or punch biopsy forceps), different types of internal-external drains and/or external drains • Understand the concept of a rendezvous with ERC through biliary drainage • Have knowledge of the types of stents available and when to use covered, partially covered, uncovered or removable stents • Recognise trauma to the adjacent vascular structure (portal vein or hepatic artery branch) with haemobilia • Demonstrate knowledge of how to manage complications secondary to biliary interventions **4) Renal Cancer:** **The residents should develop skills in vascular and non-vascular techniques to treat renal cancer** **4.a) Technical skills in renal cancer ablation:** • Demonstrate competence in the available ablation technologies including CRYO, RFA and MWA • Plan optimal procedural access to the tumour, patient positioning and relevant/optional imageguidance methods 54 Prostate Cancer • Plan the size and number of radiofrequency electrodes, cryo-probes or microwave antennas that are necessary to achieve a satisfactory ablation zone according to the tumour size, location and vascularity • Discuss with the anaesthetist the need/advantages of general anaesthesia/sedation and the utility of jet ventilation

		• Understand associated interventions (e.g. embolisation) that can be performed to improve the outcome of IGA • Recognise that energy-based image-guided ablation therapy in specific locations may cause injury to non-target areas (bowel, duodenum, pancreas, adrenal glands, ureter, etc.) • Be able to use the different thermal insulation (hydro-, CO2- and balloon-dissection, as well as pyeloperfusion) in order to protect the surrounding structures at risk • Be able to recognise intra-operative and post-operative complications of IGA therapy and undertake the appropriate investigation and management of complications such as haemorrhage, infection, urinomas, ureteral strictures and digestive fistulas **4.b) Technical skills in vascular renal cancer:** • Know the indications of palliative embolisation and arterial embolisation in combination with thermal ablation techniques • Demonstrate technical competence in performing targeted selective embolisation • Know the different types of catheters, guidewires, microcatheters and sheaths available to make access easier • Know the different embolic agents that can be used **5) Prostate Cancer:** **The residents should develop skills in treatment of prostatic cancer** • Acquire the necessary competence to carry out TRUS-guided prostate biopsies according to local protocols • Competence in guidance for brachytherapy implants • Know how to plan for cryotherapy of prostate gland • Be able to plan the number and type of electrodes needed and where to position them • Know how to create a separation plane between the rectum and the prostate to avoid rectal complications • Understand how to protect the urinary bladder during ablation procedures • Know how to monitor the progress of the ice ball and when to stop • Understanding of planning for HIFU and how to place the probe for tumour ablation

		• Understanding and planning for laser ablation • Know how many laser fibres will be needed and where to place them to achieve an effective and complete ablation **6) Musculoskeletal Cancer:** **The residents should develop skills in treatment of musculo-skeletal cancer**. • Plan optimal procedural access to vertebra and other bones, patient positioning and relevant/ optional image guidance methods • Understand adjunctive interventions (e.g. embolisation) that can be performed to improve the outcome of image-guided ablation • Discuss with the anaesthetist the need/advantages of sedation, spinal anaesthesia, regional nerve block or general anaesthesia according to the type of procedure planned, the site and extent of the disease • Be able to use separation techniques to help create a buffer zone between tumour and neighbouring vital structures (e.g. hydrodissection or dissection with CO_2) • Recognise the need to place thermocouples to monitor the temperature of sensitive structures during ablative procedures • Recognise bone lesions at risk of fracture and understand when to perform IGA therapy with cementoplasty in order to provide additional structural support • Know the type of ablation (laser, MWA, RFA and CRYO) technique optimal for the bone lesion with reference to the position of the lesion, the size of the lesion and the adjacent sensitive structures • Be able to recognise intra-procedural and post-procedural complications and arrange interventional radiological management if appropriate • Be able to monitor motor and sensory functions of the extremities in order to rule out neural damage after ablation of lesions close to major nerve bundles • Be familiar with all measures to protect and monitor sensitive neural structures in the spine (including active and passive thermoprotection by means of air or CO_2 injection, thermocouples, evoked potentials, etc.) • Be familiar with sclerotherapy for vertebral haemangioma, how to use sclersant. • To know how to monitor the patient for need of emergency decompression, or plan for simultaneous decompression procedure after the sclerotherapy • Be aware of when to plan a vertebroplasty after a sclerotherapy procedure **7) Soft Tissue Tumors (Desmoid / Fibromatosis):**

		• Know which ablation technique to use (CRYO, RFA) • Know how to use hydrodissection or dissection with CO2 to protect adjacent structures • Know and explain to the patient what to expect after the treatment, including how long the pain will last • Know how and where to correctly place the needles to get optimal ablation • Define if the treatment is with curative intent or to treat symptoms • Know how to manage the post-treatment period. **8) Endocrine Malignancies (Thyroid/Adrenal & Pancreatic):** **8.a) Thyroid:** The resident need to have basic knowledge of understanding and feasibility of thyroid ablation • Plan optimal procedural access, patient positioning and relevant/optional image guidance methods. Be able to use separation techniques to help create a buffer zone between the tumour and neighbouring vital structures such as the recurrent laryngeal nerve, carotid artery, internal jugular vein, pleura, trachea and mediastinum in the case of large tumours. • Be able to decide which kind of ablative technology (RFA, CRYO) to use for treatment depending on the type and size of tumour, as well as its imaging, pathology characteristics and adjacent structures (vascular, bronchi, mediastinal structures, nerves and heart) • Plan the correct positioning of the electrodes in the tumour to achieve optimal results • Plan the size of the electrode to use to acquire effective ablation • Know the specificities of ablation of the thyroid gland to adapt the protocol for optimal thyroid ablation. **8.b) Adrenal:** The resident need to have basic knowledge of understanding and feasibility of adrenal ablation. • Plan optimal procedural access, patient positioning and relevant/optional image-guidance methods. Be able to use separation techniques to help create a buffer zone between the tumour and neighbouring vital structures such as the pleura, kidney, IVC, liver and diaphragm

		• Be able to decide which kind of ablative technology (RFA, CRYO) to use for treatment depending on the size and type of tumour and its imaging, pathology characteristics and adjacent structures • Plan the correct positioning of the electrodes in the tumour to achieve optimal results • Plan the size of the electrode to use to acquire effective ablation • Know the difference between ablation of the pancreas and other organs such as lung, liver, etc. to adapt the protocol for optimal pancreatic tumour ablation **8.c) Gastro-entero-pancreatic neuroendocrine tumour (GEP-NET):** The resident need to have basic knowledge of understanding and feasibility of pancreas ablation. • Plan optimal procedural access, patient positioning and relevant/optional image guidance methods. • Be able to use separation techniques to help create a buffer zone between the tumour and neighbouring vital structures such as the normal pancreatic tissue, pancreatic duct and bowel • Be able to decide which kind of ablative technology (IRE, CRYO) to use for treatment depending on the size and type of tumour and its imaging, pathology characteristics and adjacent structures (stomach, bowel, pancreatic duct and splenic vein) • Plan the correct positioning of the electrodes in the tumour to achieve optimal results • Plan the size of the electrode to use to acquire effective ablation • Know the difference between ablation of the pancreas and other organs such as lung, liver, etc. to adapt the protocol for optimal pancreatic tumour ablation
		Miscellaneous Interventions **1) Vascular Malformation:** **The resident should develop technical skills in treating vascular malformation:** • Demonstrate competence and understanding of the principles, agents and techniques used in treatment of high-flow vascular malformations

		• Demonstrate competence in managing complications of treatment of high-flow vascular malformations • Demonstrate competence and understanding of the principles, agents and techniques used in treatment of low-flow vascular malformations • Demonstrate competence in managing complications of treatment of low-flow vascular malformations • Demonstrate competence and understanding of the principles, agents and techniques used in the treatment of lymphatic malformations • Demonstrate competence in managing complications of treatment of lymphatic malformations **2) Vertebral Body Compression Fracture Management:** • Demonstrate knowledge of proper vertebral body access techniques (transpedicular, parapedicular) • Be familiar with interventional equipment used in including needles, cements and cement delivery systems. • Understand when PV can be combined with other curative or palliative minimally invasive techniques of ablation • Be familiar with all measures to protect and monitor sensitive neural structures in the spine (including active and passive thermoprotection bymeans of air or CO2 injection, thermocouples, evoked potentials, etc.) • Be familiar with sclerotherapy for vertebral haemanginoma, how to use sclerosant as well as how to monitor the patient for need of emergency decompression if need be, or plan as simultaneous decompression procedure after the sclerotherapy • Be aware of when to plan a vertebroplasty after a sclerotherapy procedure **3) Enteral Tube placement.** • Demonstrate technical competence in carrying out the procedures with selection of the most appropriate image guidance • Demonstrate how to use guidewires and catheters to primarily place a gastrostomy or use these for a retrograde approach to allow placement of a pull type gastrostomy • Converting a gastrostomy to a gastrojejunostomy

		• Recognise and treat complications including pain, bleeding, tube displacement and peritonitis • Ensure clear pre-procedural and post–procedural instructions (fasting, antibiotics, etc.) and pathways for tube care • Administer adequate IV hydration and antibiotic therapy for safe and comfortable interventional procedures

M.Ch. in Surgical Oncology (Program Code: HLTH10B01)

Program Code : HLTH10B01	Programme Outcome	To train the surgical candidates in basics of clinical oncology.
		To understand the role of medical and radiation oncologic principles and their role in holistic, multidisciplinary management of cancer patients.
		To provide exposure to the comprehensive management, including diagnosis, planning treatment, be a part of the multidisciplinary team delivering treatment and follow-up of a patient with cancer.
		To build surgical skill set (open& laparoscopic) and early exposure to robotic surgery in various disciplines of oncology.
		To provide a platform for clinical and SOS translational research early in their training to generate interest.
		To provide national and international platform for presentations of clinical/surgical research data.
		The training should produce consultants to practice all over the country, and teachers to propagate training to future generations of trainees in TMC and elsewhere.

Course Structure:

I. Courses at TMC

Program Code : HLTH10B01	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms.
		All the necessary training and mandatory theory are specified in the syllabus of the MCh Surgical Oncology Course.
		The student is expected to participate in the regular appraisal examinations and academic programmes conducted in the institute.
		The purpose would be to acquire an understanding of the subject of surgical oncology in specific and clinical oncology in general.
		The candidate's progress through the 3 years will also be assessed with feedback from all stake holders, including the candidate and work-based assessment.

(A) CORE COURSE

Sr. No.	Name of the Course	Course code
1	Basic Sciences	09HLTH10B01-001-C
2	Principals of oncology	09HLTH10B01-002-C
3	Clinical Practice of Surgical Oncology	09HLTH10B01-003-C
4	Recent Advances in Oncology	09HLTH10B01-004-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Basic Sciences	09HLTH10B01-001-C	To be able to understand the basics of cancer biology and molecular pathology.
		To understand the pathophysiology of various neoplastic and pre-neoplastic processes.
		To understand the newer advances in molecular diagnostics
		To develop the insight and ability to apply this knowledge in the field of clinical and translational cancer research.
Principals of oncology	09HLTH10B01-002-C	To understand the multidisciplinary management of cancers and basic principles of medical and radiation oncology so as to provide the best treatment option to patients.
		To be able to provide complete oncologic care in future practice.
		To be able to grasp the basics of biostatistics and conduct of clinical research and randomised controlled trials.
		To learn planning of evidence based neoadjuvant and adjuvant chemo-radiation protocols so as to help and guide patients with cancer to choose appropriate modality of treatment.
Clinical Practice of Surgical Oncology	09HLTH10B01-003-C	To diagnose, stage and plan appropriate evidence based surgical procedure. To understand the principles of surgery for cancer, the radicality of the surgeries involved,
		To learn the nuances of pre-operative work up andpost-operative care
Recent Advances in Oncology	09HLTH10B01-004-C	To understand newer modalities and advances in surgical care such as use of microscopes, imaging devices, laparoscopic equipment and robotics.
		To have abasic working knowledge of next generation molecular biology techniques.
		To be aware of recent advances in diagnostic imaging and adjuvant modalities in cancer

M.Ch. in Gynaecological Oncology (Program Code: HLTH10B02)

Program Code : HLTH10B02	Programme Outcome	To train gynecologistsin basics of clinicalgynecologic oncology
		To understand medical and radiation oncologic principles and their role in holistic, multidisciplinary management of cancer patients
		To provide exposure to the comprehensive management, including diagnosis, planning treatment, be a part of the multidisciplinary team delivering treatment and follow-up of a patient with cancer.
		To build surgical skill set (open& laparoscopic) and early exposure to robotic surgery in various disciplines of oncology.
		To provide a platform for clinical and SOS translational research early in their training to generate interest.
		To provide national and international platform for presentations of clinical/surgical research data.
		The training should produce consultants to practice all over the country, and teachers to train future generations of trainees

Course Structure:

I. Courses at TMC

Program Code : HLTH10B02	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms.
		All the necessary training and mandatory theory are specified in the syllabus of the MChGynecological Oncology Course.
		The student is expected to participate in the regular appraisal examinations and academic programmes conducted in the institute.
		The purpose would be to acquire an understanding of the subject of gynecological oncology in specific and clinical oncology in general.
		The candidate's progress through the 3 years will also be assessed with feedback from all stake holders, including the candidate and work-based assessment.

(A) TRAINING MODULES

GYNECOLOGICAL ONCOLOGY MODULES

Sr. No.	Name of the Course	Course code
1	General Assessment of a Gynecological Oncology Patient	09HLTH10B02-001-M
2	Pre-, Peri- and Post-operative Care	09HLTH10B02-002-M
3	Generic Surgical Skills In Gynaecological Oncology	09HLTH10B02-003-M

SITE-SPECIFIC MODULES

Sr. No.	Name of the Course	Course code
1	Cancer of the Cervix	09HLTH10B02-004-M
2	Ovarian Cancer	09HLTH10B02-005-M
3	Cancers of the Uterine corpus	09HLTH10B02-006-M
4	Cancer of the Vulva	09HLTH10B02-007-M
5	Vaginal Cancer	09HLTH10B02-008-M

ALLIED SURGICAL SPECIALTY MODULES

Sr. No.	Name of the Course	Course code
1	Uro-oncological surgery	09HLTH10B02-009-M
2	Gastrointestinal/Colorectal surgery	09HLTH10B02-010-M
3	Breast Cancer Surgery	09HLTH10B02-011-M

ALLIED NON-SURGICAL SPECIALTIES

Sr. No.	Name of the Course	Course code
1	Radio-Diagnostics	09HLTH10B02-012-M
2	Medical Oncology	09HLTH10B02-013-M
3	Radiation Oncology	09HLTH10B02-014-M

Course Outcomes:

(A) TRAINING MODULES

GYNECOLOGICAL ONCOLOGY MODULES

Name of the Course	Course code	Course Outcome
General Assessment of a Gynecological Oncology Patient	09HLTH10B02-001-M	The candidate should be well trained in assessing the patient with an adequate history taking and clinical examination.
		The training should help the candidate to identify the appropriate diagnostic techniques needed to establish the diagnosis and establish the extent of disease.
		They should be able to stage the cancer according to the current F.I.G.O. staging for gynecological cancers and the corresponding TNM classification
		They should be able to evaluate co-existing disease which may have an important bearing on selection of and response to treatment
		They should be able to evaluate the response of cancer to treatment and communicate clinical plan to patient and relatives.
Pre-, Peri- and Post-operative Care	09HLTH10B02-002-M	The candidate should gain expertise in preoperative evaluation of gynecological oncology patients.
		To preoperatively prepare the patient on ground of pulmonary function and give adequate thrombo-prophylaxis.
		They should be able to take a valid informed consent from patient and witness after a detailed counseling.
		The candidate should get familiar with common as well as rare complications associated with commonly performed surgical procedures for gynecological cancers.
		The candidate should have sufficient training and experience in the postoperative care and aftercare management of these patients.
Generic Surgical Skills In Gynecological Oncology	09HLTH10B02-003-M	The candidate should gain sufficient expertise in the surgical anatomy comprising detailed knowledge of the pelvic abdominal and retroperitonealanatomy, including female genital tract, urinary and G.I tracts and other areas of relevance, e.g. thorax, thigh and neck
		The candidate should know the rationale, indications, complications and operative steps of various important surgical procedures in gynecological oncology.

		The candidate should have sufficient training and experience to perform surgical procedures in gynecological oncology independently.

SITE-SPECIFIC MODULES

Name of the Course	Course code	Course Outcome
Cancer of the Cervix	09HLTH10B02-004-M	The candidate should know the epidemiology &aetiology, risk and protective factors for cervical cancer.
		Sufficient training should be given regarding the role of HPV vaccination, diagnostic and primary and secondary prevention of cervical cancer
		To know the principles of colposcopy and colposcopic guided procedures
		The candidate should be trained in basic cytology, pathology, diagnosis and staging of cervical cancer.
		The candidate should be able to manage cervical precancer lesions independently
		They should be able to formulate treatment of all stages of cervical cancer with the help of surgery, radiation or chemotherapy.Alsolong and short term complications of various modalities of treatment used in cervical cancer.
		They should know the role and indications of fertility sparing treatments in cervical cancers.
		The candidate should be aware of follow up protocols, patterns of recurrence and be able to diagnose and manage them.
Ovarian Cancer	09HLTH10B02-005-M	The candidate should know the epidemiology &aetiology, risk and protective factors for ovarian cancer
		The candidate should be trained in basic pathology, pre-treatment evaluation, imaging, tumor markers, diagnosis and staging of ovarian cancer.
		They should be able to decide for management of all stages of ovarian cancer with the help of surgery or chemotherapy (Adjuvant & neoadjuvant chemotherapy).
		They should know the role of laparoscopy and fertility sparing surgery in ovarian cancer
		To be adequately trained in primary and interval debulking of ovarian cancers.
		To manage various complications: Bowel obstruction, anastomotic leak
		To learn both intravenous &intraperitoneal chemotherapy including HIPEC
		The candidate should be aware of follow up protocols, to diagnose and manage including

		indications for secondary debulking, Second line chemotherapy
		To learn various targeted therapy in the management of ovarian cancer and their mechanisms of action.
		To learn hereditary ovarian cancer syndromes, role of genetic testing, management of healthy individuals with genetic mutations including surveillance protocols and risk reducing surgeries
Cancers of the Uterine corpus	09HLTH10B02-006-M	The candidate should know the epidemiology &aetiology, risk and protective factors for uterine cancer
		The candidate should know the histological subtypes, basic pathology, use of imaging and diagnosis of uterine cancer.
		To be able to do pre-operative assessment, staging of endometrial cancer and uterine sarcomas
		The candidate should be to perform surgery for uterine cancer and know the need for lymphadenectomy and indications of use of minimal access surgery
		Should understand the role of sentinel node biopsy and how to perform it
		Should be aware of fertility sparing medical management for endometrial cancers in young women
		Should know the indications of adjuvant therapy: Radiation, Chemotherapy & Hormones and be able to decide for various patients accordingly
		The candidate should be aware of follow up protocols, patterns of recurrence and be able to diagnose and manage them.
Cancer of the Vulva	09HLTH10B02-007-M	The candidate should know the epidemiology &aetiology, risk and protective factors for vulvar cancer
		Should know the histo-pathological subtypes, patterns of spread and staging of vulvar cancer.
		Should be able to investigate, diagnose & decide for treatment of vulvar cancer including surgery and radiotherapy.
		Should know the role of sentinel node biopsy and inguinal lymphadenectomy in vulvar cancers.
		Should be aware of various flaps for wound closure in vulvar cancer

		Should be able to manage various complications such as wound breakdown, lymphocysts, lymphedema and neuralgia
		Should know the indications of adjuvant therapy: Radiation, Chemotherapy in vulvar cancer
		The candidate should be aware of follow up protocols, patterns of recurrence and be able to diagnose and manage them.
Vaginal Cancer	09HLTH10B02-008-M	The candidate should know the epidemiology &aetiology, risk and protective factors for vulvar cancer
		Should be able to diagnose carcinoma, sarcoma and metastatic lesions and do staging of vaginal cancer
		Should be able to adequately manage VAIN. Should be able to differentiate malignant from benign lesions.
		Should be able to decide and plan for partial & radical vaginectomy
		Should be able to manage the psychosexual morbidity associated with various procedures involved in treatment of vaginal cancers.
		Should be able to decide for radiation therapy for vaginal cancers.
		The candidate should be aware of follow up protocols, patterns of recurrence and be able to diagnose and manage them.

ALLIED SURGICAL SPECIALTY MODULES

Name of the Course	Course code	Course Outcome
Uro-oncological surgery	09HLTH10B02-009-M	Should know the anatomy & physiology of kidney, ureter, bladder & urethra
		Should understand the effects of gynecologic cancers and various treatments used in gynecological cancers on the urinary tract
		The candidate should be able to perform or assist urinary tract procedures related to gynaecological malignancy in collaboration with urological surgeons where necessary
		Should be able to avoid, diagnose as well as manage injuries to the urinary tract while performing surgeries in gynecological oncology.
Gastrointestinal/ Colorectal surgery	09HLTH10B02-010-M	Should know the anatomy & physiology of GI tract
		Should know the principles of bowel handling, resection & repair
		The candidate should be able to perform or assist gastrointestinal procedures related to gynaecological malignancy in collaboration with colorectal surgeons where necessary
		Should be able to avoid, diagnose as well as manage injuries to the gastrointestinal tract while performing surgeries in gynecological oncology.
		Should be be able to perform appendicectomy, repair of bowel injury, stoma, bowel resection when needed.
Breast Cancer Surgery	09HLTH10B02-011-M	Should know the anatomy of breast, axillary lymph node and patterns of spread of breast cancer.
		Should learn about hereditary breast cancer syndromes, role of genetic testing, management of healthy individuals with genetic mutations including surveillance protocols and risk reducing surgeries
		Should know the role of sentinel lymph node in surgery for breast cancer
		Should know the preoperative and postoperative use of chemotherapy and hormonal therapy in breast cancer
		The candidate should be able to perform or assist breast cancer surgeries in collaboration with breast cancer surgeons where necessary

ALLIED NON-SURGICAL SPECIALTIES

Name of the Course	Course code	Course Outcome
Radio-Diagnostics	09HLTH10B02-012-M	Should know the various modalities available for radiographic diagnosis in gynecological cancers
		Should be able toreadradiographs of chest, abdomen and skeletal system
		Should be able to advise and read ultrasonography for gynecological cancer patients when necessary
		Should be able to read CT Scan and MRI images related to gynecological oncology
		Should be able to decide for angiography, intravenous and retrograde urography, gastrointestinal and colonic radiography and mammography
Medical Oncology	09HLTH10B02-013-M	The student should understand the pharmacology and pharmacokinetics of the major drugs used in cancer chemotherapy for gynecological cancers
		Should understand cell biology including cell cycle kinetics, log kill hypothesis and cycle and phase specificity
		Should know the classes of chemotherapeutic agents, mechanism of action and pharmacology of specific agents
		Should know about the various targeted therapy drugs used in gynecological cancers, their mechanism of action and indications
		Should understand the general guidelines for clinical evaluation including the definitions of complete or partial responses, the concept of phase I, II and III drug trials and adjuvant therapy
		Should know the various short and long term complications associated with administration of chemotherapeutic drugs
Radiation Oncology	09HLTH10B02-014-M	The student should have sufficient familiarity with the principles and practice of radiation oncology in treatment planning, in the execution of intracavitary applications and in the management of irradiation induced complications.
		Should know the general principles of Radiobiology and techniques in molecular biology
		Should understand the radiotherapy treatment planning including principles of conformal therapy and intensity modulated radiation therapy
		Should understand the various radiotherapy equipments, radiation doses, techniques and principles of use.
		Should know how to diagnose irradiation induced complications and how to manage them

M.Ch. in Plastic Surgery & Reconstructive Surgery (Program Code: HLTH10B03)

Program Code : HLTH10B03	Programme Outcome	To train the M.Ch. candidates in basics of Plastic and reconstructive surgery.
		To provide holistic management for patients, including diagnosis, planning Reconstructive procedures to improve the quality of life and rehabilitation of the surgical patients.
		To build clinical skills in various Plastic Reconstructive Procedures
		To create an understanding regarding basic principles of clinical research, and translating application to various Plastic and reconstructive procedures
		To provide national and international platform for presentations of research data in the field of Plastic and reconstructive surgery.
		The training should produce consultants to practice all over the country, and teachers to propagate training to future generations of trainees in the field of Plastic and Reconstructive surgery with special emphasis on oncoreconstruction

Course Structure:

I. Courses at TMC

Program Code : HLTH10B03	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms.
		To complete the necessary training the students need to complete the rotation at Sion / Nair / KEM for a total period of one Year
		The student is expected to participate in the regular appraisal examinations and academic programmes conducted in the institute.
		The purpose would be to acquire an understanding of the subject of Plastic and Reconstructive surgery
		The candidate's progress through the 3 years will also be assessed with feedback from all stake holders, including the candidate and work-based assessment.

(A) BASIC SCIENCE

Sr. No.	Name of the Course	Course code
1	Embryology and development of human tissues	09HLTH10B03-001-BS
2	Genetics and congenital abnormalities	09HLTH10B03-002-BS
3	Mechanism of healing of tissues, factors affecting the healing	09HLTH10B03-003-BS
4	Infection and its management	09HLTH10B03-004-BS
5	General principles of Surgery	09HLTH10B03-005-BS
6	The suture materials and suture techniques	09HLTH10B03-006-BS
7	Clinical examination of various systems and clinical photography	09HLTH10B03-007-BS
8	General anesthesia pre and post-operative care for general anesthesia	09HLTH10B03-008-BS
9	Local, regional and other nerve blocks	09HLTH10B03-009-BS
10	Hypertensive and hypothermic anesthesia	09HLTH10B03-010-BS
11	Management of benign and malignant lesions	09HLTH10B03-011-BS
12	Wound healing, wound care, dressings and splints	09HLTH10B03-012-BS
13	Fluid and electrolyte balance, acid base balance	09HLTH10B03-013-BS
14	Shock and pulmonary failure, blood transfusions, ventilator support and criticalcare	09HLTH10B03-014-BS
15	Assessment of trauma, vascular emergencies embolism	09HLTH10B03-015-BS

(B) GENERAL TOPICS

Sr. No.	Name of the Course	Course code
1	History of Plastic Surgery	09HLTH10B03-001-G
2	Scope of Plastic Surgery	09HLTH10B03-002-G
3	Tissue distortion, tissue loss and its management	09HLTH10B03-003-G
4	Tissue culture, Transplantation biology and its applications	09HLTH10B03-004-G
5	Plastic Surgery instruments and equipments	09HLTH10B03-005-G
6	Maintenance of medical records, informed consent	09HLTH10B03-006-G
7	Applications of computer and related programs	09HLTH10B03-007-G
8	Social psychological, ethical and medico legal aspects communication skills	09HLTH10B03-008-G
9	Implants, orthotics and prosthesis and applied to Plastic Surgery	09HLTH10B03-009-G
10	Tissue expansion and tissue distraction	09HLTH10B03-010-G
11	Management of Leprosy, leprosy deformities and leprosy reconstructive surgery	09HLTH10B03-011-G
12	Endoscopic Plastic Surgery	09HLTH10B03-012-G
13	Advances, recent advances and current trends in Plastic Surgery	09HLTH10B03-013-G
14	Principles of surgical audit, understanding journal and review articles, text books and reference books, critical assessment of articles	09HLTH10B03-014-G
15	Research methodology and biostatistics	09HLTH10B03-015-G
16	Arteriovenous malformations, varicose veins, chronic venous insufficiency	09HLTH10B03-016-G
17	Meningomyelocoele, encephalocoele, spinal fusion defects, ventral defects,anorectal anomalies	09HLTH10B03-017-G

Course Outcomes:

(A) BASIC SCIENCE

Name of the Course	Course code	Course Outcome
Embryology and development of human tissues	09HLTH10B03-001-BS	To teach the concepts of Embryology and development of human tissues
Genetics and congenital abnormalities	09HLTH10B03-002-BS	To teach the diagnosis and management of genetic and congenital abnormalities
Mechanism of healing of tissues, factors affecting the healing	09HLTH10B03-003-BS	To teach the diagnosis and management of healing of tissues, factors affecting the healing
Infection and its management	09HLTH10B03-004-BS	To teach the diagnosis and management ofInfection
General principles of Surgery	09HLTH10B03-005-BS	To teach the general principles of surgery and their application in plastic and reconstructive surgery
The suture materials and suture techniques	09HLTH10B03-006-BS	To teach the usage of correct suture material and suturing techniques
Clinical examination of various systems and clinical photography	09HLTH10B03-007-BS	To teach proper clinical examination and documentation using clinical photography
General anesthesia pre and post-operative care for general anesthesia	09HLTH10B03-008-BS	To teach the monitoring of patients in pre and post op period after general anesthesisa
Local, regional and other nerve blocks	09HLTH10B03-009-BS	To teach the proper techniques and use of Local, regional and other nerve blocks
Hypertensive and hypothermic anesthesia	09HLTH10B03-010-BS	To teach the applications of hypertensive and hypothermic anaesthesia in plastic surgical procedures
Management of benign and malignant lesions	09HLTH10B03-011-BS	To teach the management of benign and malignant lesions and their reconstructive options.
Wound healing, wound care, dressings and splints	09HLTH10B03-012-BS	To teach the concepts of wound healing, proper wound care. Applications of various available dressings. Application of splints in trauma, burns
Fluid and electrolyte balance, acid base balance	09HLTH10B03-013-BS	To teach the Fluid and electrolyte balance, acid base balance in burns management and post op period
Shock and pulmonary failure, blood transfusions, ventilator support and criticalcare	09HLTH10B03-014-BS	To teach the basics of management of shock, pulmonary failure, blood transfusion.
Assessment of trauma, vascular emergencies embolism	09HLTH10B03-015-BS	To teach the diagnosis and management of trauma and vascular emergencies

(B) GENERAL TOPICS

Name of the Course	Course code	Course Outcome
History of Plastic Surgery	09HLTH10B03-001-G	To understand the development of various procedures and contributions of stalwarts in the field of plastic surgery
Scope of Plastic Surgery	09HLTH10B03-002-G	The spectrum of Plastic surgery is very wide.To understand the application of plastic and reconstructive surgery procedures in various aspects of patient care ranging from burns, cosmetic , hand, trauma, oncoreconstruction etc.
Tissue distortion, tissue loss and its management	09HLTH10B03-003-G	To understand the concept of tissue replacement after excision, disease, accident, congenital anamolies etc.
Tissue culture, Transplantation biology and its applications	09HLTH10B03-004-G	To develop understanding of tissue culture like skin and muscle, and their applications for reconstructive procedures.
Plastic Surgery instruments and equipments	09HLTH10B03-005-G	To teach the handling and proper use of instruments like microscopes, loupes etc. required for various procedures in plastic and reconstructive surgery.
Maintenance of medical records, informed consent	09HLTH10B03-006-G	To teach the importance of data maintenance for evaluation of results, publications and importance of consent in surgery and trials.
Applications of computer and related programs	09HLTH10B03-007-G	To develop understanding of Applications of software for making presentations, projects, statistics etc.
Social psychological, ethical and medico legal aspects communication skills	09HLTH10B03-008-G	To develop communication skills, and teach the medicolegal aspects necessary for handling surgeries
Implants, orthotics and prosthesis and applied to Plastic Surgery	09HLTH10B03-009-G	To teach the available Orthodontic treatments, prosthesis and implants and their uses in Plastic and reconstructive surgeries
Tissue expansion and tissue distraction	09HLTH10B03-010-G	To teach the uses and techniques of tissue expansions and tissue distractions in various procedures
Management of Leprosy, leprosy deformities and leprosy reconstructive surgery	09HLTH10B03-011-G	To study the deformities and their subsequent correction resulting due to leprosy.

Endoscopic Plastic Surgery	09HLTH10B03-012-G	To teach the applications of endoscopic plastic surgery eg. In muscle only harvest.
Advances, recent advances and current trends in Plastic Surgery	09HLTH10B03-013-G	To teach and study the recent advances and current practises for improving patient care and more relevant research projects.
Principles of surgical audit, understanding journal and review articles, text books and reference books, critical assessment of articles	09HLTH10B03-014-G	To evaluate our own results and constantly improvising our results through surgical audits. To apply newer modalities in clinical practise and research.
Research methodology and biostatistics	09HLTH10B03-015-G	To create an understanding regarding basic principles of clinical research ,statistics and emphasis on Good Clinical Practice guidelines (GCP) and translating this knowledge application to plastic and reconstructive procedures.
Arteriovenous malformations, varicose veins, chronic venous insufficiency	09HLTH10B03-016-G	To train in management of arteriovenous malformations, varicose veins, chronic venous insufficiency.
Meningomyelocoele, encephalocoele, spinal fusion defects, ventral defects,anorectal anomalies	09HLTH10B03-017-G	To train in management ofMeningomyelocoele, encephalocoele, spinal fusion defects, ventral defects,anorectal anomalies

M.Ch. in Head & Neck Oncology (Program Code: HLTH10B04)

Program Code : HLTH10B04	Programme Outcome	To provide holistic training to the candidates in clinical and surgical skills regarding head and neck oncology
		To train residents about the basics of oncology, medical and radiation oncology and rehabilitation in head and neck cancer management.
		Through joint clinics and disease management group meetings provide the understanding of comprehensive multidisciplinary management.
		To build in surgical skills, rigid direct laryngoscopy, micro laryngoscopy, laser excision and various aspects of robotic surgery.
		To provide exposure to national and international institutes to understand the variation in treatment approach and to understand the treatment planning in different institutes.
		To provide the platform to attend in house conferences held in the institute e.g. Oral cavity Master course, Evidence Based Medicine meetings, Post Laryngectomy rehabilitation meetings, Oncosurg, Laser workshop, Thyroid Preceptorship program, etc.
		To provide national and international platform for clinical research data presentation.
		To inculcate the habit of innovative thinking and rational and evidence based approach and translational research.

Course Structure:

I. Courses at TMC

Program Code : HLTH10B04	Programme Specific Outcome	The candidate should complete the training programme as per prespecified norms.
		The student shall follow the prespecified rotation schedule for the course to gain perspective about oncological reconstruction, radiation oncology and experience from other institutes (national/international).
		The student is expected to participate in the regular ward rounds, seminars and meetings, appraisal examinations and academic programmes conducted in the institute.
		The purpose would be to acquire an understanding of the subject of head and neck oncology in specific and clinical oncology in general.
		To update the candidate about the nuances in head and neck oncology e.g. intraoperative nerve monitoring, Transoral ultrasonic surgery etc.
		To provide platform to grasp the basics of biostatistics, clinical research and randomised consoled trials.

(A) CORE COURSES

Sr. No.	Name of the Course	Course code
1	Oral cavity and Oropharynx	09HLTH10B04-001-C
2	Parotid and Thyroid	09HLTH10B04-002-C
3	Nasopharynx, Paranasal sinus, Neck, other sites - Eye, Ears etc	09HLTH10B04-003-C
4	Larynx and Hypopharynx	09HLTH10B04-004-C

Course Outcomes:

(A) CORE COURSES

Name of the Course	Course code	Course Outcome
Oral cavity and Oropharynx	09HLTH10B04-001-C	To be able to understand the basics of cancer of oral cavity and oropharynx.
		To understand the pathophysiology of various neoplastic and pre-neoplastic processes and to understand the newer advances.
		To be able to apply the acquired knowledge clinically and surgically.
		To be able to have insight and ability for clinical and cancer research
		To understand the multidisciplinary management of cancer and role of chemotherapy and radiation.
Parotid and Thyroid	09HLTH10B04-002-C	To be able to understand the basics of cancer of parotid and thyroid.
		To understand the pathophysiology of various benign and malignant cancers and to understand the newer advances.
		To be able to apply the acquired knowledge clinically and surgically.
		To be able to have insight and ability for clinical and cancer research
Nasopharynx, Paranasal sinus, Neck, other sites - Eye, Ears etc	09HLTH10B04-003-C	To be able to understand the basics of cancer of nasopharynx, PNS, neck and other sites.
		To understand the pathophysiology of various benign and malignant lesions and to understand the newer advances.
		To be able to apply the acquire knowledge clinically and surgically.
		To understand the basic principles of medical and radiation oncology, biostatistics and molecular biology.
		To be able to have insight and ability for clinical and cancer research
		To understand the multidisciplinary management of skull base tumors with neurosurgery, radiation oncology and pathology department during Skull Base Clinic.
Larynx and Hypopharynx	09HLTH10B04-004-C	To be able to understand the basics of cancer of larynx and hypopharynx
		To understand the pathophysiology of various neoplastic and pre-neoplastic processes and to understand the newer advances.
		To be able to apply the acquired knowledge

		clinically and surgically.
		To be able to have insight and ability for clinical and cancer research
		To learn the rehabilitation of the laryngeal and hypo pharyngeal patients i.e. olfactory, speech ad swallowing rehabilitation.

Post M. Sc. Diploma in Radiological Physics (Dip. R. P.) (Program Code: HLTH11)

I. COURSE at BARC

Program Code : HLTH11	Programme Specific Outcome	Understand and apply principles of physics for understanding the medical physics and ionising radiation safety in healthcare.
		Understand and apply mathematical techniques for describing and deeper understanding of medical physics
		Understand and apply statistical methods for describing the various radiological processes in radiation dosimetry and safety.
		Understand and apply inter-disciplinary concepts and computational skills for understanding and describing the medical physics and radiation safety.
		Understanding basic safety standards for protection from the health hazard arising due to ionising radiation exposure.
		Provide in-depth knowledge and skill in various speciality of Radiological/ Medical Physics (radiation oncology physics, diagnostic and interventional radiology physics, nuclear medicine physics, and radiation protection)
		Provide in-depth knowledge and skill in standardization and calibration of medical equipment and for the accuracy of physical methods used in clinical applications and dosimetry, including physical measurements for evaluation of the dose delivered to the patient.
		Engage in research and life-long learning to adapt to changing healthcare practices.
		Understand and apply principles of physics for understanding the medical physics and ionising radiation safety in healthcare.

Course Structure:

Sr. No.	Name of the Course	Course code
1	RADIATION PHYSICS & RADIATION GENERATORS	01HLTH11-001-C
2	APPLIED MATHEMATICS	01HLTH11-002-C
3	RADIATION DOSIMETRY AND STANDARDIZATION	01HLTH11-003-C
4	RADIATION DETECTION, MEASUREMENT AND NUCLEAR ELECTRONICS	01HLTH11-004-C
5	PRACTICALS	01HLTH11-001-P
6	CLINICAL AND RADIATION BIOLOGY	01HLTH11-005-C
7	MEDICAL IMAGING	01HLTH11-006-C
8	RADIATION THERAPY	01HLTH11-007-C
9	RADIATION SAFETY	01HLTH11-008-C
10	PRACTICALS	01HLTH11-002-P

Course Outcomes

Name of the Course	Course code	Course Outcome
RADIATION PHYSICS & RADIATION GENERATORS	01HLTH11-001-C	Refresh the knowledge of Nuclear and Radiation physics
		Understand the concept of interaction of radiation with matter
		Understand the mechanism and technology of various particle accelerators used in medicine and research
		Understand the mechanism of X-ray generation and technology of X-ray equipment used in medicine, industry and research.
APPLIED MATHEMATICS	01HLTH11-002-C	Understand the theory of probability, counting statistics and errors with special reference to radiological/medical physics
		Application of Numerical methods and Monte Carlo simulation in radiation physics
		To strengthen the knowledge and skill in use of computational techniques and tools for solving the practical problems of radiological sciences

RADIATION DOSIMETRY AND STANDARDIZATION	01HLTH11-003-C	Understanding of radiation quantities and units
		Detailed knowledge of various radiation sources including their production process application aspects
		Competency to perform absolute, reference and relative radiation dosimetry with various radiation generators and sources
		Knowledge and skill in dosimetry of neutron and standardisation of radionuclides
		Understanding radiation chemistry and use of chemical dosimetry techniques
RADIATION DETECTION, MEASUREMENT AND NUCLEAR ELECTRONICS	01HLTH11-004-C	Understanding the principles of radiation detection and measurement instrumentation
		Working and operational principle of radiation detectors used for various types of radiation
		Electronics involved in various radiation detectors and its instrumentation
		Understanding and use of various radiation monitoring instruments
PRACTICALS	01HLTH11-001-P	Understanding radiation physics and mathematical concepts applied to radiological processes
		Construction, characterisation and calibration of various radiation detectors and use of spectrometry techniques in radiological physics
		Preparation, standardisation and uses of chemical dosimeters
		Preparation, standardisation and safety aspects of sealed/unsealed radiation sources
CLINICAL AND RADIATION BIOLOGY	01HLTH11-005-C	Knowledge of cell biology, human anatomy, physiology and tumour pathology
		Understanding of mechanism and outcome of interaction of radiation with human cells and associated biological effects

		Basic knowledge of clinical aspects of medical imaging and radiation oncology and detailed knowledge of biological basis of radiotherapy
		Thorough knowledge of dose fractionation in radiotherapy and time-dose models
MEDICAL IMAGING	01HLTH11-006-C	Understanding the process of X-ray based imaging using both conventional and advanced imaging systems such as digital X-ray imaging systems (radiography and mammography), dental imaging systems and computed tomography (CT) scanners
		Knowledge of working principles and use of open isotope based imaging systems such as Gamma Camera, Single Photon Emission Tomography (SPECT), Positron Emission Tomography (PET)
		Understanding of the technology and use of medical cyclotron and Internal dosimetry techniques
		Concepts of magnetic resonance imaging (MRI) and ultrasound imaging in diagnosis of various types of cancer
RADIATION THERAPY	01HLTH11-007-C	Understanding the technology and working principles of various beam therapy equipment such as Telecobalt machine, Medical electron linear accelerators (LINAC), and medical proton accelerator
		Understanding the technology and use of brachytherapy equipment, sources and techniques as well as dosimetry and treatment planning in brachytherapy
		Competence in medical radiation dosimetry, quality assurance of various radiotherapy equipment and use of computers in radiation treatment planning including optimisation and associated radiation safety

		Thorough knowledge and competence in applying special and advanced techniques of radiation therapy such as total body irradiation (TBI), total skin electron therapy (TSET), stereotactic radiosurgery/radiotherapy (SRS/SRT), stereotactic body radiotherapy (SBRT), intensity modulated radiotherapy (IMRT), image guided radiotherapy (IGRT), volumetric modulated radiotherapy (VMAT) and associated patient specific quality assurance
RADIATION SAFETY	01HLTH11-008-C	Comprehensive knowledge of radiation protection standards and recommendations towards occupational and public safety
		Competence in radiation monitoring, evaluation of external/internal radiation hazard, assessment of safety status of a radiation facility and control of contamination
		Thorough knowledge of radiation safety in the medical uses of radiation which involves planning of medical radiation installations, evaluation of hazard and radiation waste disposal
		Understanding of applications and safety aspects of industrial, agricultural and research use of ionizing radiation such as industrial radiography, radio-tracers, planning of radiation installations and isotope laboratory, radiation protection measures and hazards evaluation in tritium monitoring
		Knowledge of the concepts of radioactive waste disposal like sources of waste including classification, treatment techniques of waste and disposal of used radiation sources and radiation generators
		Detailed knowledge in transportation of radioactive substances including packaging, documentation, shipment, emergencies and regulations
		Familiarization with National Legislations (acts, rules, standards, and guides) for the use of radiation in various applications
		Knowhow of radiation emergencies and their medical management

PRACTICALS	01HLTH11-002-P	Study and evaluation of parameters involved in X-ray diagnostic and associated radiation safety
		Practical knowledge of measuring the strength of open isotopes, thyroid uptake, patient monitoring and safety assessment of nuclear medicine imaging and therapy facilities
		Skill of radiation dose measurement in beam therapy, brachytherapy, and nuclear medicine
		Practical knowledge of architecture and capabilities of radiotherapy treatment planning systems
		Practical competence in radiation protection survey of various medical installations and safety assessment

BACK TO MAIN

INTERGRATED M.Sc. in CHEMICAL SCIENCES (Program Code: CHEM13)

Course Structure:

I. Courses at NISER

<table>
<tr><td rowspan="5">Program Code : CHEM13</td><td rowspan="5">Programme Specific Outcome</td><td>Ability to think independently and write short research proposals</td></tr>
<tr><td>Ability to characterize various Organic/Inorganic/Organometallic compounds by spectroscopic techniques</td></tr>
<tr><td>Understanding the chemical reaction mechanisms through physical and theoretical studies</td></tr>
<tr><td>Understanding the organic biochemical processes and their role in human health</td></tr>
<tr><td>Understanding the role of chemistry in day to day life</td></tr>
</table>

1) MAJOR in CHEMISRTY

(A) SEMISTER I

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Mathematics-I	M101
4	Programming & Data Structure Lab-I	CS141
5	Biology-I	B101
6	Biology Laboratory-I	B141
7	Physics-I	P101
8	Physics Laboratory-I	P141
9	Technical Communication-I	H109
10	Introduction to Psychology	H125

(B) SEMISTER II

Sr. No.	Name of the Course	Course code
1	Chemistry-II	C102
2	Chemistry Laboratory-II	C142
3	Mathematics-II	M102
4	Programming & Data Structure Lab-II	CS142
5	Biology-II	B102
6	Biology Laboratory-II	B142
7	Physics-II	P102
8	Physics Laboratory-II	P142
9	Technical Communication-II	H110
10	Introduction to Sociology	H133

(C) SEMISTER III

Sr. No.	Name of the Course	Course code
1	Basic inorganic Chemistry	C201
2	Reaction Mechanisms in Organic Chemistry	C203
3	Mathematical Methods for Chemists	C207
4	Inorganic Chemistry Lab	C245
5	Elective-I	****
6	Elective-II(Humanities)	****
7	Elective-III(Humanities)	****

(D) SEMISTER IV

Sr. No.	Name of the Course	Course code
1	Reagents in Organic Syntheses	C204
2	Main group and Organometallic Chemistry	C205
3	Quantum Chemistry I	C206
4	Physical Chemistry Lab I	C243

5	Biomolecular Chemistry Lab	C244
6	Elective-IV	****
7	Elective-V(Humanities)	****
8	Elective-VI(Humanities)	****

(E) SEMISTER V

Sr. No.	Name of the Course	Course code
1	Physical Organic Chemistry	C301
2	Molecular Spectroscopy and group Theory	C302
3	Thermodynamics and Electrochemistry	C307
4	Organic Chemistry Lab I	C341
5	Inorganic Chemistry Lab I	C342
6	Elective-VII	****

(F) SEMISTER VII

Sr. No.	Name of the Course	Course code
1	Physical Methods in Chemistry II	C401
2	Chemistry of Heterocycles and Natural Products	C403
3	Chemistry project	C498
4	Elective-IX	****

(G)SEMISTER VIII

Sr. No.	Name of the Course	Course code
1	Chemical Rate Processes	C402
2	Chemistry Project	C499
3	Elective-XI	****
4	Elective-XI	****

(H) SEMISTER IX

Sr. No.	Name of the Course	Course code
1	Chemistry Project	C598
2	Elective-XII	****
3	Elective-XIII	****

(I) SEMISTER X

Sr. No.	Name of the Course	Course code
1	Chemistry Dissertation	C599
2	Elective-XIV	****

2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Photochemistry	C351
2	Pharmaceutical Chemistry	C352
3	Classics in Molecules	C353
4	Molecular Modeling	C551
5	Solid State Chemistry	C552
6	Crystallography	C554
7	Principles of Drug action	C555
8	Advanced Bio-inorganic Chemistry	C556
9	Nuclear Magnetic Resonance	C557
10	Advanced Functional Materials	C558
11	Supramolecular Chemistry	C559
12	Chemistry of Nanomaterials	C560
13	Advanced Bio-organic Chemistry	C561
14	Polymer Chemistry	C562
15	Molecular Reaction Dynamics	C563
16	Theory of Molecular Spectroscopy	C564

17	Advanced Organic Chemistry	C565
18	Catalysis: Reaction Mechanisms and Applications	C566
19	Advanced Main group Chemistry	C567
20	Advanced Fluorescence Spectroscopy	C568
21	Biomacromolecules	C569
22	Advanced Heterocyclic Chemistry	C570
23	Statistical Mechanics	C571

COURSE OUTCOMES:

1) MAJOR in CHEMISRTY

(A) SEMISTER I

Name of the Course	Course code	Course Outcome
Chemistry-I	C101	The basics of atomic and molecular structure and spectroscopy
		Thermodynamics of different chemical processes
		Kinetics of chemical reactions
Chemistry Laboratory-I	C141	Introduction to synthesis of small organic compounds
		Qualitative analysis of chemicals present in tea, coffee, fruits etc.
		Synthesis of simple drugs such as paracetamol

(B) SEMISTER II

Name of the Course	Course code	Course Outcome
Chemistry-II	C102	Apply the fundamental principles of measurement, matter, atomic theory, chemical periodicity, chemical bonding, general chemical reactivity and solution chemistry to subsequent courses in science, engineering, technology.

		Students will be able to explain why chemistry is an integral activity for addressing social, economic, and environmental problems
		Students will be able to explore new areas of research in both chemistry and allied fields of science and technology after getting their concepts clear in Basic Chemistry
Chemistry Laboratory-II	C142	Introduction to quantitative analysis in chemistry.
		Students will learn basic concepts on electrochemistry
		Students will be given hands on practice on conductometry, polarimetry and flame photometry
		They will apply these concepts to estimate binding constant, solubility product etc.

(C) SEMISTER III

Name of the Course	Course code	Course Outcome
Basic inorganic Chemistry	C201	To understand basic facts and concepts in Chemistry while retaining the exciting aspects of Chemistry so as to develop interest in the study of chemistry as a discipline.
		To develop the ability to apply the principles of Chemistry.
		To appreciate the achievements in Chemistry and to know the role of Chemistry in nature and in society.
		To develop problem solving skills.
		To be familiarized with the emerging areas of Chemistry and their applications in various spheres of Chemical sciences and to apprise the students of its relevance in future studies.

		To be exposed to the different processes used in industries and their applications
Reaction Mechanisms in Organic Chemistry	C203	Introduction of basic organic reactions (Substitutions, Additions & Eliminations) and writing organic reaction mechanisms
		Reactivity of unsaturated hydrocarbons (alkene, alkyne and aromatic)
		Understanding the role of substitutions to influence the rate of reactions
		Stereochemistry in organic chemistry: Chemoselectivity, Diastereoselectivity, Enantioselectivity, Stereospecificity, Stereoconvergence
		Introduction of asymmetric synthesis with and without asymmetric catalysts
Mathematical Methods for Chemists	C207	Introduce the standard mathematical techniques that are typically used by Chemists.
		To learn how to apply mathematics to chemistry research.
		To learn how to use Fourier transform in different spectroscopy.
		The course, mostly differential equation is useful to learn quantum chemistry and chemical kinetics.
Inorganic Chemistry Lab.	C245	Concepts used in inorganic experiments
		Laboratory procedures to perform inorganic experiments
		Characterization techniques
		Laboratory safety

(D) SEMISTER IV

Name of the Course	Course code	Course Outcome
Reagents in Organic Syntheses	C204	Design the chemical reactions based on various metals and non-metal reagents
		Application of the reagents in organic synthesis.
		Design the synthesis of unknown target molecules
Main group and Organometallic Chemistry	C205	Learn the characterization of organometallic compounds.
		Learn the synthesis, structure and application of organometallics of Li, Mg, B, Al and Si elements
		Understand the synthesis, structure and bonding aspects of selected examples of unusual main group compounds
		Organometallics of transition metal chemistry and its application in catalysis
Quantum Chemistry I	C206	Understanding the need of Quantum mechanics based on failures of Classical mechanics.
		Learning the basic building blocks of Quantum Mechanics.
		Learning to use the mathematical structure of quantum mechanics in several systems comprising one or many quantum particles.
		Understanding the bridge between the mathematical structure of quantum mechanics and different spectroscopic techniques based on that.
Physical Chemistry Lab I	C243	This is a lab. course that introduces several spectroscopic methods to the under graduate students.
		Students can learn to use UV-Vis and fluorescence spectroscopy to determine pKa.

		To learn polarimetry to study the kinetics and to check chirality of a chemical.
		Introduces different electrochemical methods that are used in chemistry research.
Biomolecular Chemistry Lab	C244	Experience about synthesis of various biologically important molecules such as peptides, nuclease modification, quantification of amino acids and sugars.
		This course enables students to visualise the different techniques, principles, difficulties involved in synthesizing biomolecules

(E) SEMISTER V

Name of the Course	Course code	Course Outcome
Physical Organic Chemistry	C301	Understanding the Woodward-Hoffmann Rules and Molecular Orbitals and their application in stereoselective organic synthesis.
		Photoinduced chemical reactions
		Radical initiated processes and radical intermediates in chemical reactions
Molecular Spectroscopy and group Theory	C302	Understand the fundamentals of Group Theory and apply it to molecular spectroscopy
		Understand the link between molecular spectroscopy, symmetry and information content of molecular spectra.
		Understanding the formation of molecular orbitals.
		Calculate/predict energy levels and spectral features using symmetry as a simplification tool
		Use symmetry arguments to possibly solve molecular Problems.
		Understand the basics of light-matter interaction.

		Understand the fundamentals of rotational, vibrational and electronic spectroscopy. Calculation of some useful parameters from spectral data. Etc
Thermodynamics and Electrochemistry	C307	Understanding the laws of Thermodynamics and Phase equilibrium of multicomponent systems.
		Understanding the thermodynamics of surfaces and different adsorption isotherms of gases on solids.
		Key concepts for the Electrochemistry and applications of Electrochemistry.
		Key concepts of Statistical Thermodynamics.
Organic Chemistry Lab I	C341	To learn basic reaction techniques
		To preform air and moisture sensitive reactions such as Grignard, Friedel Craft reactions
		To purify the organic compounds
		To learn characterization of organic molecules such as spectral and analytical data
		To perform mg to gram scale reactions
Inorganic Chemistry Lab I	C342	Learn synthesis, purification, extraction and recrystallization techniques along with various techniques for characterization viz. IR, UV-Vis Spectroscopy, CV (cyclic voltammetry), and magnetic susceptibilities.
		Learn preparation and use of ion exchange column which is used in pharmaceutical Industry.
		Able to clearly communicate the results of scientific work in oral, written and electronic formats to both scientists and the public at large

(F) SEMISTER VI

Name of the Course	Course code	Course Outcome
Coordination Chemistry	C304	Importance of crystal field theory and Molecular orbital theory with various inorganic complexes.
		Learn the concept of magnetism and also to know about single molecular magnet
		Understanding the inner and outer sphere reaction mechanisms.
		Role of metal ions in bioinorganic chemistry
		Understand the basic concepts of supramolecular chemistry
Chemical Binding	C305	Understand the quantum mechanics of molecules
		Construct molecular orbitals for polyatomic molecules
		Apply symmetry and molecular orbital theory to derive molecular terms
		Understand the theory Hartree-Fock (HF), DFT, and semi-empirical methods
Physical Methods in Chemistry I	C306	Understand the basics of absorption and fluorescence spectroscopy.
		Theoretical prediction of absorption maximum of some organic molecules.
		Identifying and distinguishing various type of electronic transition using solvent perturbation techniques.
		Understanding the concept of micropolarity and the importance of this parameter in spectroscopy
		Understanding some important photoprocessess such as electron transfer and energy transfer and their applications in energy related applications.

		Applications of fluorescence spectroscopy in detecting various analytes (Sensing applications)
Physical Chemistry Lab II	C343	Understanding the concepts of energy minimization, frequency calculations and transition state optimization.
		Practical experience in applications of quantum chemical calculations
Organic Chemistry Lab II	C344	Independent ability to set up a chemical reaction
		Understanding the reaction progress and monitoring
		Isolation and characterization of organic compounds

(G)SEMISTER VII

Name of the Course	Course code	Course Outcome
Physical Methods in Chemistry II	C401	To learn the instrument techniques such as NMR and EPR
		To interpret the data obtained from these techniques
		To understand various aspects involved in NMR, EPR, ENDOR and Mossbauer.
		To find out the radical nature of the materials.
Chemistry of Heterocycles and Natural Products	C403	Understanding nomenclature, structure and reactivity of aromatic and non-aromatic heterocycles.
		Understanding the design and application of various organic reactions for the synthesis of natural products.
		Understanding the classification, structure and synthesis of biomolecules
Chemistry project	C498	Understanding review of literature in a specified research field

		Learning basic laboratory techniques
		Formulate a minor research problem and write a report
		Ability to document and present the project results

(H)SEMISTER VIII

Name of the Course	Course code	Course Outcome
Chemical Rate Processes	C402	Students can learn verities of chemical reactions and time scale of those reactions.
		Describes different spectroscopy and analytical techniques to study chemical kinetics.
		Introduces enzyme kinetics.
		It is a useful course for chemistry and biology students to learn about chemical and biological reactions
Chemistry Project	C499	Ability to study in detail about selected research problem
		Ability to understand the mechanisms involved in the research problem
		Ability to prepare a road map for successful completion of a research problem
		Ability to collaborate

(I) SEMISTER IX

Name of the Course	Course code	Course Outcome
Chemistry Project	C598	Ability to interpret/characterize the results
		Ability to find new alternative approaches to a research problem
		Ability to find newer applications
		Ability to design future plans

(J) SEMISTER X

Name of the Course	Course code	Course Outcome
Chemistry Dissertation	C599	Ability to collate and conclude results
		Ability to have broad understanding of a research area
		Ability to develop a new research idea
		Ability to defend the project well during final presentation

2) ELECTIVES

Name of the Course	Course code	Course Outcome
Photochemistry	C351	Understanding the photoinduced reactions in chemical and biological systems.
		Understanding the photo-physical processes
		Basic principles and application of fluorescence spectroscopy
		Use the knowledge of photochemistry in materials applications
Pharmaceutical Chemistry	C352	To learn pharmacokinetics and pharmacology
		To understand pharmacores and their interactions in molecular targets
		To interpret AMDE principle of drugs (absorption, distribution, metabolism, and excretion)
		To understand drug discovery processes
Classics in Molecules	C353	To learn discovery of organic molecules and their impact on the world such as Urea, Glucose, & Penicillin
		To understand the basic organic chemistry for learning chemical biology
		To learn the small organic molecules that interaction with molecular targets

		To find the nature of drugs and their function in biological changes
Molecular Modeling	C551	Construct potential energy surfaces and force-fields for molecules
		Perform HF, DFT, and semi-empirical calculations on molecules
		Perform chemical dynamics simulations for simple reactions
		Apply molecular dynamics and Monte-Carlo simulations on large sized molecules
Solid State Chemistry	C552	Describe the principles concerning solid state structures
		Describe specific crystal structures by applying basic crystallographic concepts
		Describe the experimental use of the diffraction phenomenon
		Use powder diffraction data for characterising cubic substances
		Analyse thermograms and phase diagrams in known systems
Crystallography	C554	Define concepts such as lattice, point and space groups
		Be familiar with Bragg's Law and explain its the relation to crystal structure
		Identify and describe different diffraction methods
		Interpret and assign X-ray and electron diffraction patterns
		use crystallographic data for a validated phase analysis
Principles of Drug action	C555	To learn pharmacokinetics and pharmacology
		To understand absorption, distribution, metabolism, and excretion of drugs

		To learn various stages of drug discovery process such as clinical trails
		To find the modern drug discovery and development processes including the identification of molecular targets, High-throughput screening (HTS)
Advanced Bio-inorganic Chemistry	C556	Apply the basic principles in inorganic and general chemistry to interdisciplinary topics in the field of bioinorganic chemistry.
		Describe the main roles of metal ions in biological processes, and identify the chemical properties that are required to each particular function.
		Describe the role of metal ions in enzymes involved in acid-base reactions.
		Describe the role of metal ions that are involved in electron-transfer reactions in biological systems.
		Describe how oxygen is transported in different species and identify the metal centers involved in this task.
		Describe the different metal-activation sites in enzymes that are involved in the activation of oxygen.
		Identify the main toxicological mechanisms of metals and the biological defenses against the toxic effects.
		List some medical applications of inorganic compounds.
		Oral and written communicate using the specific language of bioinorganic chemistry and common
Nuclear Magnetic Resonance	C557	Theoretical understanding of the basic working principle of NMR spectroscopy.
		Building in-depth knowledge of the routinely performed experimental steps.

		Analysis of pulse sequence of few key one- and two-dimensional experiments to understand how certain spectra are generated.
		Understanding the theory behind common problems encountered during routine operation of an NMR spectrometer.
Advanced Functional Materials	C558	Introduction to materials in modern technology
		Learn about semiconductor and dielectric materials.
		Exploring the role of magnetic materials in inter-disciplinary sciences
		Use of polymer materials and nano-composites in chemistry and day-today life.
Supramolecular Chemistry	C559	Learn various noncovalent interactions.
		Design the synthesis of novel macrocycles
		Understand the stabilization of anions, cations and neutral substrates.
		To evaluate the binding and stability constants
Chemistry of Nanomaterials	C560	Key concepts of Bottom-up and Top down approaches
		Understanding the mechanism of formation of 0-D, 1-D, 2-D, 3-D
		nanostructured materials.
		Understanding the structure-property relationship of carbon nanomaterials and
		self-assembled monolayers.
		Application of nanomaterials for energy applications and biological applications.
Advanced Bio-organic Chemistry	C561	Introduction of Biomacromolecules, and Enzymology
		Synthesis and application of DNA, RNA and related analogues

		Attract for biosynthesis of natural products
		Impress the role biomacromoleculs in therapy.
Polymer Chemistry	C562	Different types of polymers
		Concepts of polymers
		Applications of polymers
		Challenges involved in making bio-degradable polymers
Molecular Reaction Dynamics	C563	Apply transition state theory and RRKM theory to compute rate constants
		Understand the theory of classical and quantum scattering phenomena
		Learn, how to follow the dynamics of chemical reactions experimentally and theoretically
Theory of Molecular Spectroscopy	C564	Separate the molecular motion into translations, rotations, and vibrations components
		Transform between internal and normal mode coordinates
		Understand the rovibronic spectroscopy of molecules
		Understand multiphoton processes and their application in modern spectroscopy
Advanced Organic Chemistry	C565	Understanding of important organic transformations with advanced mechanisms.
		Learning the recent advances in organic chemistry
		Enhanced ability to connect the learned topics with current research problem and envisage new research projects.
Catalysis: Reaction Mechanisms and Applications	C566	Understanding the principles of catalysis.
		Key concepts of various elementary steps which are important in catalytic cycle.

		Understanding the development of various catalysts in many important catalytic reactions.
		Implications and applications of catalysis in industry and academia.
Advanced Main group Chemistry	C567	Understanding the structure and bonding aspects of metal-metal single or multiple bond of main group elements
		Soluble main group metal hydrides: synthesis and their reactivity studies.
		Group 13 and Group 14 low valent metallacylces: synthesis and reactivity studies
		Application of Main group compounds in homogeneous catalysis.
Advanced Fluorescence Spectroscopy	C568	Describes basic principles and application of fluorescence spectroscopy.
		To learn, how fluorescence spectroscopy is used for frequency and time domain studies of important chemical process.
		To learn to use fluorescence spectroscopy in biological related molecules.
		It also introduces fluorescence imaging**.**
Biomacromolecules	C569	Basic understanding of biomolecules with respect to their structure
		Structure and function relation of biologically important molecules
		In-depth understanding of various biological processes such as DNA replication, protein synthesis
Advanced Heterocyclic Chemistry	C570	Introduction of Heterocyclic Chemistry: Nomenclature, spectral characteristics, reactivity and aromaticity of heterocycles (three and four membered)

		Synthesis and reactivity of five membered rings, benzofused six membered rings with one, two and three heteroatoms, seven and large membered
		Recent methods of C-H functionalization/activations of heterocyclic derivatives.
		Beneficial to synthesized therapeutic drugs
Statistical Mechanics	C571	Understanding the concepts of ensembles, energy partition and probability distribution
		Learning of classical and quantum statistical mechanics
		Application of statistical mechanics to study the thermodynamic properties of simple gases and solids.

3) MINOR SUBJECTS in LIFE SCIENCES

Sr. No.	Course Name	Course No
1	Biology I: Science of Life	B101
2	Biology Laboratory-1	B141
3	Biology II: Cellular and Genetic basis of life	B102
4	Biology Laboratory-2	B142
5	Biochemistry	B202
6	Cell Biology	B204
7	Genetics	B205
8	Molecular Biology	B304
9	Evolutionary Biology	B306

10	Any one course from biology subjected to qualified prerequisite	Bx5x

COURSE OUTCOME OF MINOR SUBJECTS in LIFE SCIENCES

Course Name	Course No	Course Outcome
Biology I: Science of Life	B101	Understanding the origin and evolution of life.
		Fundamental understanding of the structure and function of the molecules of life.
		Fundamental understanding of the structure & function of cellular organelles.
Biology Laboratory-1	B141	Introduce to students analytical tools/approaches to study biomolecules and cell structure.
		Build basics of experimentation and data recording in biology labs
Biology II: Cellular and Genetic basis of life	B102	Understanding the principles of cellular mechanisms driving development of an organism.
		Key evolutionary concepts in Lamarckism, Darwinism and Speciation
		Understanding the genetic basis of inheritance
		Fundamental understanding of molecular Biology
Biology Laboratory-2	B142	Understand a microscope and various staining and microscopic techniques
		Knowledge of the basis of human blood groups (ABO)
		Experimental approaches to study cell growth and differentiation and Gene regulation
		Use of microscope to know various stages of cell division in mitosis and meiosis
Biochemistry	B202	Understanding the principles governing Protein structure & function
		Basic concepts on metabolism and their implications in living organisms
		Concept on signal transduction

<table>
<tr><td></td><td></td><td>Implications in Evolution, Health and disease.</td></tr>
<tr><td rowspan="4">Cell Biology</td><td rowspan="4">B204</td><td>Understanding the basic principles governing cell structure and functions</td></tr>
<tr><td>Biochemcial, biophysical, genetical basis of cell and its response</td></tr>
<tr><td>Key concepts in maintenance of cell structure</td></tr>
<tr><td>Evolution of cell organelles, importance in health and disease.</td></tr>
<tr><td rowspan="4">Genetics</td><td rowspan="4">B205</td><td>Understanding the basic principles of inheritance</td></tr>
<tr><td>Knowledge of genetic disease mechanism</td></tr>
<tr><td>Comprehension of monogenic, polygenic and multifactorial diseases</td></tr>
<tr><td>Application in health and diseases</td></tr>
<tr><td rowspan="2">Molecular Biology</td><td rowspan="2">B304</td><td>Understanding the key components of cell involved in central dogma of molecular biology.</td></tr>
<tr><td>Understanding of structure-function of genetic material, replication, repair, transcription and translation.</td></tr>
<tr><td rowspan="4">Evolutionary Biology</td><td rowspan="4">B306</td><td>Understanding how life originated on the planet</td></tr>
<tr><td>Understanding the formation of species and underlying genetic diversity</td></tr>
<tr><td>Understanding biology from an organismal point of view and why some species evolve slowly while others evolve rapidly</td></tr>
<tr><td>Understanding systematic relationships between organisms using phylogenetic tools</td></tr>
<tr><td>Any one course from biology subjected to qualified prerequisite</td><td>Bx5x</td><td>To meet the research requirement of the individual student.
(Course content varies according to instructor’s choice.)</td></tr>
</table>

4) MINOR SUBJECTS in MATHEMATICAL SCIENCES

Sr. No.	Name of the Course	Course code
1	Mathematics-I	M101
2	Mathematics-II	M102
3	Real Analysis	M201
4	Group Theory	M202
5	Metric Spaces	M204
6	Linear Algebra	M205
7	Probability Theory	M206
8	Differential Equations	M303

COURSE OUTCOME OF MINOR SUBJECTS in MATHEMATICAL SCIENCES

Name of the Course	Course code	Course Outcome
Mathematics-I	M101	Expects students to learn how to prove theorems, expressing mathematical objects, and understand the construction of natural numbers and symmetry of plane figures.
Mathematics-II	M102	Upon successful completion of the course students will become aware of some basic properties of real line and real valued functions.
Real Analysis	M201	Knowledge on Continuity differentiable and Riemann integration theory. Sequence and series and it's application to numerical analysis.
Group Theory	M202	Upon successful completion of the course students will be able to understand the notion of symmetries in the language of groups. Furthermore, students will become aware of various properties of groups and subgroups.
Metric Spaces	M204	Upon successful completion of the course students will become aware about generalisation of euclidean distance on arbitrary sets and various properties of functions defined on them.
Linear Algebra	M205	Upon successful completion of the course students will learn the relation between linear transformations and matrices. Moreover, student will also learn various fundamental results of matrices, namely, diagonalisa-tion, triangulation and primary decomposition theorem.

Probability Theory	M206	Students will be introduced to the basic theory of probability starting from axiomatic definition of probability up to limit theorems of probability.
Differential Equations	M303	This course starts with the origin and applications of differential equations and discusses many solution techniques such as separation of vari-able, variation of parameter, annihilator method and Frobenious method, etc. Then it introduces basic theory of existence and uniqueness for the sys-tem of first order ODEs which is essential for many branches of mathematics. This course also gives a glimpse how to analyze the behavior of solutions (maximum principle, stability, asymptotic stability, etc.).
		This course ends with an introduction to partial differential equations and method of charac-teristics, a technique to solve first order partial differential equations. Upon successful completion of this course the student will be able to model some practical situations into ordinary differential equations or partial differential equations and analyze the solution to get information about the parameters involved in the model.

5) MINOR SUBJECTS in PHYSICAL SCIENCES

Sr. No.	Course Name	Course No
1	Physics I (Mechanics and Thermodynamics)	P101
2	Physics Laboratory I	P141
3	Physics II (Electricity, Magnetism and Optics)	P102
4	Physics Laboratory II	P142
5	Classical Mechanics I	P201
6	Mathematical Methods I	P202
7	Electromagnetism I	P204
8	Quantum Mechanics I	P206

9	Statistical Mechanics	P302
10	Any one of the other theory courses	

COURSE OUTCOME OF MINOR SUBJECTS in PHYSICAL SCIENCES

Course Name	Course No	Course Outcome
Physics I (Mechanics and Thermodynamics)	P101	Builds understanding of basic classical mechanics and thermodynamics.
Physics Laboratory I	P141	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment
Physics II (Electricity, Magnetism and Optics)	P102	Builds basic understanding of electro and magneto static phenomena and processes. Introduces important concepts of polarization, electromagnetic waves, interference and diffraction.
Physics Laboratory II	P142	Laboratory Experience with Coupled Oscillator Circuits:
		Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors
		Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
		Laboratory Experience with Flip-flops and Microcontrollers.
Classical Mechanics I	P201	Training in basic classical mechanics, prepares the student for advanced mechanics courses.
Mathematical Methods I	P202	Acquiring knowledge of vector spaces and it applications to various physical problems.

		Acquiring knowledge of complex analysis and it applications to various physical problems.
		Acquiring knowledge of the theory of ordinary differential equations and it applications in various physical problems.
		Acquiring basic knowledge of the theory of statistics and its applications in interpretation of data
Electromagnetism I	P204	Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces to the idea of energy momentum tensor and Gauge invariance.
Quantum Mechanics I	P206	Acquiring working knowledge of the basic concepts of quantum mechanics: states, operators and time evolution.
		Understanding of the role of symmetries in quantum mechanics.
		Understanding of the theory of angular momentum in quantum mechanics.
		Acquiring knowledge of applications such as the hydrogen atom, charged particle in a magnetic field and a particle in a periodic potential.
		Acquiring knowledge of perturbation theory in quantum mechanics and applications such as Stark and Zeeman effect.
Statistical Mechanics	P302	space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.

		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Any one of the other theory courses		To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SCHOOL OF HUMANITIES

(A) Core Courses:

1. Semester I

Sr.No.	Name of the Course	Course code
1	Technical Communication I	H109
2	Introduction to Sociology	H133

2. Semester II

Sr.No.	Name of the Course	Course code
1	Technical Communication II	H110
2	Introduction to Economics	H101

(A) Electives:

Sr.No.	Name of the Course	Course code
1	Introduction to Psychology	H225
2	Environmental Economics and Environmental Impact Assessment	H201
3	Introduction to Innovation System	H239
4	Life and Community in Urban World	H238
5	Organizational Behaviour	H227
6	Sociology of Science and Technology	H235
7	Perspectives on Indian Society	H236
8	Science Communication and Citizen	H237
9	The City in Modern Fiction	HS 210
10	Speculative Fiction	H 209

Course Outcome:

(A) Core Courses

1. Semester I

Name of the Courses	Courses Code	Course Outcome
Technical Communication I	H109	Connecting Language and cultural contexts.
		Understand the process behind writing.
		Learn to critically engage with texts.
Introduction to Sociology	H133	Sociological insights that are meaningful and of practical importance to students
		Meaningfully relate with the immediate social environment.
		From a sociological perspective, observe those features which are common to all cultures and be able to assess them in the context of one's own unique setting.
		develop an objective view of social reality
		understand the structure and functioning of the society and its consequent processes of social change

2. Semester II

Name of the Courses	Courses Code	Course Outcome
Technical Communication II	H110	be familiar with the essentials of effective communication
		know the different tools of effective technical communication
		understand the importance of staging the argument, and know various institutional / disciplinary norms
Introduction to Economics	H101	familiarity with the basic concepts of economy such as: Price determination, policies for controlling inflation, role of government, sources of revenue and expenditure of the Union, State and Local government and Balance of Payment

(A) Electives

Name of the Courses	Courses Code	Course Outcome
Introduction to Psychology	H225	better understanding of human behavior.
		differentiate between scientific and non-scientific information about human behavior and mental processes.
		understand the working of their own conscious behavior and interpersonal relationship.
		apply psychological principles everyday life situations.
Environmental Economics and Environmental Impact Assessment	H201	Students would get to know the interaction between economy and environment
		Economic tools used for controlling environmental degradation
		Understanding the need for environmental impact assessment of developmental projects and its procedure
Introduction to Innovation System	H239	Appreciate the imperative of innovation within society.
		Critically analyze different types of innovation.
		Use evidence to critically challenge innovation practices. Identify possible changes in innovation system.
Life and Community in Urban World	H238	Formulate effective argumentation on city life.
		Explain and evaluate historical and contemporary urbanization processes.
		Demonstrate understanding of the diverse nature of urban populations and social problems these populations.
		Identify ways of creating sustainable, and efficient built environments.
Organizational Behaviour	H227	demonstrate knowledge organizational behavior theories and concepts.
		explain the challenges that managers and leaders face in contemporary organizations
		critically evaluate organizational practices and the impact on work behavior and performance.
		describe how the individual, groups and organization level variables interact and influence major organizational outcomes.

Sociology of Science and Technology	H235	Familiarization with the societal perspective in study of science and technology
		provide a basic understanding of issues that fall under broader spectrum of inter-relationship between science & technology and society
Perspectives on Indian Society	H236	Understanding of the basic features of Indian Society: both past and contemporary.
		To acquaint the Students about some of the major social Institutions from Sociological Perspectives
		Understanding of various processes of Social Change and Problems of Indian Society.
Science Communication and Citizen	H237	Evaluate the role of communication in science.
		Provide constructive analysis of popular science communication in a variety of real-world settings.
		Identify target audience and define applicable message.
		Develop a sense of the social and political context for science communication.
The City in Modern Fiction	HS 210	To learn to read critically.
		To learn to contextualize concepts and themes using the framework of the 'modern.'
		To learn structural elements, such as plot, setting, characters, techniques of exposition, that underpins fiction.
Speculative Fiction	H 209	the literary, social, political and genre importance of Speculative Fiction in the contemporary times as well as historically
		a detailed overview of the way Speculative Fiction has developed historically,
		some important works in Speculative Fiction , and the rich diversity in the field,
		not just the Western tradition of Speculative Fiction, but also the Indian tradition of Speculative Fiction, from ancient times to the present
		some of the oft-occurring themes such as utopias, dystopias, and issues of gender, class, environment, multiculturalism, technology, myth-making, alternate history, etc.

SCHOOL of COMPUTER SCIENCES

(A) Core Courses:

Sr. No.	Name of the Course	Course code
1	Programming and Data Structures Lab – I	CS141
2	Programming and Data Structures Lab – II	CS142
3	Theory of Computation	CS201
4	Discrete Structures and Computation	CS202
5	Design and Analysis of Algorithms	CS301

(B) Electives:

Sr. No.	Name of the Course	Course code
1	Modern Cryptology	CS451
2	Algorithmic Coding Theory	CS452
3	Complexity Theory	CS453
4	Linear Programming and Combinatorial Optimization	CS454
5	Distributed Network Algorithms	CS455

Course Outcome:

(A) Core Courses

Name of the Courses	Courses Code	Course Outcome
Programming and Data Structures Lab – I	CS141	Learn the fundamentals of programming.
		Write code for basic programming tasks.
		Create new data types suitable to the requirements
Programming and Data Structures Lab – II	CS142	Learn the fundamentals of data structures
		Write efficient codes for a wide range of programming tasks.
Theory of Computation	CS201	Learn the Mathematical Foundations of computers
		Construct abstract computational machines for basic tasks.
		Understand principles of programming languages and compilers
Discrete Structures and	CS202	Solve problems related to fundamentals of mathematical logic.

Computation		Model and solve practical problems using graph-theoretic techniques.
		Solve problems related to counting and combinatorics.
Design and Analysis of Algorithms	CS301	Learn the basics of algorithms.
		Measure the efficiency of candidate algorithms.
		Write new algorithms for basic computational tasks.

(B) Electives

Name of the Courses	Courses Code	Course Outcome
Modern Cryptology	CS451	Learn the basics of information security
		Write codes for implementing security protocols.
		Analyze candidate information security solutions.
Algorithmic Coding Theory	CS452	Learn the fundamentals of information theory.
		Write a new data compression algorithm
		Create error resilient storage solutions.
Complexity Theory	CS453	Learn the efficiency limits of computations.
		Derandomizing randomized algorithms
Linear Programming and Combinatorial Optimization	CS454	Solve linear optimization problems
		Model certain game theoretic problems as linear programming problems.
Distributed Network Algorithms	CS455	Design new algorithms for distributed networks
		Find the efficiency limit of distributed algorithms.

INTEGRATED M.Sc. in LIFE SCIENCES

(Program Code: LIFE13)

I. Courses at NISER:

Program Code: LIFE13	Programme Specific Outcome	Ability to think independently and write short research proposals
		Application of bioinformatics knowledge in understanding relationships at sequence, structure and network-level
		Application of physics and statistical concepts to understand biological phenomena.
		Acquire problem solving skills in the domain of biophysics and biostatistics
		Ability to apply the knowledge of biostatistics and biophysics in health and diseases.

(A) Core Courses

1st Year

1. SEMISTER I

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Mathematics-I	M101
4	Programming & Data Structure Lab-I	CS141
5	Biology-I	B101
6	Biology Laboratory-I	B141
7	Physics-I	P101
8	Physics Laboratory-I	P141

9	Technical Communication-I	H109
10	Introduction to Psychology	H125

2. SEMISTER II

Sr. No.	Name of the Course	Course code
1	Chemistry-II	C102
2	Chemistry Laboratory-II	C142
3	Mathematics-II	M102
4	Programming & Data Structure Lab-II	CS142
5	Biology-II	B102
6	Biology Laboratory-II	B142
7	Physics-II	P102
8	Physics Laboratory-II	P142
9	Technical Communication-II	H110
10	Introduction to Sociology	H133

2ND YEAR

1. SEMISTER III

Sr. No.	Name of the Course	Course code
1	Microbiology	B201
2	Biochemistry	B202
3	Biophysics and Biostatistics	B203
4	Laboratory-3 (Microbiology)	B241
5	Laboratory-4 (Biochemistry)	B242

2. SEMISTER IV

Sr. No.	Name of the Course	Course code
1	Cell Biology	B204
2	Genetics	B205

3	Elective-1	B251-255
4	Laboratory-5 (Cell Biology)	B243
5	Laboratory-6 (Genetics)	B244

3RD YEAR

1. **SEMISTER V**

Sr. No.	Name of the Course	Course code
1	Physiology-I (Animal)	B301
2	Physiology-II (Plant)	B302
3	Ecology	B303
4	Laboratory-7 (Plant physiology)	B342
5	Elective-2	B351-355

2. **SEMISTER VI**

Sr. No.	Name of the Course	Course code
1	Molecular Biology	B304
2	Immunology	B305
3	Evolutionary Biology	B306
4	Laboratory-8 (Molecular Biology)	B343
5	Laboratory-9 (Immunology)	B344
6	Elective-3	B351-355

4TH YEAR

1. **SEMISTER VII**

Sr. No.	Name of the Course	Course code
1	Bioinformatics	B403
2	Developmental Biology	B402
3	Biology Project	B498
4	Elective-4	B451-460
5	Elective-5	B451-460

2. **SEMISTER VIII**

Sr. No.	Name of the Course	Course code
1	Bio-techniques	B405
2	Elective-6	B551-B562
3	Elective-7	B551-B562
4	Biology Project	B499

5TH YEAR

1. **SEMISTER IX**

Sr. No.	Name of the Course	Course code
1	Biology Project /Dissertation	B598

2. **SEMISTER X**

Sr. No.	Name of the Course	Course code
1	Biology Project /Dissertation	B599

(B) ELECTIVES

2ND & 3RD YEAR

Sr. No.	Name of the Course	Course code
1	Principles of Drug Design	B351
2	Endocrinology	B352
3	Plant Developmental Biology	B353
4	Neurobiology	B354
5	Structural Biology	B355

4TH YEAR

Sr. No.	Name of the Course	Course code
1	Advanced Cell Biology	B451

2	Genetic engineering	B452
3	Advance Biochemistry	B453
4	Advance Microbiology	B454
5	Enzymology	B455
6	Advance Neurobiology	B456
7	Chemical Biology	B457
8	Virology	B460

5^TH YEAR

Sr. No.	Name of the Course	Course code
1	Advanced Molecular Biology	B551
2	Advanced Immunology	B552
3	Infectious Disease Biology	B553
4	Cancer Biology	B554
5	Advanced Genetics	B555
6	Immune regulation and Infection immunity	B556
7	Macromolecular crystallography	B557
8	Quantitative Biology	B558
9	Ion Channels	B559
10	Concepts in Mechanobiology	B561
11	Molecular errors in disease pathogenesis	B562

Course Outcomes:

(A) Core Course

1^ST YEAR

1. SEMISTER I

Name of the Course	Course code	Course Outcome
Biology I: Science of Life	B101	Understanding the origin and evolution of life.
		Fundamental understanding of the structure and function of the molecules of life.
		Fundamental understanding of the structure & function of cellular organelles.

Biology Laboratory-1	B141	Introduce to students analytical tools/approaches to study biomolecules and cell structure.
		Build basics of experimentation and data recording in biology labs

2. SEMISTER II

Name of the Course	Course code	Course Outcome
Biology II: Cellular and Genetic basis of life	B102	Understanding the principles of cellular mechanisms driving development of an organism.
		Key evolutionary concepts in Lamarckism, Darwinism and Speciation
		Understanding the genetic basis of Inheritance
		Fundamental understanding of molecular Biology
Biology Laboratory-2	B142	Understand a microscope and various staining and microscopic techniques
		Knowledge of the basis of human blood groups (ABO)
		Experimental approaches to study cell growth and differentiation and Gene regulation
		Use of microscope to know various stages of cell division in mitosis and meiosis

2ND YEAR

1. SEMISTER III

Name of the Course	Course code	Course Outcome
Microbiology	B201	Microbiology as a science.
		Key concepts in Microbes in health & disease.
		Overview of role of microbes in nutrient Cycling
		Implications in Evolution, Health and disease.
Biochemistry	B202	Understanding the principles governing Protein structure & function
		Basic concepts on metabolism and their implications in living organisms
		Concept on signal transduction
		Implications in Evolution, Health and disease.

Biophysics and Biostatistics	B203	Introducing the concepts of Biophysics and Biostatistics
		Understanding the laws and tools of physics that are applied to understand biology
		How is statistics required and applied in the field of biology
		Evolution of the subject Biophysics and its Application
		Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of biophysics and biostatistics
		Understanding Biophysics to do new and more insightful biology
		Understanding details of biostatistics to understand a) the quality of the data, b) the validity of comparative biological analysis, and classification and grouping of data for better insight of the underlying biological principles
Laboratory-3 (Microbiology)	B241	Culturing of microbes as pure culture, growth disinfection & sterilization.
		Microscopic examination of microbial
		Identification of unknown bacterial Cultures
		Antibiotic susceptibility testing.
Laboratory-4 (Biochemistry)	B242	Understanding the principles and methodology to isolate, purify, quantitate and separate various biomolecules such as protein, DNA, RNA
		Concept and practical experience about the enzyme kinetics, enzyme activity and effect of temperature and pH

2. **SEMISTER IV**

Name of the Course	Course code	Course Outcome
Cell Biology	B204	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell Structure

		Evolution of cell organelles, importance in health and disease.
Genetics	B205	Understanding the basic principles of Inheritance
		Knowledge of genetic disease mechanism
		Comprehension of monogenic, polygenic and multifactorial diseases
		Application in health and diseases
Elective-1	B251-255	To meet the research requirement of the individual student. (Course content varies according to instructor’s choice.)
Laboratory-5 (Cell Biology)	B243	Direct exposure to different types of plant and animal cells
		Direct labelling of different cell organelles and visualization.
		Direct exposure to different cell biology related techniques and high-end instruments
		Learning of research methodology and conducting experiments
Laboratory-6 (Genetics)	B244	Understanding the basic principles of inheritance
		Knowledge of basic techniques used in population genetics and cytogenetics

3RD YEAR

1. **SEMISTER V**

Name of the Course	Course code	Course Outcome
Physiology-I (Animal)	B301	Learning molecular, chemical and physical principles of animal body plan.
		Understanding structure-function relationships and how various physiological systems work.
		Integrating knowledge to understand health and disease.
Physiology-II (Plant)	B302	Entrain the students with different hormone physiology and it’s interaction.
		Learning light physiology, transformation and photosynthesis.
Ecology	B303	Understanding biotic and biotic factors governing the distributions of organisms

		Understanding the biosphere from the viewpoint of organism, population, community and ecosystem
		Understand organismal diversity and functional diversity of organisms in a landscape or ecosystem
Laboratory-7 (Plant physiology)	B342	Train students with tissue culture techniques and plant physiology experiments.
		Aims to bring physiology, biochemistry and molecular biology together.
Elective-2	B351-355	As an interdisciplinary course, the students will be introduced to the different concepts of drug discovery and development.
		Understanding the concepts of hormones and endocrine regulation.
		Knowledge about the structure and function of different endocrine glands and evolutionary significance.
		Applying the knowledge of endocrine regulation to analyze disorders associates with hormonal imbalance.
		Learning molecular genetics approaches to understand plant development.
		Understanding the interaction of biotic and abiotic component is major focus.
		Designing experimental strategies understanding plant development.
		Understanding the organization of nervous system, structure and function of neuron and glial cells.
		Knowledge about the ion basis of action potential, synapse, neurotransmitter release, neural circuits, and behavior.
		Leaning the key techniques in neuroscience research, organization and evolution of the brain.
		Analyzing the neural basis of behavior and neurological disorders.
		Understanding the protein structures in modular approach, correlating the structure to function, and deducing the mechanistic models for the functioning, methods for 3D-structure determination, validation of structures

2. SEMISTER VI

Name of the Course	Course code	Course Outcome
Molecular Biology	B304	Understanding the key components of cell involved in central dogma of molecular biology.
		Understanding of structure-function of genetic material, replication, repair, transcription and translation.
Immunology	B305	Understating the basics of the immune system and the immunological processes during infection, tumor progression, inflammation and immunogenic responses of various cases of altered host physiological functions and phenotypes
Evolutionary Biology	B306	Understanding how life originated on the planet
		Understanding the formation of species and underlying genetic diversity
		Understanding biology from an organismal point of view and why some species evolve slowly while others evolve rapidly
		Understanding systematic relationships between organisms using phylogenetic tools
Laboratory-8 (Molecular Biology)	B343	Hands on training of techniques used in Molecular biology research
		Understanding the working principles by experimental verification
Laboratory-9 (Immunology)	B344	Understating the basic concepts and training of immunological techniques associated to experimentation in the field of immunology
Elective-3	B351-355	As an interdisciplinary course, the students will be introduced to the different concepts of drug discovery and development.
		Understanding the concepts of hormones and endocrine regulation.
		Knowledge about the structure and function of different endocrine glands and evolutionary significance.

		Applying the knowledge of endocrine regulation to analyze disorders associates with hormonal imbalance.
		Learning molecular genetics approaches to understand plant development.
		Understanding the interaction of biotic and abiotic component is major focus.
		Designing experimental strategies understanding plant development.
		Understanding the organization of nervous system, structure and function of neuron and glial cells.
		Knowledge about the ion basis of action potential, synapse, neurotransmitter release, neural circuits, and behavior.
		Leaning the key techniques in neuroscience research, organization and evolution of the brain.
		Analyzing the neural basis of behavior and neurological disorders.
		Understanding the protein structures in modular approach, correlating the structure to function, and deducing the mechanistic models for the functioning, methods for 3D-structure determination, validation of structures

4TH YEAR

1. **SEMISTER VII**

Name of the Course	Course code	Course Outcome
Bioinformatics	B403	Understanding the principles governing development of an organism from conception to birth.
		Key concepts in maintenance of growth of an organism and aging.
		Implications in Evolution, Health and disease.
Developmental Biology	B402	Application of bioinformatics knowledge in understanding relationships at sequence, structure and network-level.
		Demonstration of popularly used bioinformatics tools for research work

		Help understand the patterns of life and rhythms
Biology Project	B498	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-4	B451-460	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell structure
		Evolution of cell organelles, importance in health and disease.
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
		Understanding the basic principles of Recombinant DNA technology
		Knowledge of various tools and techniques used in genetic engineering
		Applications in the generation of transgenic models
		Understanding the mechanism of protein folding
		In depth knowledge about Post translational modifications of proteins
		Mechanisms and implications of
		protein turn over in cells
		Develop understanding of bacterial responses to various stimuli
		Gain insights into bacterial biofilm formation and quorum sensing mechanisms
		Build comprehension on nature and functioning of enzymes.
		Make students understand kinetics of enzyme mediated reactions and enzyme inhibition kinetics
		Develop basic understanding on enzyme engineering
		Develop understanding about the central nervous system-controlled process and their mechanism of regulation.

		In-depth understanding of the neural circuits and behavior.
		Understand and analyze the recent updates in the field and significance.
		Introducing the concept of chemical biology
		Application of chemistry to advance the study of biological systems
		Understanding biology to do new chemistry?
		How is chemical biology used to advance science and human health?
		Understanding chemical structures of bio-molecules
		Comparative understanding of biosynthesis and laboratory synthesis
		Understanding energetics of biochemical pathways and processes
		Be competent in reading and interpreting primary literature in the areas of chemical biology
		At completion of the course, student is expected to comprehend structural organization, and different biological processes of viruses.
		Develop basic knowledge of biology and pathological manifestation of few important human and animal viral pathogens
		Develop comprehension of tools and approaches to study viral biology.
Elective-5	B451-460	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell structure
		Evolution of cell organelles, importance in health and disease.
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
		Understanding the basic principles of Recombinant DNA technology

		Knowledge of various tools and techniques used in genetic engineering
		Applications in the generation of transgenic models
		Understanding the mechanism of protein folding
		In depth knowledge about Post translational modifications of proteins
		Mechanisms and implications of protein turn over in cells
		Develop understanding of bacterial responses to various stimuli
		Gain insights into bacterial biofilm formation and quorum sensing mechanisms
		Build comprehension on nature and functioning of enzymes.
		Make students understand kinetics of enzyme mediated reactions and enzyme inhibition kinetics
		Develop basic understanding on enzyme engineering
		Develop understanding about the central nervous system-controlled process and their mechanism of regulation.
		In-depth understanding of the neural circuits and behavior.
		Understand and analyze the recent updates in the field and significance.
		Introducing the concept of chemical biology
		Application of chemistry to advance the study of biological systems
		Understanding biology to do new chemistry?
		How is chemical biology used to advance science and human health?
		Understanding chemical structures of bio-molecules
		Comparative understanding of biosynthesis and laboratory synthesis
		Understanding energetics of biochemical pathways and processes
		Be competent in reading and interpreting primary literature in the areas of chemical biology

		At completion of the course, student is expected to comprehend structural organization, and different biological processes of viruses
		Develop basic knowledge of biology and pathological manifestation of few important human and animal viral pathogens
		Develop comprehension of tools and approaches to study viral biology.

2. SEMISTER VIII

Name of the Course	Course code	Course Outcome
Bio-techniques	B405	Basic principle behind the biophysical, and biochemical experiments. Troubleshoot the experiments, interpretation of results, plotting of graphs, design the experiments.
Elective-6	B551-B562	Understand the recent advancements in molecular biology, structure-function analysis and regulation. Reading research articles, designing experiment and data analysis.
		Understating the current concepts of immunological processes associated to infection immunity, tumor immunity, autoimmunity and other immuno-regulatory states of altered host immune system.
		Develop understanding infection process, infection epidemiology, host-pathogen interactions and evolution of pathogens
		Understanding basic molecular and cellular mechanisms of carcinogenesis.
		Integrating knowledge to understand therapeutic approaches.
		Stimulate research interest.
		Integrating knowledge of Basic genetics, molecular biology and genomics to understand advances in the field of Genetics.
		Stimulate research interest.

		Comprehensive understanding on Immune regulation, immune deviation in bacterial, viral and parasitic infections
		Insights in to Translational aspects of Immunology such as vaccines, immunomodulatory agents in infectious as well as autoimmune diseases
		Introducing the concepts of mathematics in biology
		Understanding the quantitative aspects of biology
		How is statistics and mathematics required and applied in the field of biology
		Understanding how mathematical models of biology are developed
		Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of quantitative biology
		Understanding quantitative biology to do new and more insightful biology
		Understand theory behind the X-ray diffraction to structure determination. Data collection strategy, processing, interpretation of data statistics, structure solution methods, refinement methods, interpretation of electron density map.
		Understanding the principles governing ion channel functions
		Biochemcial, biophysical, genetical basis of ion channel and its response
		Key concepts in maintenance of ion
		channel structure, function and ionic homeostasis of the cell
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
		Comprehend the concept that cells are complex micron-sized machines/ nano-machines.

		Understanding of the mechanical behavior of cell and tissues and the biological responses of these biological systems to mechanical stimuli.
		Gain knowledge on how cells generate and sustain mechanical forces within their environment, as part of their normal physiology.
		Ability to visualize that cells are active materials that can detect mechanical stimulation by the activation of mechanosensitive signaling pathways, and respond to physical cues through cytoskeletal re-organization and force generation.
		Competence in reading and interpretation of primary literature in the area of mechanobiology and address research questions relating to cell processes using mechanobiological approaches.
		Enable students of disciplines other than biology to understand how principles of mechanics and engineering can be applied to biological systems and problems.
		Understanding the concepts of molecular pathogenesis.
		Basic understanding of the common pathologies of organ systems.
		Understanding of the recent advances in molecular explanation for such pathologies.
Elective 7	B551-B562	Understand the recent advancements in molecular biology, structure-function analysis and regulation. Reading research articles, designing experiment and data analysis.
		Understating the current concepts of immunological processes associated to infection immunity, tumor immunity, autoimmunity and other immuno-regulatory states of altered host immune system.
		Develop understanding infection process, infection epidemiology, host-pathogen interactions and evolution of pathogens

		Understanding basic molecular and cellular mechanisms of carcinogenesis.
		Integrating knowledge to understand therapeutic approaches.
		Stimulate research interest.
		Integrating knowledge of Basic genetics, molecular biology and genomics to understand advances in the field of Genetics.
		Stimulate research interest.
		Comprehensive understanding on Immune regulation, immune deviation in bacterial, viral and parasitic infections
		Insights in to Translational aspects of Immunology such as vaccines, immunomodulatory agents in infectious as well as autoimmune diseases
		Introducing the concepts of mathematics in biology
		Understanding the quantitative aspects of biology
		How is statistics and mathematics required and applied in the field of biology
		Understanding how mathematical models of biology are developed
		Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of quantitative biology
		Understanding quantitative biology to do new and more insightful biology
		Understand theory behind the X-ray diffraction to structure determination.
		Data collection strategy, processing, interpretation of data statistics, structure solution methods, refinement methods, interpretation of electron density map.
		Understanding the principles governing ion channel functions
		Biochemcial, biophysical, genetical basis of ion channel and its response

		Key concepts in maintenance of ion channel structure, function and ionic homeostasis of the cell
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
		Comprehend the concept that cells are complex micron-sized machines/ nano-machines.
		Understanding of the mechanical behavior of cell and tissues and the biological responses of these biological systems to mechanical stimuli.
		Gain knowledge on how cells generate and sustain mechanical forces within their environment, as part of their normal physiology.
		Ability to visualize that cells are active materials that can detect mechanical stimulation by the activation of mechanosensitive signaling pathways, and respond to physical cues through cytoskeletal re-organization and force generation.
		Competence in reading and interpretation of primary literature in the area of mechanobiology and address research questions relating to cell processes using mechanobiological approaches.
		Enable students of disciplines other than biology to understand how principles of mechanics and engineering can be applied to biological systems and problems.
		Understanding the concepts of molecular pathogenesis.
		Basic understanding of the common pathologies of organ systems.
		Understanding of the recent advances in molecular explanation for such pathologies.

Biology Project	B499	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

5TH YEAR

1. **SEMISTER IX**

Name of the Course	Course code	Course Outcome
Biology Project /Dissertation	B598	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

2. **SEMISTER X**

Name of the Course	Course code	Course Outcome
Biology Project /Dissertation	B599	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) ELECTIVES

2ND & 3RD YEAR

Name of the Course	Course code	Course Outcome
Principles of Drug Design	B351	As an interdisciplinary course, the students will be introduced to the different concepts of drug discovery and development.
Endocrinology	B352	Understanding the concepts of hormones and endocrine regulation.
		Knowledge about the structure and function of different endocrine glands and evolutionary significance.
		Applying the knowledge of endocrine regulation to analyze disorders associates with hormonal imbalance.
Plant Developmental Biology	B353	Learning molecular genetics approaches to understand plant development.
		Understanding the interaction of biotic and abiotic component is major focus.
		Designing experimental strategies understanding plant development.

Neurobiology	B354	Understanding the organization of nervous system, structure and function of neuron and glial cells.
		Knowledge about the ion basis of action potential, synapse, neurotransmitter release, neural circuits, and behavior.
		Leaning the key techniques in neuroscience research, organization and evolution of the brain.
		Analyzing the neural basis of behavior and neurological disorders.
Structural Biology	B355	Understanding the protein structures in modular approach, correlating the structure to function, and deducing the mechanistic models for the functioning, methods for 3D-structure determination, validation of structures

4^{TH} YEAR

Name of the Course	Course code	Course Outcome
Advanced Cell Biology	B451	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell structure
		Evolution of cell organelles, importance in health and disease.
		Importance of ion channels in health and disease, pharmacology and applications
		Advanced knowledge of details of microscopy
		Bridging the gap between theory and research methodology
Genetic engineering	B452	Understanding the basic principles of Recombinant DNA technology
		Knowledge of various tools and techniques used in genetic engineering
		Applications in the generation of transgenic models
Advance Biochemistry	B453	Understanding the mechanism of protein folding
		In depth knowledge about Post translational modifications of proteins
		Mechanisms and implications of protein turn over in cells

Advance Microbiology	B454	Develop understanding of bacterial responses to various stimuli
		Gain insights into bacterial biofilm formation and quorum sensing mechanisms
Enzymology	B455	Build comprehension on nature and functioning of enzymes.
		Make students understand kinetics of enzyme mediated reactions and enzyme inhibition kinetics
		Develop basic understanding on enzyme engineering
Advance Neurobiology	B456	Develop understanding about the central nervous system-controlled process and their mechanism of regulation.
		In-depth understanding of the neural circuits and behavior.
		Understand and analyze the recent updates in the field and significance.
Chemical Biology	B457	Introducing the concept of chemical biology
		Application of chemistry to advance the study of biological systems
		Understanding biology to do new chemistry?
		How is chemical biology used to advance science and human health?
		Understanding chemical structures of bio-molecules
		Comparative understanding of biosynthesis and laboratory synthesis
		Understanding energetics of biochemical pathways and processes
		Be competent in reading and interpreting primary literature in the areas of chemical biology
Virology	B460	At completion of the course, student is expected to comprehend structural organization, and different biological processes of viruses
		Develop basic knowledge of biology and pathological manifestation of few important human and animal viral pathogens
		Develop comprehension of tools and approaches to study viral biology.

5^{TH} YEAR

Name of the Course	Course code	Course Outcome
Advanced Molecular Biology	B551	Understand the recent advancements in molecular biology, structure-function analysis and regulation. Reading research articles, designing experiment and data analysis.
Advanced Immunology	B552	Understating the current concepts of immunological processes associated to infection immunity, tumor immunity, autoimmunity and other immuno-regulatory states of altered host immune system.
Infectious Disease Biology	B553	Develop understanding infection process, infection epidemiology, host-pathogen interactions and evolution of pathogens
Cancer Biology	B554	Understanding basic molecular and cellular mechanisms of carcinogenesis.
		Integrating knowledge to understand therapeutic approaches.
		Stimulate research interest.
Advanced Genetics	B555	Integrating knowledge of Basic genetics, molecular biology and genomics to understand advances in the field of Genetics.
		Stimulate research interest.
Immune regulation and Infection immunity	B556	Comprehensive understanding on Immune regulation, immune deviation in bacterial, viral and parasitic infections
		Insights in to Translational aspects of Immunology such as vaccines, immunomodulatory agents in infectious as well as autoimmune diseases
Macromolecular crystallography	B557	Understand theory behind the X-ray diffraction to structure determination. Data collection strategy, processing, interpretation of data statistics, structure solution methods, refinement methods, interpretation of electron density map.
Quantitative Biology	B558	Introducing the concepts of mathematics in biology
		Understanding the quantitative aspects of biology

		How is statistics and mathematics required and applied in the field of biology
		Understanding how mathematical models of biology are developed
		Didactic methodology of teaching is used to make the students think more analytically and get oriented to develop problem solving skills in the domain of quantitative biology
		Understanding quantitative biology to do new and more insightful biology
Ion Channels	B559	Understanding the principles governing ion channel functions.
		Biochemcial, biophysical, genetical basis of ion channel and its response.
		Key concepts in maintenance of ion channel structure, function and ionic homeostasis of the cell.
		Importance of ion channels in health and disease, pharmacology and applications. Advanced knowledge of details of microscopy.
		Bridging the gap between theory and research methodology.
Concepts in Mechanobiology	B561	Comprehend the concept that cells are complex micron-sized machines/ nano-machines.
		Understanding of the mechanical behavior of cell and tissues and the biological responses of these biological systems to mechanical stimuli.
		Gain knowledge on how cells generate and sustain mechanical forces within their environment, as part of their normal physiology.
		Ability to visualize that cells are active materials that can detect mechanical stimulation by the activation of mechanosensitive signaling pathways, and respond to physical cues through cytoskeletal re-organization and force generation

		Competence in reading and interpretation of primary literature in the area of mechanobiology and address research questions relating to cell processes using mechanobiological approaches.
		Enable students of disciplines other than biology to understand how principles of mechanics and engineering can be applied to biological systems and problems.
Molecular errors in disease pathogenesis	B562	Understanding the concepts of molecular pathogenesis.
		Basic understanding of the common pathologies of organ systems.
		Understanding of the recent advances in molecular explanation for such pathologies.

(C) MINOR SUBJECTS in CHEMICAL SCIENCES

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Chemistry-II	C102
4	Chemistry Laboratory-II	C142
5	Basic Inorganic Chemistry	C201
6	Reaction Mechanism in Organic Chemistry	C203
7	Quantum Chemistry-I	C206
8	Mathematical methods for Chemists	C207
9	Physical Methods in Chemistry-I	C306
10	Thermodynamics and Electrochemistry	C307

COURSE OUTCOME OF MINOR SUBJECTS in CHEMICAL SCIENCES

Name of the Course	Course code	Course Outcome
Chemistry-I	C101	The basics of atomic and molecular structure and spectroscopy

		Thermodynamics of different chemical processes
		Kinetics of chemical reactions
Chemistry Laboratory-I	C141	Introduction to synthesis of small organic compounds
		Qualitative analysis of chemicals present in tea, coffee, fruits etc.
		Synthesis of simple drugs such as paracetamol
Chemistry-II	C102	Apply the fundamental principles of measurement, matter, atomic theory, chemical periodicity, chemical bonding, general chemical reactivity and solution chemistry to subsequent courses in science, engineering, technology.
		Students will be able to explain why chemistry is an integral activity for addressing social, economic, and environmental problems
		Students will be able to explore new areas of research in both chemistry and allied fields of science and technology after getting their concepts clear in Basic Chemistry
Chemistry Laboratory-II	C142	Introduction to quantitative analysis in chemistry.
		Students will learn basic concepts on electrochemistry
		Students will be given hands on practice on conductometry, polarimetry and flame photometry
		They will apply these concepts to estimate binding constant, solubility product etc.
Basic Inorganic Chemistry	C201	To understand basic facts and concepts in Chemistry while retaining the exciting aspects of Chemistry so as to develop interest in the study of chemistry as a discipline.
		To develop the ability to apply the principles of Chemistry.

		To appreciate the achievements in Chemistry and to know the role of Chemistry in nature and in society.
		To develop problem solving skills.
		To be familiarized with the emerging areas of Chemistry and their applications in various spheres of Chemical sciences and to apprise the students of its relevance in future studies.
		To be exposed to the different processes used in industries and their applications
Reaction Mechanism in Organic Chemistry	C203	Introduction of basic organic reactions (Substitutions, Additions & Eliminations) and writing organic reaction mechanisms
		Reactivity of unsaturated hydrocarbons (alkene, alkyne and aromatic)
		Understanding the role of substitutions to influence the rate of reactions
		Stereochemistry in organic chemistry: Chemoselectivity, Diastereoselectivity, Enantioselectivity, Stereospecificity, Stereoconvergence
		Introduction of asymmetric synthesis with and without asymmetric catalysts
Quantum Chemistry-I	C206	Understanding the need of Quantum mechanics based on failures of Classical mechanics.
		Learning the basic building blocks of Quantum Mechanics.
		Learning to use the mathematical structure of quantum mechanics in several systems comprising one or many quantum particles.
		Understanding the bridge between the mathematical structure of quantum mechanics and different spectroscopic techniques based on that.

Mathematical methods for Chemists	C207	Introduce the standard mathematical techniques that are typically used by Chemists.
		To learn how to apply mathematics to chemistry research.
		To learn how to use Fourier transform in different spectroscopy.
		The course, mostly differential equation is useful to learn quantum chemistry and chemical kinetics.
Physical Methods in Chemistry-I	C306	Understand the basics of absorption and fluorescence spectroscopy.
		Theoretical prediction of absorption maximum of some organic molecules.
		Identifying and distinguishing various type of electronic transition using solvent perturbation techniques.
		Understanding the concept of micropolarity and the importance of this parameter in spectroscopy
		Understanding some important photoprocessess such as electron transfer and energy transfer and their applications in energy related applications.
		Applications of fluorescence spectroscopy in detecting various analytes (Sensing applications)
Thermodynamics and Electrochemistry	C307	Understanding the laws of Thermodynamics and Phase equilibrium of multicomponent systems.
		Understanding the thermodynamics of surfaces and different adsorption isotherms of gases on solids.
		Key concepts for the Electrochemistry and applications of Electrochemistry.
		Key concepts of Statistical Thermodynamics.

(D) MINOR SUBJECTS in MATHEMATICAL SCIENCES

Sr. No.	Name of the Course	Course code
1	Mathematics-I	M101
2	Mathematics-II	M102
3	Real Analysis	M201
4	Group Theory	M202
5	Metric Spaces	M204
6	Linear Algebra	M205
7	Probability Theory	M206
8	Differential Equations	M303

COURSE OUTCOME OF MINOR SUBJECTS in MATHEMATICAL SCIENCES

Name of the Course	Course code	Course Outcome
Mathematics-I	M101	Expects students to learn how to prove theorems, expressing mathematical objects, and understand the construction of natural numbers and symmetry of plane figures.
Mathematics-II	M102	Upon successful completion of the course students will become aware of some basic properties of real line and real valued functions.
Real Analysis	M201	Knowledge on Continuity differentiable and Riemann integration theory. Sequence and series and it's application to numerical analysis.
Group Theory	M202	Upon successful completion of the course students will be able to understand the notion of symmetries in the language of groups. Furthermore, students will become aware of various properties of groups and subgroups.
Metric Spaces	M204	Upon successful completion of the course students will become aware about generalisation of euclidean distance on arbitrary sets and various properties of functions defined on them.

Linear Algebra	M205	Upon successful completion of the course students will learn the relation between linear transformations and matrices. Moreover, student will also learn various fundamental results of matrices, namely, diagonalisa-tion, triangulation and primary decomposition theorem.
Probability Theory	M206	Students will be introduced to the basic theory of probability starting from axiomatic definition of probability up to limit theorems of probability.
Differential Equations	M303	This course starts with the origin and applications of differential equations and discusses many solution techniques such as separation of vari-able, variation of parameter, annihilator method and Frobenious method, etc. Then it introduces basic theory of existence and uniqueness for the sys-tem of first order ODEs which is essential for many branches of mathematics. This course also gives a glimpse how to analyze the behavior of solutions (maximum principle, stability, asymptotic stability, etc.).
		This course ends with an introduction to partial differential equations and method of charac-teristics, a technique to solve first order partial differential equations. Upon successful completion of this course the student will be able to model some practical situations into ordinary differential equations or partial differential equations and analyze the solution to get information about the parameters involved in the model.

(E) MINOR SUBJECTS in PHYSICAL SCIENCES

Sr. No.	Course Name	Course No
1	Physics I (Mechanics and Thermodynamics)	P101
2	Physics Laboratory I	P141
3	Physics II (Electricity, Magnetism and Optics)	P102
4	Physics Laboratory II	P142
5	Classical Mechanics I	P201
6	Mathematical Methods I	P202
7	Electromagnetism I	P204

8	Quantum Mechanics I	P206
9	Statistical Mechanics	P302
10	Any one of the other theory courses	

COURSE OUTCOME OF MINOR SUBJECTS in PHYSICAL SCIENCES

Course Name	Course No	Course Outcome
Physics I (Mechanics and Thermodynamics)	P101	Builds understanding of basic classical mechanics and thermodynamics.
Physics Laboratory I	P141	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment
Physics II (Electricity, Magnetism and Optics)	P102	Builds basic understanding of electro and magneto static phenomena and processes. Introduces important concepts of polarization, electromagnetic waves, interference and diffraction.
Physics Laboratory II	P142	Laboratory Experience with Coupled Oscillator Circuits:
		Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors
		Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
		Laboratory Experience with Flip-flops and Microcontrollers.
Classical Mechanics I	P201	Training in basic classical mechanics, prepares the student for advanced mechanics courses.
Mathematical Methods I	P202	Acquiring knowledge of vector spaces and it applications to various physical problems.

Mathematical Methods I	P202	Acquiring knowledge of vector spaces and it applications to various physical problems.
		Acquiring knowledge of complex analysis and it applications to various physical problems.
		Acquiring knowledge of the theory of ordinary differential equations and it applications in various physical problems.
		Acquiring basic knowledge of the theory of statistics and its applications in interpretation of data
Electromagnetism I	P204	Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces to the idea of energy momentum tensor and Gauge invariance.
Quantum Mechanics I	P206	Acquiring working knowledge of the basic concepts of quantum mechanics: states, operators and time evolution.
		Understanding of the role of symmetries in quantum mechanics.
		Understanding of the theory of angular momentum in quantum mechanics.
		Acquiring knowledge of applications such as the hydrogen atom, charged particle in a magnetic field and a particle in a periodic potential.
		Acquiring knowledge of perturbation theory in quantum mechanics and applications such as Stark and Zeeman effect.
Statistical Mechanics	P302	space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.

		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Any one of the other theory courses		To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SCHOOL OF HUMANITIES

(A) Core Courses:

1. Semester I

Sr.No.	Name of the Course	Course code
1	Technical Communication I	H109
2	Introduction to Sociology	H133

2. Semester II

Sr.No.	Name of the Course	Course code
1	Technical Communication II	H110
2	Introduction to Economics	H101

(A) Electives:

Sr.No.	Name of the Course	Course code
1	Introduction to Psychology	H225
2	Environmental Economics and Environmental Impact Assessment	H201
3	Introduction to Innovation System	H239
4	Life and Community in Urban World	H238
5	Organizational Behaviour	H227
6	Sociology of Science and Technology	H235
7	Perspectives on Indian Society	H236
8	Science Communication and Citizen	H237
9	The City in Modern Fiction	HS 210
10	Speculative Fiction	H 209

Course Outcome:

(A) Core Courses

1. Semester I

Name of the Courses	Courses Code	Course Outcome
Technical Communication I	H109	Connecting Language and cultural contexts.
		Understand the process behind writing.
		Learn to critically engage with texts.
Introduction to Sociology	H133	Sociological insights that are meaningful and of practical importance to students
		Meaningfully relate with the immediate social environment.
		From a sociological perspective, observe those features which are common to all cultures and be able to assess them in the context of one's own unique setting.
		develop an objective view of social reality
		understand the structure and functioning of the society and its consequent processes of social change

2. Semester II

Name of the Courses	Courses Code	Course Outcome
Technical Communication II	H110	be familiar with the essentials of effective communication
		know the different tools of effective technical communication
		understand the importance of staging the argument, and know various institutional / disciplinary norms
Introduction to Economics	H101	familiarity with the basic concepts of economy such as: Price determination, policies for controlling inflation, role of government, sources of revenue and expenditure of the Union, State and Local government and Balance of Payment

(A) Electives

Name of the Courses	Courses Code	Course Outcome
Introduction to Psychology	H225	better understanding of human behavior.
		differentiate between scientific and non-scientific information about human behavior and mental processes.
		understand the working of their own conscious behavior and interpersonal relationship.
		apply psychological principles everyday life situations.
Environmental Economics and Environmental Impact Assessment	H201	Students would get to know the interaction between economy and environment
		Economic tools used for controlling environmental degradation
		Understanding the need for environmental impact assessment of developmental projects and its procedure
Introduction to Innovation System	H239	Appreciate the imperative of innovation within society.
		Critically analyze different types of innovation.
		Use evidence to critically challenge innovation practices. Identify possible changes in innovation system.
Life and Community in Urban World	H238	Formulate effective argumentation on city life.
		Explain and evaluate historical and contemporary urbanization processes.
		Demonstrate understanding of the diverse nature of urban populations and social problems these populations.
		Identify ways of creating sustainable, and efficient built environments.
Organizational Behaviour	H227	demonstrate knowledge organizational behavior theories and concepts.
		explain the challenges that managers and leaders face in contemporary organizations
		critically evaluate organizational practices and the impact on work behavior and performance.
		describe how the individual, groups and organization level variables interact and influence major organizational outcomes.

Sociology of Science and Technology	H235	Familiarization with the societal perspective in study of science and technology
		provide a basic understanding of issues that fall under broader spectrum of inter-relationship between science & technology and society
Perspectives on Indian Society	H236	Understanding of the basic features of Indian Society: both past and contemporary.
		To acquaint the Students about some of the major social Institutions from Sociological Perspectives
		Understanding of various processes of Social Change and Problems of Indian Society.
Science Communication and Citizen	H237	Evaluate the role of communication in science.
		Provide constructive analysis of popular science communication in a variety of real-world settings.
		Identify target audience and define applicable message.
		Develop a sense of the social and political context for science communication.
The City in Modern Fiction	HS 210	To learn to read critically.
		To learn to contextualize concepts and themes using the framework of the 'modern.'
		To learn structural elements, such as plot, setting, characters, techniques of exposition, that underpins fiction.
Speculative Fiction	H 209	the literary, social, political and genre importance of Speculative Fiction in the contemporary times as well as historically
		a detailed overview of the way Speculative Fiction has developed historically,
		some important works in Speculative Fiction , and the rich diversity in the field,
		not just the Western tradition of Speculative Fiction, but also the Indian tradition of Speculative Fiction, from ancient times to the present
		some of the oft-occurring themes such as utopias, dystopias, and issues of gender, class, environment, multiculturalism, technology, myth-making, alternate history, etc.

SCHOOL of COMPUTER SCIENCES

(A) Core Courses:

Sr. No.	Name of the Course	Course code
1	Programming and Data Structures Lab – I	CS141
2	Programming and Data Structures Lab – II	CS142
3	Theory of Computation	CS201
4	Discrete Structures and Computation	CS202
5	Design and Analysis of Algorithms	CS301

(B) Electives:

Sr. No.	Name of the Course	Course code
1	Modern Cryptology	CS451
2	Algorithmic Coding Theory	CS452
3	Complexity Theory	CS453
4	Linear Programming and Combinatorial Optimization	CS454
5	Distributed Network Algorithms	CS455

Course Outcome:

(A) Core Courses

Name of the Courses	Courses Code	Course Outcome
Programming and Data Structures Lab – I	CS141	Learn the fundamentals of programming.
		Write code for basic programming tasks.
		Create new data types suitable to the requirements
Programming and Data Structures Lab – II	CS142	Learn the fundamentals of data structures
		Write efficient codes for a wide range of programming tasks.
Theory of Computation	CS201	Learn the Mathematical Foundations of computers
		Construct abstract computational machines for basic tasks.
		Understand principles of programming languages and compilers
Discrete Structures and	CS202	Solve problems related to fundamentals of mathematical logic.

Computation		Model and solve practical problems using graph-theoretic techniques.
		Solve problems related to counting and combinatorics.
Design and Analysis of Algorithms	CS301	Learn the basics of algorithms.
		Measure the efficiency of candidate algorithms.
		Write new algorithms for basic computational tasks.

(B) Electives

Name of the Courses	Courses Code	Course Outcome
Modern Cryptology	CS451	Learn the basics of information security
		Write codes for implementing security protocols.
		Analyze candidate information security solutions.
Algorithmic Coding Theory	CS452	Learn the fundamentals of information theory.
		Write a new data compression algorithm
		Create error resilient storage solutions.
Complexity Theory	CS453	Learn the efficiency limits of computations.
		Derandomizing randomized algorithms
Linear Programming and Combinatorial Optimization	CS454	Solve linear optimization problems
		Model certain game theoretic problems as linear programming problems.
Distributed Network Algorithms	CS455	Design new algorithms for distributed networks
		Find the efficiency limit of distributed algorithms.

INTEGRATED M.Sc. in MATHEMATICAL SCIENCES
(Program Code: MATH13)

Course Structure:

I. Courses at NISER

Program Code: MATH13	**Programme Specific Outcome**	The core courses of the program provide a basic understanding in all areas of Mathematics which will be a foundation for further study of advanced topics.
		The electives courses provide knowledge in specialized topics and interconnection between different areas of Mathematics.
		Projects/Dissertation under the guidance of the faculty members give students exposure to current research in different areas of Mathematics and imbibe effective scientific and/or technical communication in both oral and writing.

(A) Core Courses

SEMISTER I

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Mathematics-I	M101
4	Programming & Data Structure Lab-I	CS141
5	Biology-I	B101
6	Biology Laboratory-I	B141
7	Physics-I	P101
8	Physics Laboratory-I	P141
9	Technical Communication-I	H109

10	Introduction to Psychology	H125

SEMISTER II

Sr. No.	Name of the Course	Course code
1	Chemistry-II	C102
2	Chemistry Laboratory-II	C142
3	Mathematics-II	M102
4	Programming & Data Structure Lab-II	CS142
5	Biology-II	B102
6	Biology Laboratory-II	B142
7	Physics-II	P102
8	Physics Laboratory-II	P142
9	Technical Communication-II	H110
10	Introduction to Sociology	H133

SEMISTER III

Sr. No.	Name of the Course	Course code
1	Real Analysis	M201
2	Group Theory	M202
3	Discrete Mathematics	M203
4	Number Theory	M207
5	Elective – I	****
6	Elective – II	****

SEMISTER IV

Sr. No.	Name of the Course	Course code
1	Metric Spaces	M204
2	Linear Algebra	M205
3	Probability Theory	M206
4	Graph Theory	M208
5	Elective-III	****

6	Elective-IV	****

SEMISTER V

Sr. No.	Name of the Course	Course code
1	Calculus of Several Variables	M306
2	Rings and Modules	M302
3	Differential Equations	M303
4	Topology	M304
5	Statistics	M305
6	Elective-V	****

SEMISTER VI

Sr. No.	Name of the Course	Course code
1	Lebesgue Integration	M301
2	Field Theory	M307
3	Complex Analysis	M308
4	Geometry of Curves and Surfaces	M310
5	Numerical Analysis	M311
6	Elective-VI	****

SEMISTER VII

Sr. No.	Name of the Course	Course code
1	Functional Analysis	M401
2	Commutative Algebra	M403
3	Project-I	M498
4	Elective-VII	****
5	Elective-VIII	****
6	Elective-IX	****

SEMISTER VIII

Sr. No.	Name of the Course	Course code
1	Algebraic Topology	M404
2	Representations of Finite Groups	M402
3	Project-II	M499
4	Elective-X	****
5	Elective-XI	****
6	Elective-XII	****

SEMISTER IX

Sr. No.	Name of the Course	Course code
1	Dissertation	M598
2	Elective-XIII	****

SEMISTER X

Sr. No.	Name of the Course	Course code
1	Dissertation	M599
2	Elective-XIV	****

(B) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Advanced Complex Analysis	M451
2	Advanced FunctionalAnalysis	M452
3	Advanced Linear Algebra	M453
4	Partial Differential Equations	M454
5	Introduction to Stochastic Processes	M455
6	Algebraic Geometry	M456
7	Algebraic Graph Theory	M457
8	Algebraic Number Theory	M458
9	Algorithm	M460

10	Cryptology	M462
11	Finite Fields	M463
12	Information and Coding Theory	M464
13	Mathematical Logic	M465
14	Measure Theory	M466
15	Nonlinear Analysis	M467
16	Operator Theory	M468
17	Theory of Computation	M469
18	Abstract Harmonic Analysis	M470
19	Advanced Number Theory	M471
20	Advanced Probability	M472
21	Algebraic Combinatorics	M473
22	Foundations of Cryptography	M474
23	Incidence Geometry	M475
24	Lie Algebras	M476
25	Optimization Theory	M477
26	Advanced Partial Differential Equations	M478
27	Random Graphs	M479
28	Randomized Algorithms and Probabilistic Methods	M480
29	Statistical Inference I	M481
30	Multivariate Statistical Analysis	M482
31	Introduction to Manifolds	M483
32	Algebraic Computation	M551
33	Analytic Number Theory	M552
34	Classical Groups	M553
35	Ergodic Theory	M554
36	Harmonic Analysis	M555
37	Lie Groups and Lie Algebras-I	M556

38	Operator Algebras	M557
39	Representations of Linear Lie Groups	M558
40	Harmonic Analysis on Compact Groups	M559
41	Modular Forms of One Variable	M560
42	Elliptic Curves	M561
43	Brownian Motion and Stochastic Calculus	M562
44	Differentiable Manifolds and Lie Groups	M563
45	Lie Groups and Lie Algebras-II	M564
46	Mathematical Foundations for Finance	M565
47	Designs and Codes	M566
48	Statistical Inference II	M567

COURSE OUTCOMES:

(A) Core Courses

SEMISTER I

Name of the Course	**Course code**	**Course Outcome**
Mathematics-I	M101	Expects students to learn how to prove theorems, expressing mathematical objects, and understand the construction of natural numbers and symmetry of plane figures.

SEMISTER II

Name of the Course	**Course code**	**Course Outcome**
Mathematics-II	M102	Upon successful completion of the course students will become aware of some basic properties of real line and real valued functions.

SEMISTER III

Name of the Course	**Course code**	**Course Outcome**
Real Analysis	M201	Knowledge on Continuity differentiable and Riemann integration theory. Sequence and series and it's application to numerical analysis.

Group Theory	M202	Upon successful completion of the course students will be able to understand the notion of symmetries in the language of groups. Furthermore, students will become aware of various properties of groups and subgroups.
Discrete Mathematics	M203	Learning different combinatorial techniques to solve many counting problems and understanding some mathematical structures
Number Theory	M207	Expects students to learn elementary properties of rings of integers including divisibility, congruences, continued fractions and Gauss reciprocity laws.
Elective-I	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-II	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER IV

Name of the Course	**Course code**	**Course Outcome**
Metric Spaces	M204	Upon successful completion of the course students will become aware about generalisation of euclidean distance on arbitrary sets and various properties of functions defined on them.
Linear Algebra	M205	Upon successful completion of the course students will learn the relation between linear transformations and matrices. Moreover, student will also learn various fundamental results of matrices, namely, diagonalisation, triangulation and primary decomposition theorem.
Probability Theory	M206	Students will be introduced to the basic theory of probability starting from axiomatic definition of probability up to limit theorems of probability.
Graph Theory	M208	Understanding the fundamentals of graph theory and learning the structure of graphs and techniques used to analyze different problems
Elective-III	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-IV	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER V

Name of the Course	Course code	Course Outcome
Calculus of Several Variables	M306	Upon successful completion of the course students will learn the notion of limits, continuity, differentiation and integration in the higher dimensional euclidean spaces.
Rings and Modules	M302	Expects students to learn structure and various properties of rings and modules, structure of finitely generated modules over PID.
Differential Equations	M303	This course starts with the origin and applications of differential equations and discusses many solution techniques such as separation of variable, variation of parameter, annihilator method and Frobenious method, etc. Then it introduces basic theory of existence and uniqueness for the system of first order ODEs which is essential for many branches of mathematics. This course also gives a glimpse how to analyze the behavior of solutions (maximum principle, stability, asymptotic stability, etc.). This course ends with an introduction to partial differential equations and method of characteristics, a technique to solve first order partial differential equations. Upon successful completion of this course the student will be able to model some practical situations into ordinary differential equations or partial differential equations and analyze the solution to get information about the parameters involved in the model.
Topology	M304	This course builds the foundations of point set topology and also covers basic algebraic topology (basics of covering spaces and fundamental group). After taking this course the students will be proficient in the abstract notion of a topological space, where continuous functions are defined in terms of open sets (and not the traditional $\varepsilon - \delta$ definition used in analysis). The students will appreciate some of the most important concepts in analysis from a topological perspective. For example, they will realize Intermediate value theorem is a statement about connectedness, Bolzano Weirstrass Theorem is a statement about compactness and so on. They will also get a solid grasp of quotient topology (which is a fundamentally new concept that is not an extension of the things already taught in analysis).

		The students will then be taught deeper concepts such as Ursysohn Lemma, Tietze extension theorem and Tychonoff Theorem. These topics will be of great use to anyone pursuing further studies in Topology, Functional Analysis, PDE and Probability.
		The students will also learn the basics of fundamental group and covering spaces; they will be able to compute the fundamental group of a circle (but not much more beyond that in this course). After this course, they will be fully ready to study a more advanced course in Algebraic Topology that gets into the intricate details of fundamental group and singular homology. This course will also be very useful to anyone pursuing further studies in Differential Geometry (theory of manifolds).
Statistics	M305	Students will be introduced to the discipline of statistics, learn about descriptive statistics of data sets including graphical representation using some statistical software. The focus is to learn about basic theory of point estimation, interval estimation, hypothesis testing and linear regression.
Elective-V	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER VI

Name of the Course	**Course code**	**Course Outcome**
Lebesgue Integration	M301	Upon successful completion of the course students will learn the concept of measures and measurable functions. Students also learn Lebesgue integration and their various properties
Field Theory	M307	Expects students to learn basic properties of fields including the fundamental theorem of Galois theory.
Complex Analysis	M308	Upon successful completion of the course students will learn the concept of (complex) differentiation and integration of functions defined on the complex plane and their properties.
Geometry of Curves and Surfaces	M310	Knowledge on curve and surfaces, manifold and vector field some application on geometry of surfaces.
Numerical Analysis	M311	Upon successful completion of the course students will learn prac-tical use of some

		important results from real analysis and linear algebra.
Elective-VI	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER VII

Name of the Course	Course code	Course Outcome
Functional Analysis	M401	Upon successful completion of the course students will learn the concept of normed linear space and various properties of operators defined on them.
Commutative Algebra	M403	Expects students to understand various properties of commuta-tive rings, various class of commutative rings, and dimension theory.
Project-I	M498	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-VII	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-VIII	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-IX	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER VIII

Name of the Course	Course code	Course Outcome
Algebraic Topology	M404	This course lays down the foundations of fundamental group ($\pi 1$) and singular homology. The students will get a good in-depth knowledge of covering spaces. To begin with, they will study covering spaces as a tool to compute fundamental group (such as the circle, torus etc). Later on, they will study covering spaces in much greater depth; they will get an understanding of the correspondence between conjugacy classes of $\pi 1$ and the different covering spaces they correspond

		to. They will also learn that this correspondence is bijective if and only if the space is reasonable (path connected, locally path connected and semi-locally simply connected). Students will also learn different techniques to compute the fundamental group such as homotopy invariance and Van-Kampen Theorem.
		The students will also learn about the basics of singular homology. They will learn different techniques to compute singular homology of a space, including homotopy invariance, Mayer-Vietoris, excision, long exact sequence etc. The students will also learn about the degree of a map. They will be able to use these concepts to prove non-trivial theorems such as invariance of domain, hairy ball theorem etc.
Representations of Finite Groups	M402	This course gives an introduction to the representation of finite groups via character theory.
Project-II	M499	Learning formulation and execution of research project.
Elective-X	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-XI	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-XII	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER IX

Name of the Course	**Course code**	**Course Outcome**
Dissertation	M598	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective-XIII	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SEMISTER X

Name of the Course	Course code	Course Outcome
Dissertation	M599	Learning effective communication of research results in writing and ethics in publication.
Elective-XIV	****	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) ELECTIVES

Name of the Course	Course code	Course Outcome
Advanced Complex Analysis	M451	Students will learn some important theorems in complex analysis such as Riemann mapping theorem, Weirstrass factorization theorem, Runges theorem, Hardamard factorization theorem, Little Picards theorem and Great Picards theorem. They will also learn some basic techniques of harmonic functions and characterization of Dirichlet Region. These results are very useful in many branches of mathematics such as Number Thoery, Differential Geometry, Operator theory, Partal Differential Equations etc.
Advanced Functional Analysis	M452	Upon successful completion of the course students will become aware of the concept of topological vector space, as a generalisation of normed linear spaces, and various properties of operators defined on them.
Advanced Linear Algebra	M453	Upon successful completion of the course students will become aware of various decomposition results of matrices and their applications.
Partial Differential Equations	M454	Students will learn explicit representations of solutions of four important classes of PDEs, namely, Transport equations, Heat equation, Laplace equation and wave equation for initial value problems. They will study the properties of solutions of these equations such as mean value property, maximum principles and regularity. They will also study Cauchy-Kowalevski Theorem and uniqueness theorem of Holmgreen for quasilinear equations.

Introduction to Stochastic Processes	M455	Students will be introduced to the theory of both discrete time and continuous time Markov chains.
Algebraic Geometry	M456	This course will introduce the students to the fundamentals of classical algebraic geometry. They will learn about the theory of Riemann surfaces, divisors, line bundles, Chern Classes and the Riemann Roch Theorem.
Algebraic Graph Theory	M457	Learning the different algebraic techniques used in the study of the graphs
Algebraic Number Theory	M458	This course gives an introduction to the basic properties of number fields, computation of class numbers and zeta functions.
Algorithm	M460	Students will learn (i) Data structure, (ii) design and analysis algorithms and (iii) some important algorithms like sortings, graph theoretics, polynomial related and optimization
Cryptology	M462	It introduces the basics of Cryptography and cryptanalysis. Stu-dents learn theory and design of cryptographic schemes like stream ciphers, block ciphers and public key ciphers like RSA, El-Gamal, elliptic curve cryptosystem. Further, they learn about data authentication, integrity and secret sharing.
Finite Fields	M463	This course gives a structure of finite fields, factorization of polynomials, some applications towards cryptography, coding theory and combinatorics.
Information and Coding Theory	M464	It introduces information theory and coding theory. In information theory, students learn how to measure information and encoding of information. In coding theory, students learn theory and techniques of error correcting codes like Reed-Muller codes, BCH codes, Reed- Solomon codes, Algebraic codes.
Mathematical Logic	M465	Students will learn Mathematical logic. It starts from the propositional logic and then first order theory. Then introduces the completeness and compactness theorems with Godels incompleteness theorem.
Measure Theory	M466	Upon successful completion of the course students will learn the concept of measures and measurable functions. Students also learn integration and their various properties.

Nonlinear Analysis	M467	Students will learn Calculus in Banach Spaces and degree theory. As an application of degree theory, they will study fixed point theorems of Brouwer and Schauder. Students will also learn homotopy, homotopy extension and invariance theorems and its applications. This course is very useful for the students who want to specialize in Partial Differential Equations.
Operator Theory	M468	Upon successful completion of the course students will become familiar with concepts of C*-algebra, von-Neuman algebra and toeplitz operators and the notion of index for Fredholm operators.
Theory of Computation	M469	It introduces the theory of computer science. Here, the students learn (i) Automata and Language Theory by studying automata and context free language (ii) Computability theory by studying Turing machine and halting problem (iii) Complexity theory by studying P and NP class problems
Abstract Harmonic Analysis	M470	Knowledge on Haar measure, convolution structure on Lie group with emphasize to harmonic analysis on the groups Circle and real line.
Advanced Number Theory	M471	This advanced course gives a brief introduction to p-adic numbers, quadratic forms, Dirichlet series and modular forms.
Advanced Probability	M472	Students will learn about measure theoretic probability starting from probability spaces to theory of martingales.
Algebraic Combinatorics	M473	Learning the use of different algebraic technique to study the combinatorial problems
Foundations of Cryptography	M474	The theoretical study of cryptography which puts foundation for the study and design of real-life cryptography.
Incidence Geometry	M475	Understanding different kinds of incidence structures such as projective spaces, affine spaces, generalized quadrangles, polar spaces and quadratic sets.

Lie Algebras	M476	This course serves two purposes. (i) To introduce the basics of Lie algebras to the students who are interested in algebra and pursue further in the studies of infinite dimensional Lie algebras like Kac-Moody Lie algebras on one hand and finite dimensional Lie algebras and their representations over any field on the other hand. (ii) As Lie algebras play infinitesimal part of Lie groups, they play important role in understanding Lie groups. The theory of semisimple Lie algebras is extremely rich thanks to Cartan, Weyl without which, one cannot understand the geometry of semisimple Lie groups and their representations and also compact Lie groups.
		After having done this course, one can pursue the studies on either Lie algebras or Representation theory of Lie groups.
Optimization Theory	M477	Understanding the different techniques used to solve the linear and non-linear programming problem
Advanced Partial Differential Equations	M478	Students will learn basics of distribution Theory, Sobolev Spaces and their properties. Using Sobolev space Theory, students will learn existence theory of solutions for Dirichlet, Neuman and oblique derivative problems for second order elliptic partial differential equations. They will also learn weak and strong maximum principles, Hopf Maximum Principle and Alexandrof- Bakelmann-Pucci estimate for the solutions. This course is very useful for the students who want to specialize in Partial
Random Graphs	M479	The aim is to learn random graphs and its applications.
Randomized Algorithms and Probabilistic Methods	M480	The aim is to learn how to use probabilistic techniques to different areas of mathematics and computer science.
Statistical Inference I	M481	The outcome of this course is to learn about parametric statistical inference to be applicable to almost all branches of statistics. Students will learn various methods of estimation and hypothesis testing and their large sample and small sample properties.

Multivariate Statistical Analysis	M482	Students will learn about various modern statistical tools to analyze and draw inference from multivariate data sets. Starting from multivariate normal distribution, students will learn inference about multivariate sample mean and variance, techniques of dimension reduction, introductory factor analysis, cluster analysis and statistical pattern recognition.
Introduction to Manifolds	M483	This course lays the foundations of modern Differential Geometry. After taking this course, the students will get a good knowledge of smooth manifolds, tangent and cotangent spaces, vector bundles, (co)tangent bundles, vector fields, differential forms, exterior differentiation, De-Rham co-homology, integration on manifolds, homotopy invariance of De-Rham coho-mology and the statement of Poincare Duality. After studying this course, students will be fully prepared to pursue further studies in (complex) algebraic geometry, theory of Riemann surfaces and Riemannian Geometry. Students will also be fully equipped to pursue further studies in analysis on manifolds, particularly the theory of Elliptic operators on smooth manifolds and Hodge Theory (which culminates in the proof of Poincare Duality). Students who are interested in either Topology, Differential Geometry,
		Algebraic Geometry and certain topics in analysis and PDE, with a geometric flavor (i.e. Geometric Analysis) will find this course very useful.
Algebraic Computation	M551	It is a unique style of course where the mathematics students having interest in computation can learn to compute different algebraic problems in computer. Here students will learn the computation of the problems related (i) linear algebra, (ii) non-linear system of quations like Grobner bases, (iii) polynomial, (iv) Algebraic number theory and (v) elliptic curve.
Analytic Number Theory	M552	Expects students to learn elementary properties of Dirichlet series and distribution of primes.
Classical Groups	M553	Understanding the basic facts about classical groups defined over fields such as General Linear groups, Special Linear groups, Symplectic groups, Orthogonal groups and

Ergodic Theory	M554	The origin and motivation of studies of Ergodic theory comes from the statistical physics. One of the main branches in Analysis, it aims to give a formal mathematical treatment of movements of particles in a measure space. The important application is to study the behaviours of atoms and molecules in the ambit of aggregate systems. So, naturally the probability theory lies in the undercurrent of Ergodic theory. This theory emerged as a bridge between Probability theory, Physics and Functional analysis. It has a lot of applications in Statistical physics and mathematical biology.
Harmonic Analysis	M555	Knowledge on Fourier Series, Fourier transforms and celebrated differentiation theorem and important operators like Hilbert transform and Maximal function.
Lie Groups and Lie Algebras-I	M556	Understanding the technique used for constructing combinatorial designs and its relation with linear codes Outcomes: The aim of this course and M564- Lie groups and Lie algebras II is to give a strong foundation on the study of Lie groups and their infinitesimal version viz., Lie algebras. The prominent role played by Lie groups in the study of Geometry and theoritical physics needs no further emphasis. This course is tremendously beneficial for the mathematics students and physics students as well.
		It begins with the rudiments of Lie groups and finally ends with irreducible representations of compact Lie groups parametrised by Weyl Character formula.
Operator Algebras	M557	Upon successful completion of the course students will become familiar with concepts and various structure theorems of C*-algebra and von-Neuman algebra.
Representations of Linear Lie Groups	M558	This course is a more basic than M556 and M564 laying founda-tion for the students who want to take up one of the branches of mainstream mathematics namely, non-abelian harmonic analysis. The prototype of the complications that might arise in the study of non-abelian harmonic anal-ysis, is amply found in the study of Linear Lie groups. Yet, these linear Lie groups are plausible to understand as they are concrete examples of non-compact non-abelian Lie groups.

		The course starts from the first principles of representations and goes upto understanding the important examples of 3 different types of groups, viz., compact, nilpotent and solvable groups. It is quite beneficial for the students who want to get into representation theory.
Harmonic Analysis on Compact Groups	M559	Knowledge on representaion on compact lie groups with examples SU(2), SO(n).
Modular Forms of One Variable	M560	This course gives an introduction to modular forms over 2 and their congruence subgroups, and their Hecke theory.
Elliptic Curves	M561	This course gives an introduction to elliptic curves and the struc-ture of their rational points.
Brownian Motion and Stochastic Calculus	M562	Students will learn about the theory of Brownian motion and it applications to stochastic differential equations.
Differentiable Manifolds and Lie Groups	M563	This course will introduce the students to the fundamentals of Lie groups and Lie Algebras. After studying this course, students will get a working knowledge of smooth manifolds, but unlike M483, this course will get into an in depth study of Lie Groups. The students will study about (bi)invariant vector fields, integration on Lie Groups, Cartan's Theorem etc. After studying this course, students will be fully equipped to study Abstract Harmonic Analysis on Lie Groups (and the construction of Haar Measure).
Lie Groups and Lie Algebras-II	M564	This course is the sequel of M556 - Lie groups and Lie algebras I. It mostly deals with the representation theory of Lie groups. Lie groups that are studied in this course, are compact Lie groups and the group SL(2,C) . Another aspect of this course is to classify all simple Lie algebras through root system. As it is well known, the study of subatomic particles depend on the irreducible representations of certain Lie groups that are contained in GL(n, R). This course gives a vivid account of mathematics that is needed to understand these representations. To sum up, it is a gateway for the students of mathematics to pursue harmonic analysis of Lie groups.
Mathematical Foundations for Finance	M565	Students will learn about the mathematical modeling of simple stock markets and techniques to analyze them.
Designs and Codes	M566	Understanding the technique used for constructing combinatorial designs and its relation with linear codes.

Statistical Inference II	M567	Students will be introduced to decision theory and learn about Bayesian estimation and testing. Moreover, students will learn about large sample theory including asymptotic tests, confidence intervals, asymptotic efficiency and optimality of estimators and tests.

(A) MINOR SUBJECTS in CHEMICAL SCIENCES

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Chemistry-II	C102
4	Chemistry Laboratory-II	C142
5	Basic Inorganic Chemistry	C201
6	Reaction Mechanism in Organic Chemistry	C203
7	Quantum Chemistry-I	C206
8	Mathematical methods for Chemists	C207
9	Physical Methods in Chemistry-I	C306
10	Thermodynamics and Electrochemistry	C307

COURSE OUTCOME OF MINOR SUBJECTS in CHEMICAL SCIENCES

Name of the Course	Course code	Course Outcome
Chemistry-I	C101	The basics of atomic and molecular structure and spectroscopy
		Thermodynamics of different chemical processes
		Kinetics of chemical reactions
Chemistry Laboratory-I	C141	Introduction to synthesis of small organic compounds
		Qualitative analysis of chemicals present in tea, coffee, fruits etc.
		Synthesis of simple drugs such as paracetamol

Chemistry-II	C102	Apply the fundamental principles of measurement, matter, atomic theory, chemical periodicity, chemical bonding, general chemical reactivity and solution chemistry to subsequent courses in science, engineering, technology.
		Students will be able to explain why chemistry is an integral activity for addressing social, economic, and environmental problems
		Students will be able to explore new areas of research in both chemistry and allied fields of science and technology after getting their concepts clear in Basic Chemistry
Chemistry Laboratory-II	C142	Introduction to quantitative analysis in chemistry.
		Students will learn basic concepts on electrochemistry
		Students will be given hands on practice on conductometry, polarimetry and flame photometry
		They will apply these concepts to estimate binding constant, solubility product etc.
Basic Inorganic Chemistry	C201	To understand basic facts and concepts in Chemistry while retaining the exciting aspects of Chemistry so as to develop interest in the study of chemistry as a discipline.
		To develop the ability to apply the principles of Chemistry.
		To appreciate the achievements in Chemistry and to know the role of Chemistry in nature and in society.
		To develop problem solving skills.
		To be familiarized with the emerging areas of Chemistry and their applications in various spheres of Chemical sciences and to apprise the students of its relevance in future studies.
		To be exposed to the different processes used in industries and their applications

Reaction Mechanism in Organic Chemistry	C203	Introduction of basic organic reactions (Substitutions, Additions & Eliminations) and writing organic reaction mechanisms
		Reactivity of unsaturated hydrocarbons (alkene, alkyne and aromatic)
		Understanding the role of substitutions to influence the rate of reactions
		Stereochemistry in organic chemistry: Chemoselectivity, Diastereoselectivity, Enantioselectivity, Stereospecificity, Stereoconvergence
		Introduction of asymmetric synthesis with and without asymmetric catalysts
Quantum Chemistry-I	C206	Understanding the need of Quantum mechanics based on failures of Classical mechanics.
		Learning the basic building blocks of Quantum Mechanics.
		Learning to use the mathematical structure of quantum mechanics in several systems comprising one or many quantum particles.
		Understanding the bridge between the mathematical structure of quantum mechanics and different spectroscopic techniques based on that.
Mathematical methods for Chemists	C207	Introduce the standard mathematical techniques that are typically used by Chemists.
		To learn how to apply mathematics to chemistry research.
		To learn how to use Fourier transform in different spectroscopy.
		The course, mostly differential equation is useful to learn quantum chemistry and chemical kinetics.
Physical Methods in Chemistry-I	C306	Understand the basics of absorption and fluorescence spectroscopy.
		Theoretical prediction of absorption maximum of some organic molecules.

		Identifying and distinguishing various type of electronic transition using solvent perturbation techniques.
		Understanding the concept of micropolarity and the importance of this parameter in spectroscopy
		Understanding some important photoprocessess such as electron transfer and energy transfer and their applications in energy related applications.
		Applications of fluorescence spectroscopy in detecting various analytes (Sensing applications)
Thermodynamics and Electrochemistry	C307	Understanding the laws of Thermodynamics and Phase equilibrium of multicomponent systems.
		Understanding the thermodynamics of surfaces and different adsorption isotherms of gases on solids.
		Key concepts for the Electrochemistry and applications of Electrochemistry.
		Key concepts of Statistical Thermodynamics.

(B) MINOR SUBJECTS in LIFE SCIENCES

Sr. No.	Course Name	Course No
1	Biology I: Science of Life	B101
2	Biology Laboratory-1	B141
3	Biology II: Cellular and Genetic basis of life	B102
4	Biology Laboratory-2	B142
5	Biochemistry	B202
6	Cell Biology	B204
7	Genetics	B205

8	Molecular Biology	B304
9	Evolutionary Biology	B306
10	Any one course from biology subjected to qualified prerequisite	Bx5x

COURSE OUTCOME OF MINOR SUBJECTS in LIFE SCIENCES

Course Name	Course No	Course Outcome
Biology I: Science of Life	B101	Understanding the origin and evolution of life.
		Fundamental understanding of the structure and function of the molecules of life.
		Fundamental understanding of the structure & function of cellular organelles.
Biology Laboratory-1	B141	Introduce to students analytical tools/approaches to study biomolecules and cell structure.
		Build basics of experimentation and data recording in biology labs
Biology II: Cellular and Genetic basis of life	B102	Understanding the principles of cellular mechanisms driving development of an organism.
		Key evolutionary concepts in Lamarckism, Darwinism and Speciation
		Understanding the genetic basis of inheritance
		Fundamental understanding of molecular Biology
Biology Laboratory-2	B142	Understand a microscope and various staining and microscopic techniques
		Knowledge of the basis of human blood groups (ABO)
		Experimental approaches to study cell growth and differentiation and Gene regulation
		Use of microscope to know various stages of cell division in mitosis and meiosis

Biochemistry	B202	Understanding the principles governing Protein structure & function
		Basic concepts on metabolism and their implications in living organisms
		Concept on signal transduction
		Implications in Evolution, Health and disease.
Cell Biology	B204	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell structure
		Evolution of cell organelles, importance in health and disease.
Genetics	B205	Understanding the basic principles of inheritance
		Knowledge of genetic disease mechanism
		Comprehension of monogenic, polygenic and multifactorial diseases
		Application in health and diseases
Molecular Biology	B304	Understanding the key components of cell involved in central dogma of molecular biology.
		Understanding of structure-function of genetic material, replication, repair, transcription and translation.
Evolutionary Biology	B306	Understanding how life originated on the planet
		Understanding the formation of species and underlying genetic diversity
		Understanding biology from an organismal point of view and why some species evolve slowly while others evolve rapidly
		Understanding systematic relationships between organisms using phylogenetic tools
Any one course from biology subjected to qualified prerequisite	Bx5x	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(C) MINOR SUBJECTS in PHYSICAL SCIENCES

Sr. No.	Course Name	Course No
1	Physics I (Mechanics and Thermodynamics)	P101
2	Physics Laboratory I	P141
3	Physics II (Electricity, Magnetism and Optics)	P102
4	Physics Laboratory II	P142
5	Classical Mechanics I	P201
6	Mathematical Methods I	P202
7	Electromagnetism I	P204
8	Quantum Mechanics I	P206
9	Statistical Mechanics	P302
10	Any one of the other theory courses	

COURSE OUTCOME OF MINOR SUBJECTS in PHYSICAL SCIENCES

Course Name	Course No	Course Outcome
Physics I (Mechanics and Thermodynamics)	P101	Builds understanding of basic classical mechanics and thermodynamics.
Physics Laboratory I	P141	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment
Physics II (Electricity, Magnetism and Optics)	P102	Builds basic understanding of electro and magneto static phenomena and processes. Introduces important concepts of polarization, electromagnetic waves, interference and diffraction.

Physics Laboratory II	P142	Laboratory Experience with Coupled Oscillator Circuits: Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors
		Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
		Laboratory Experience with Flip-flops and Microcontrollers.
Classical Mechanics I	P201	Training in basic classical mechanics, prepares the student for advanced mechanics courses.
Mathematical Methods I	P202	Acquiring knowledge of vector spaces and it applications to various physical problems.
		Acquiring knowledge of complex analysis and it applications to various physical problems.
		Acquiring knowledge of the theory of ordinary differential equations and it applications in various physical problems.
		Acquiring basic knowledge of the theory of statistics and its applications in interpretation of data
Electromagnetism I	P204	Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces to the idea of energy momentum tensor and Gauge invariance.
Quantum Mechanics I	P206	Acquiring working knowledge of the basic concepts of quantum mechanics: states, operators and time evolution.
		Understanding of the role of symmetries in quantum mechanics.
		Understanding of the theory of angular momentum in quantum mechanics.
		Acquiring knowledge of applications such as the hydrogen atom, charged particle in a magnetic field and a particle in a periodic potential.
		Acquiring knowledge of perturbation theory in quantum mechanics and applications such as Stark and Zeeman effect.
Statistical Mechanics	P302	Space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.

		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.
		Acquiring knowledge of the basics of interacting classical systems: non- ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Any one of the other theory courses		To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

SCHOOL OF HUMANITIES

(A) Core Courses:

1. Semester I

Sr.No.	Name of the Course	Course code
1	Technical Communication I	H109
2	Introduction to Sociology	H133

2. Semester II

Sr.No.	Name of the Course	Course code
1	Technical Communication II	H110
2	Introduction to Economics	H101

(A) Electives:

Sr.No.	Name of the Course	Course code
1	Introduction to Psychology	H225
2	Environmental Economics and Environmental Impact Assessment	H201
3	Introduction to Innovation System	H239
4	Life and Community in Urban World	H238
5	Organizational Behaviour	H227
6	Sociology of Science and Technology	H235
7	Perspectives on Indian Society	H236
8	Science Communication and Citizen	H237
9	The City in Modern Fiction	HS 210
10	Speculative Fiction	H 209

Course Outcome:

(A) Core Courses

1. Semester I

Name of the Courses	Courses Code	Course Outcome
Technical Communication I	H109	Connecting Language and cultural contexts.
		Understand the process behind writing.
		Learn to critically engage with texts.
Introduction to Sociology	H133	Sociological insights that are meaningful and of practical importance to students
		Meaningfully relate with the immediate social environment.
		From a sociological perspective, observe those features which are common to all cultures and be able to assess them in the context of one's own unique setting.
		develop an objective view of social reality
		understand the structure and functioning of the society and its consequent processes of social change

2. Semester II

Name of the Courses	Courses Code	Course Outcome
Technical Communication II	H110	be familiar with the essentials of effective communication
		know the different tools of effective technical communication
		understand the importance of staging the argument, and know various institutional / disciplinary norms
Introduction to Economics	H101	familiarity with the basic concepts of economy such as: Price determination, policies for controlling inflation, role of government, sources of revenue and expenditure of the Union, State and Local government and Balance of Payment

(A) Electives

Name of the Courses	Courses Code	Course Outcome
Introduction to Psychology	H225	better understanding of human behavior.
		differentiate between scientific and non-scientific information about human behavior and mental processes.
		understand the working of their own conscious behavior and interpersonal relationship.
		apply psychological principles everyday life situations.
Environmental Economics and Environmental Impact Assessment	H201	Students would get to know the interaction between economy and environment
		Economic tools used for controlling environmental degradation
		Understanding the need for environmental impact assessment of developmental projects and its procedure
Introduction to Innovation System	H239	Appreciate the imperative of innovation within society.
		Critically analyze different types of innovation.
		Use evidence to critically challenge innovation practices. Identify possible changes in innovation system.
Life and Community in Urban World	H238	Formulate effective argumentation on city life.
		Explain and evaluate historical and contemporary urbanization processes.
		Demonstrate understanding of the diverse nature of urban populations and social problems these populations.
		Identify ways of creating sustainable, and efficient built environments.
Organizational Behaviour	H227	demonstrate knowledge organizational behavior theories and concepts.
		explain the challenges that managers and leaders face in contemporary organizations
		critically evaluate organizational practices and the impact on work behavior and performance.
		describe how the individual, groups and organization level variables interact and influence major organizational outcomes.

Sociology of Science and Technology	H235	Familiarization with the societal perspective in study of science and technology
		provide a basic understanding of issues that fall under broader spectrum of inter-relationship between science & technology and society
Perspectives on Indian Society	H236	Understanding of the basic features of Indian Society: both past and contemporary.
		To acquaint the Students about some of the major social Institutions from Sociological Perspectives
		Understanding of various processes of Social Change and Problems of Indian Society.
Science Communication and Citizen	H237	Evaluate the role of communication in science.
		Provide constructive analysis of popular science communication in a variety of real-world settings.
		Identify target audience and define applicable message.
		Develop a sense of the social and political context for science communication.
The City in Modern Fiction	HS 210	To learn to read critically.
		To learn to contextualize concepts and themes using the framework of the 'modern.'
		To learn structural elements, such as plot, setting, characters, techniques of exposition, that underpins fiction.
Speculative Fiction	H 209	the literary, social, political and genre importance of Speculative Fiction in the contemporary times as well as historically
		a detailed overview of the way Speculative Fiction has developed historically,
		some important works in Speculative Fiction , and the rich diversity in the field,
		not just the Western tradition of Speculative Fiction, but also the Indian tradition of Speculative Fiction, from ancient times to the present
		some of the oft-occurring themes such as utopias, dystopias, and issues of gender, class, environment, multiculturalism, technology, myth-making, alternate history, etc.

SCHOOL of COMPUTER SCIENCES

(A) Core Courses:

Sr. No.	Name of the Course	Course code
1	Programming and Data Structures Lab – I	CS141
2	Programming and Data Structures Lab – II	CS142
3	Theory of Computation	CS201
4	Discrete Structures and Computation	CS202
5	Design and Analysis of Algorithms	CS301

(B) Electives:

Sr. No.	Name of the Course	Course code
1	Modern Cryptology	CS451
2	Algorithmic Coding Theory	CS452
3	Complexity Theory	CS453
4	Linear Programming and Combinatorial Optimization	CS454
5	Distributed Network Algorithms	CS455

Course Outcome:

(A) Core Courses

Name of the Courses	Courses Code	Course Outcome
Programming and Data Structures Lab – I	CS141	Learn the fundamentals of programming.
		Write code for basic programming tasks.
		Create new data types suitable to the requirements
Programming and Data Structures Lab – II	CS142	Learn the fundamentals of data structures
		Write efficient codes for a wide range of programming tasks.
Theory of Computation	CS201	Learn the Mathematical Foundations of computers
		Construct abstract computational machines for basic tasks.
		Understand principles of programming languages and compilers
Discrete Structures and	CS202	Solve problems related to fundamentals of mathematical logic.

Computation		Model and solve practical problems using graph-theoretic techniques.
		Solve problems related to counting and combinatorics.
Design and Analysis of Algorithms	CS301	Learn the basics of algorithms.
		Measure the efficiency of candidate algorithms.
		Write new algorithms for basic computational tasks.

(B) Electives

Name of the Courses	Courses Code	Course Outcome
Modern Cryptology	CS451	Learn the basics of information security
		Write codes for implementing security protocols.
		Analyze candidate information security solutions.
Algorithmic Coding Theory	CS452	Learn the fundamentals of information theory.
		Write a new data compression algorithm
		Create error resilient storage solutions.
Complexity Theory	CS453	Learn the efficiency limits of computations.
		Derandomizing randomized algorithms
Linear Programming and Combinatorial Optimization	CS454	Solve linear optimization problems
		Model certain game theoretic problems as linear programming problems.
Distributed Network Algorithms	CS455	Design new algorithms for distributed networks
		Find the efficiency limit of distributed algorithms.

BACK TO MAIN

INTEGRATED M.Sc. in PHYSICAL SCIENCES
(Program Code: PHYS13)

I. Courses at NISER

Program Code : PHYS13	Programme Specific Outcome	Understanding and knowledge of physics in the classical domain.
		Understanding and knowledge of physics in the quantum domain.
		Understanding and application of statistical methods in physics
		Laboratory experience so that students are exposed to modern experimental techniques.
		Understanding of mathematical methods in their applications in diverse settings.
		Provide exposure to various specialised areas such as condensed matter, nuclear physics, atomic physics, particle physics, astrophysics and quantum information
		Introduction to methods that will be lifelong assets for careers in research and development.

(A) Core Courses
1st Year

1. SEMISTER I

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Mathematics-I	M101
4	Programming & Data Structure Lab-I	CS141
5	Biology-I	B101
6	Biology Laboratory-I	B141
7	Physics-I	P101

8	Physics Laboratory-I	P141
9	Technical Communication-I	H109
10	Introduction to Psychology	H125

2. **SEMISTER II**

Sr. No.	Name of the Course	Course code
1	Chemistry-II	C102
2	Chemistry Laboratory-II	C142
3	Mathematics-II	M102
4	Programming & Data Structure Lab-II	CS142
5	Biology-II	B102
6	Biology Laboratory-II	B142
7	Physics-II	P102
8	Physics Laboratory-II	P142
9	Technical Communication-II	H110
10	Introduction to Sociology	H133

2ND YEAR

1. **SEMISTER III**

Sr. No.	Name of the Course	Course code
1	Classical Mechanics I	P201
2	Mathematical Methods I	P202
3	Electronics	P203
4	General Physics Laboratory	P241
5	Basic Electronics laboratory	P242

2. **SEMISTER IV**

Sr. No.	Name of the Course	Course code
1	Electromagnetism I	P204

2	Mathematical Methods II	P205
3	Quantum Mechanics I	P206
4	Modern Physics I & Optics Laboratory	P243
5	Advanced Electronics Laboratory	P244

3RD YEAR

1. **SEMISTER V**

Sr. No.	**Name of the Course**	**Course code**
1	Electromagnetism II	P301
2	Statistical Mechanics	P302
3	Quantum Mechanics II	P303
4	Special Theory of Relativity	P304
5	Nuclear Physics & Instrumentation Laboratory	P341
6	Computational Physics Laboratory	P342

2. **SEMISTER VI**

Sr. No.	**Name of the Course**	**Course code**
1	Atoms, Molecules and Radiation	P305
2	Introduction to Condensed Matter Physics	P306
3	Nucei and Particles	P307
4	Physics Project I	P398
5	Modern Physics II Laboratory	P343
6	Solid State Physics I Laboratory	P344

4TH YEAR

1. **SEMISTER VII**

Sr. No.	**Name of the Course**	**Course code**
1	Classical Mechanics II	P401
2	Solid State Physics II Laboratory	P441

3	Lasers and Spectroscopy Laboratory	P442
4	Elective 1	*
5	Elective 2	*
6	Elective 3	*

2. SEMISTER VIII

Sr. No.	Name of the Course	Course code
1	Integrated Physics Laboratory I	P443
2	Integrated Physics Laboratory II	P444
3	Elective 4	*
4	Elective 5	*
5	Elective 6	*
6	Elective 7	*

5TH YEAR

1. SEMISTER IX

Sr. No.	Name of the Course	Course code
1	Physics Dissertation project I	P598
2	Elective 8	*
3	Elective 9	*
4	Elective 10	*

2. SEMISTER X

Sr. No.	Name of the Course	Course code
1	Physics Dissertation project I	P599
2	Elective 11	*
3	Elective 12	*
4	Elective 13	*

(B) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Advanced Solid State Physics	P451
2	Computational Physics	P452
3	Quantum Field theory I	P453
4	Particle Physics	P454
5	Introduction to Phase Transition and Critical Phenomena	P455
6	Nonlinear Optics and Lasers	P456
7	General Relativity and Cosmology	P457
8	Soft Condensed Matter	P458
9	Applied Nuclear Physics	P459
10	Many Particle Physics	P460
11	Physics of Mesoscopic Systems	P461
12	Introduction to Quantum Optics	P462
13	Astronomy and Astrophysics	P463
14	Plasma Physics and Magnetohydrodynamics	P464
15	Biophysics	P465
16	Quantum and Nanoelectronics	P466
17	Nonlinear Physics, Chaos and Turbulence	P467
18	Magnetism and Superconductivity	P468
19	Density Functional Theory of Atoms, Molecules and Solids	P469
20	Quantum Field Theory II	P470
21	Quantum Information and Quantum Computation	P471
22	Experimental High Energy Physics	P472
23	Experimental Technique	P473
24	Introduction to Cosmology	P474
25	Soft Condensed Matter	P451

Course Outcomes:

(A) Core Courses

1ST YEAR

1. SEMISTER I

Name of the Course	Course code	Course Outcome
Physics I (Mechanics and Thermodynamics)	P101	Builds understanding of basic classical mechanics and thermodynamics.
Physics Laboratory I	P141	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment

2. SEMISTER II

Name of the Course	Course code	Course Outcome
Physics II (Electricity, Magnetism and Optics)	P102	Builds basic understanding of electro and magneto static phenomena and processes. Introduces important concepts of polarization, electromagnetic waves, interference and diffraction.
Physics Laboratory II	P142	Laboratory Experience with Coupled Oscillator Circuits:
		Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors
		Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator
		Laboratory Experience with Flip-flops and Microcontrollers.

2ND YEAR

1. SEMISTER III

Name of the Course	Course code	Course Outcome
Classical Mechanics I	P201	Training in basic classical mechanics, prepares the student for advanced mechanics courses.

Mathematical Methods I	P202	Acquiring knowledge of vector spaces and it applications to various physical problems.
		Acquiring knowledge of complex analysis and it applications to various physical problems.
		Acquiring knowledge of the theory of ordinary differential equations and it applications in various physical problems.
		Acquiring basic knowledge of the theory of statistics and its applications in interpretation of data
Electronics	P203	Acquiring basic knowledge of circuit theory: lumped circuit approximation, circuit elements, Kirchoff's current and voltage laws, resistive networks.
		Acquiring knowledge of basics of analog electronics, including that of diodes and LEDs.
		Acquiring knowledge basic knowledge of amplifiers.
		Acquiring knowledge of the basics digital electronics: logic gates, truth table, multiplexer, combinatorial circuits, flip-flop, and microprocessors.
General Physics Laboratory	P241	Expands the training of the students, building on P141 and P142 to train them in experimental methods in basic solid state experiments.
Basic Electronics laboratory	P242	This final basic training in experimental physics equips the student with concepts and methods for doing advanced experiments in electronics.

2. SEMISTER IV

Name of the Course	Course code	Course Outcome
Electromagnetism I	P204	Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces to the idea of energy momentum tensor and Gauge invariance.

Mathematical Methods II	P205	Prepares the student in important advanced mathematical concepts and tools. This is needed for advanced physics courses such as applications of quantum mechanics in solid state physics quantum field theory and particle phenomenology
Quantum Mechanics I	P206	Acquiring working knowledge of the basic concepts of quantum mechanics: states, operators and time evolution.
		Understanding of the role of symmetries in quantum mechanics.
		Understanding of the theory of angular momentum in quantum mechanics.
		Acquiring knowledge of applications such as the hydrogen atom, charged particle in a magnetic field and a particle in a periodic potential.
		Acquiring knowledge of perturbation theory in quantum mechanics and applications such as Stark and Zeeman effect.
Modern Physics I & Optics Laboratory	P243	The course, though experiments introduces to fundamental findings that lead to the discoveries of special relativity and quantum mechanics. In the process the course also teaches them how to use interferometers and diffraction gratings required in future courses.
Advanced Electronics Laboratory	P244	In this course the students learn advanced electronic experimentations. This includes transistors, operational amplifiers digital circuits and counters and are crucial to carrying our future experimental research.

3RD YEAR

1. **SEMISTER V**

Name of the Course	Course code	Course Outcome
Electromagnetism II	P301	Provides training in advanced concepts and methods for understanding advanced electromagnetic phenomena. Important concepts of radiation retardation, multipole expansions, covariant formulation of classical mechanics and relativistic kinematics are taught.

Statistical Mechanics	P302	space, distributions, notion of equilibrium, ensembles, Boltzmann distribution, partition function, calculating observables.
		Understanding of Statistical Mechanics of non-interacting classical systems: few level systems, ideal gases, oscillators.
		Understanding of Statistical Mechanics of non-interacting quantum systems: electrons in metals, relativistic electron systems, photons, blackbody radiation, Bose condensation.
		Acquiring knowledge of the basics of interacting classical systems: non-ideal gases, van der Waals gas, cluster expansion, classical spin models - Ising and Heisenberg, outline of exact solutions.
		A basic understanding of the theory of phase transitions.
Quantum Mechanics II	P303	Understanding of the theory and applications of scattering in quantum mechanics.
		Acquiring knowledge of the method of path integrals in quantum mechanics.
		Acquiring knowledge of the concept of entanglement in quantum mechanics and it applications such as Bell's inequalities.
		Acquiring knowledge of relativistic quantum mechanics and its applications.
Special Theory of Relativity	P304	Trains the student in basic and advanced concepts in special relativity and introduces the basic ideas up on which General relativity is based on. Also provides in depth training in applications of group theory in relativity. Prepares the student for studying general relativity in future.
Nuclear Physics & Instrumentation Laboratory	P341	This course teaches the students about basic experimentation in nuclear physics. It in conjunction with theory course on Nuclear physics P307 builds a background to carry our basic research in the field of experimental particle physics.
Computational Physics Laboratory	P342	The course provides a basic training in numerical and statistical methods used in all branches of physics though programming and hands on tutorial sessions.

2. SEMISTER VI

Name of the Course	Course code	Course Outcome
Atoms, Molecules and Radiation	P305	Important topics in atomic physics, selection rules, atomic and molecular spectroscopy is taught. The training is imperative to work in the area of applied solid state physics and optics.
Introduction to Condensed Matter Physics	P306	Understanding of the basic building blocks of matter and methods to probe structure of materials.
		Acquiring knowledge of the physics of metals.
		Acquiring knowledge of the physics of phonons.
		Acquiring knowledge of the physics of superconductors.
		Acquiring knowledge of the physics of magnetism.
Nucei and Particles	P307	Provides training in basic concepts and methods in nuclear physics, stability of nucleons and classification of interactions. Course prepares the student to begin working in experimental and theoretical high energy physics.
Physics Project I	P398	Introduces the students to basic methods in experimental techniques, statistics and error analysis. The focus is on basic mechanics and little amount of solid state physics experiments.
Modern Physics II Laboratory	P343	This course provides further experience to the students in experiments in modern quantum mechanics including highly specialized experiments on electron spin resonance and introduces them to cutting edge research area of solar cells.
Solid State Physics I Laboratory	P344	In this course the student is introduced to a variety of basic experiments in solid state physics. This prepares them for taking up more challenging experiments in this are in future courses.

4TH YEAR

1. SEMISTER VII

Name of the Course	Course code	Course Outcome
Classical Mechanics II	P401	This is an advanced course introducing the students to concepts and techniques in mechanics of continuous media. It prepares them to tackle a variety of problems in many areas such as fiber optics, fluid dynamics and structural stability of materials.
Solid State Physics II Laboratory	P441	This course exposes the student to advanced solid state experiments. It, in part, prepares them in both areas to take on further advanced experiments in future courses.
Lasers and Spectroscopy Laboratory	P442	This course exposes the student to basic laser optics and spectroscopy experiments. It, in part, prepares them in both areas to take on further advanced experiments in future courses.
Elective 1	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 2	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 3	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

2. SEMISTER VIII

Name of the Course	Course code	Course Outcome
Integrated Physics Laboratory I	P443	Performing experiments involving oscillators such as the Pohl's pendulum and chaotic oscillators.
		Performing experiments involving interferometers such as the Michelson interferometers and Mach Zehnder interferometers.
		Performing spectroscopic experiments such as the Zeeman effect.
		Performing the Millikan Oil drop experiment

Integrated Physics Laboratory II	P444	Laboratory Experience with Coupled Oscillator Circuits: Laboratory Experience with OpAmps, Diodes, Clamps, Rectifiers, Power supplies and Transistors Laboratory experience with Logic Gates: NAND gate, OR, AND, NOT; Adder, Oscillator Laboratory Experience with Flip-flops and Microcontrollers
Elective 4	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 5	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 6	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 7	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

5TH YEAR

1. **SEMISTER IX**

Name of the Course	Course code	Course Outcome
Physics Dissertation project I	P598	This is the first half of a year-long project that the final year Int. MSc student has to do. This involves preparing adequate reading material that will allow the student to take up challenging reach problem with a supervisor in a specific area of work.
Elective 8	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 9	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

Elective 10	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

2. SEMISTER X

Name of the Course	Course code	Course Outcome
Physics Dissertation project II	P599	In the final semester project, the student is expected to be able to build on the background in the ninth semester to work on a research problem. Many times this typically leads to a publication of a paper is a reputed international journal.
Elective 11	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 12	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Elective 13	*	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) ELECTIVES

Name of the Course	Course code	Course Outcome
Advanced Solid State Physics	P451	This is a course which aims to prepare students with advanced concepts, techniques and knowledge of solid state physics that allows them to start working on basic research problems in the broad area of condensed matter theory, materials theory or solid state experiments.
Computational Physics	P452	This course provides training in computation tools required in research across a wide variety of fields including condensed matter, high energy phenomenology and lattice field theories.

Quantum Field theory I	P453	Quantization for the study of many particle non-relativistic systems.
		Acquiring knowledge of the Lorentz group and its role in relativistic quantum field theory.
		Acquiring knowledge of the quantization of the Klein Gordon, Dirac and Maxwell fields.
		Acquiring knowledge of the basics of quantum electrodynamics and the study of various processes at tree level.
		Understanding of the role of gauge invariance in quantum electrodynamics.
Particle Physics	P454	Understanding physics of elementary particles.
		Learning about fundamental interactions in terms of gauge principle.
		Acquiring skills to carry out computation in Strong, Weak and Electromagnetic theory.
		Learning various techniques useful for particle physics phenomenology.
		Learning methods to compute physical observables which can tested in the laboratory.
Introduction to Phase Transition and Critical Phenomena	P455	This course teaches the students advanced concepts and methods in statistical mechanics crucial for the student to take up basic research work.
Biophysics	P456	This course teaches the students advanced concepts and methods in biophysics, with the aim to build their background for future research work in this area.
General Relativity and Cosmology	P457	This course teaches the students, advanced concepts and methods in general relativity crucial for the student for building their background for research work in general relativity and cosmology.
Soft Condensed Matter	P458	This course teaches the students advanced concepts and methods in soft matter physics, with the aim to build their background for future research work in this area.
Applied Nuclear Physics	P459	This course teaches the students advanced concepts and methods in applied nuclear physics, with the aim to build their background for future research work in this area.

Many Particle Physics	P460	This course teaches the students advanced concepts and methods in many particle physics, with the aim to build their background for future research work in this area.
Physics of Mesoscopic Systems	P461	This course teaches the students advanced concepts and methods in mesoscopic physics, with the aim to build their background for future research work in this area.
Introduction to Quantum Optics	P462	Learning about the coherent states, squeezed states and atom-photon interaction.
		Acquiring the knowledge of coherence and developing the quantum theory of atom-photon interaction.
		Developing the understanding of the quantum theory of dissipation.
		Understanding the quantum information in continuous variable systems.
		Learning the quantum state engineering.
		Learning about the cavity QED.
Astronomy and Astrophysics	P463	Learning about magnetohydrodynamics with applications to Astrophysical systems.
		Study of stellar structure and developing detailed understanding of structure of stars.
		Developing understanding of the models of galaxies.
		Acquiring knowledge of the accretion of matter due to a point mass.
		Developing introductory understanding of cosmology.
Plasma Physics and Magnetohydrodynamics	P464	This course teaches the students important concepts and methods in plasma physics and magneto hydrodynamics, with the aim to build their background for future research work in this area.
Biophysics	P465	Course is in the formulation stage
Quantum and Nanoelectronics	P466	This course teaches the students important concepts and methods in Nano electronics, with the aim to build their background for future research work in this area.

Nonlinear Physics, Chaos and Turbulence	P467	This course teaches the students important concepts and methods in classical nonlinear dynamics, with the aim to build their background for future research work in this area.
Magnetism and Superconductivity	P468	This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.
Density Functional Theory of Atoms, Molecules and Solids	P469	This course teaches the students important concepts and methods in density functional theory, with the aim to build their background for future research work in this area.
Quantum Field Theory II	P470	Understanding the Path Integral formulation of quantum field theory.
		Acquiring the knowledge of the regularisation methods and the renormalisation.
		Developing the understanding of spontaneous symmetry breaking and its implications.
		Learning the non-abelian gauge theories and their quantisation.
		Learning the renormalisation of the non-abelian gauge theories both in the symmetric and symmetry broken phase.
Quantum Information and Quantum Computation	P471	This course teaches the students important concepts and methods in quantum information and computation, with the aim to build their background for future research work in this area.
Experimental High Energy Physics	P472	This course teaches the students important concepts and methods in experimental high energy physics, with the aim to build their background for future research work in this area.
Experimental Technique	P473	This course teaches the students important concepts and methods in experimental techniques, with the aim to build their background for future research work in this area.
Introduction to Cosmology	P474	Learning about the cosmological model, the cosmological constant and the dark matter.
		Developing the understanding of the thermal history of the universe and its imprints on CMB.

		Understanding the horizon problem and its resolution by inflation.
		Acquiring the knowledge of the theory of cosmological perturbations.
		Studying the implications of the cosmological perturbation on the structure formation.
Soft Condensed Matter	P451	This course teaches the students advanced concepts and methods in soft matter physics, with the aim to build their background for future research work in this area.

(C) MINOR SUBJECTS in CHEMICAL SCIENCES

Sr. No.	Name of the Course	Course code
1	Chemistry-I	C101
2	Chemistry Laboratory-I	C141
3	Chemistry-II	C102
4	Chemistry Laboratory-II	C142
5	Basic Inorganic Chemistry	C201
6	Reaction Mechanism in Organic Chemistry	C203
7	Quantum Chemistry-I	C206
8	Mathematical methods for Chemists	C207
9	Physical Methods in Chemistry-I	C306
10	Thermodynamics and Electrochemistry	C307

COURSE OUTCOME OF MINOR SUBJECTS in CHEMICAL SCIENCES

Name of the Course	Course code	Course Outcome
Chemistry-I	C101	The basics of atomic and molecular structure and spectroscopy
		Thermodynamics of different chemical processes
		Kinetics of chemical reactions
Chemistry Laboratory-I	C141	Introduction to synthesis of small organic compounds

		Qualitative analysis of chemicals present in tea, coffee, fruits etc.
		Synthesis of simple drugs such as paracetamol
Chemistry-II	C102	Apply the fundamental principles of measurement, matter, atomic theory, chemical periodicity, chemical bonding, general chemical reactivity and solution chemistry to subsequent courses in science, engineering, technology.
		Students will be able to explain why chemistry is an integral activity for addressing social, economic, and environmental problems
		Students will be able to explore new areas of research in both chemistry and allied fields of science and technology after getting their concepts clear in Basic Chemistry
Chemistry Laboratory-II	C142	Introduction to quantitative analysis in chemistry.
		Students will learn basic concepts on electrochemistry
		Students will be given hands on practice on conductometry, polarimetry and flame photometry
		They will apply these concepts to estimate binding constant, solubility product etc.
Basic Inorganic Chemistry	C201	To understand basic facts and concepts in Chemistry while retaining the exciting aspects of Chemistry so as to develop interest in the study of chemistry as a discipline.
		To develop the ability to apply the principles of Chemistry.
		To appreciate the achievements in Chemistry and to know the role of Chemistry in nature and in society.
		To develop problem solving skills.

		To be familiarized with the emerging areas of Chemistry and their applications in various spheres of Chemical sciences and to apprise the students of its relevance in future studies.
		To be exposed to the different processes used in industries and their applications
Reaction Mechanism in Organic Chemistry	C203	Introduction of basic organic reactions (Substitutions, Additions & Eliminations) and writing organic reaction mechanisms
		Reactivity of unsaturated hydrocarbons (alkene, alkyne and aromatic)
		Understanding the role of substitutions to influence the rate of reactions
		Stereochemistry in organic chemistry: Chemoselectivity, Diastereoselectivity, Enantioselectivity, Stereospecificity, Stereoconvergence
		Introduction of asymmetric synthesis with and without asymmetric catalysts
Quantum Chemistry-I	C206	Understanding the need of Quantum mechanics based on failures of Classical mechanics.
		Learning the basic building blocks of Quantum Mechanics.
		Learning to use the mathematical structure of quantum mechanics in several systems comprising one or many quantum particles.
		Understanding the bridge between the mathematical structure of quantum mechanics and different spectroscopic techniques based on that.
Mathematical methods for Chemists	C207	Introduce the standard mathematical techniques that are typically used by Chemists.
		To learn how to apply mathematics to chemistry research.
		To learn how to use Fourier transform in different spectroscopy.

		The course, mostly differential equation is useful to learn quantum chemistry and chemical kinetics.
Physical Methods in Chemistry-I	C306	Understand the basics of absorption and fluorescence spectroscopy.
		Theoretical prediction of absorption maximum of some organic molecules.
		Identifying and distinguishing various type of electronic transition using solvent perturbation techniques.
		Understanding the concept of micropolarity and the importance of this parameter in spectroscopy
		Understanding some important photoprocessess such as electron transfer and energy transfer and their applications in energy related applications.
		Applications of fluorescence spectroscopy in detecting various analytes (Sensing applications)
Thermodynamics and Electrochemistry	C307	Understanding the laws of Thermodynamics and Phase equilibrium of multicomponent systems.
		Understanding the thermodynamics of surfaces and different adsorption isotherms of gases on solids.
		Key concepts for the Electrochemistry and applications of Electrochemistry.
		Key concepts of Statistical Thermodynamics.

(D) MINOR SUBJECTS in LIFE SCIENCES

Sr. No.	Course Name	Course No
1	Biology I: Science of Life	B101
2	Biology Laboratory-1	B141
3	Biology II: Cellular and Genetic basis of life	B102

4	Biology Laboratory-2	B142
5	Biochemistry	B202
6	Cell Biology	B204
7	Genetics	B205
8	Molecular Biology	B304
9	Evolutionary Biology	B306
10	Any one course from biology subjected to qualified prerequisite	Bx5x

COURSE OUTCOME OF MINOR SUBJECTS in LIFE SCIENCES

Course Name	Course No	Course Outcome
Biology I: Science of Life	B101	Understanding the origin and evolution of life.
		Fundamental understanding of the structure and function of the molecules of life.
		Fundamental understanding of the structure & function of cellular organelles.
Biology Laboratory-1	B141	Introduce to students analytical tools/approaches to study biomolecules and cell structure.
		Build basics of experimentation and data recording in biology labs
Biology II: Cellular and Genetic basis of life	B102	Understanding the principles of cellular mechanisms driving development of an organism.
		Key evolutionary concepts in Lamarckism, Darwinism and Speciation
		Understanding the genetic basis of inheritance
		Fundamental understanding of molecular Biology
Biology Laboratory-2	B142	Understand a microscope and various staining and microscopic techniques

		Knowledge of the basis of human blood groups (ABO)
		Experimental approaches to study cell growth and differentiation and Gene regulation
		Use of microscope to know various stages of cell division in mitosis and meiosis
Biochemistry	B202	Understanding the principles governing Protein structure & function
		Basic concepts on metabolism and their implications in living organisms
		Concept on signal transduction
		Implications in Evolution, Health and disease.
Cell Biology	B204	Understanding the basic principles governing cell structure and functions
		Biochemcial, biophysical, genetical basis of cell and its response
		Key concepts in maintenance of cell structure
		Evolution of cell organelles, importance in health and disease.
Genetics	B205	Understanding the basic principles of inheritance
		Knowledge of genetic disease mechanism
		Comprehension of monogenic, polygenic and multifactorial diseases
		Application in health and diseases
Molecular Biology	B304	Understanding the key components of cell involved in central dogma of molecular biology.
		Understanding of structure-function of genetic material, replication, repair, transcription and translation.
Evolutionary Biology	B306	Understanding how life originated on the planet
		Understanding the formation of species and underlying genetic diversity
		Understanding biology from an organismal point of view and why some species evolve slowly while others evolve rapidly
		Understanding systematic relationships between organisms using phylogenetic tools

Any one course from biology subjected to qualified prerequisite	Bx5x	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(E) MINOR SUBJECTS in MATHEMATICAL SCIENCES

Sr. No.	Name of the Course	Course code
1	Mathematics-I	M101
2	Mathematics-II	M102
3	Real Analysis	M201
4	Group Theory	M202
5	Metric Spaces	M204
6	Linear Algebra	M205
7	Probability Theory	M206
8	Differential Equations	M303

COURSE OUTCOME OF MINOR SUBJECTS in MATHEMATICAL SCIENCES

Name of the Course	Course code	Course Outcome
Mathematics-I	M101	Expects students to learn how to prove theorems, expressing mathematical objects, and understand the construction of natural numbers and symmetry of plane figures.
Mathematics-II	M102	Upon successful completion of the course students will become aware of some basic properties of real line and real valued functions.
Real Analysis	M201	Knowledge on Continuity differentiable and Riemann integration theory. Sequence and series and it's application to numerical analysis.
Group Theory	M202	Upon successful completion of the course students will be able to understand the notion of symmetries in the language of groups. Furthermore, students will become aware of various properties of groups and subgroups.

Metric Spaces	M204	Upon successful completion of the course students will become aware about generalisation of euclidean distance on arbitrary sets and vari-ous properties of functions defined on them.
Linear Algebra	M205	Upon successful completion of the course students will learn the relation between linear transformations and matrices. Moreover, student will also learn various fundamental results of matrices, namely, diagonalisa-tion, triangulation and primary decomposition theorem.
Probability Theory	M206	Students will be introduced to the basic theory of probability starting from axiomatic definition of probability up to limit theorems of probability.
Differential Equations	M303	This course starts with the origin and applications of differential equations and discusses many solution techniques such as separation of vari-able, variation of parameter, annihilator method and Frobenious method, etc. Then it introduces basic theory of existence and uniqueness for the sys-tem of first order ODEs which is essential for many branches of mathematics. This course also gives a glimpse how to analyze the behavior of solutions (maximum principle, stability, asymptotic stability, etc.).
		This course ends with an introduction to partial differential equations and method of charac-teristics, a technique to solve first order partial differential equations. Upon successful completion of this course the student will be able to model some practical situations into ordinary differential equations or partial differential equations and analyze the solution to get information about the parameters involved in the model.

SCHOOL OF HUMANITIES

(A) Core Courses:

1. Semester I

Sr.No.	Name of the Course	Course code
1	Technical Communication I	H109
2	Introduction to Sociology	H133

2. Semester II

Sr.No.	Name of the Course	Course code
1	Technical Communication II	H110
2	Introduction to Economics	H101

(A) Electives:

Sr.No.	Name of the Course	Course code
1	Introduction to Psychology	H225
2	Environmental Economics and Environmental Impact Assessment	H201
3	Introduction to Innovation System	H239
4	Life and Community in Urban World	H238
5	Organizational Behaviour	H227
6	Sociology of Science and Technology	H235
7	Perspectives on Indian Society	H236
8	Science Communication and Citizen	H237
9	The City in Modern Fiction	HS 210
10	Speculative Fiction	H 209

Course Outcome:

(A) Core Courses

1. Semester I

Name of the Courses	Courses Code	Course Outcome
Technical Communication I	H109	Connecting Language and cultural contexts.
		Understand the process behind writing.
		Learn to critically engage with texts.
Introduction to Sociology	H133	Sociological insights that are meaningful and of practical importance to students
		Meaningfully relate with the immediate social environment.
		From a sociological perspective, observe those features which are common to all cultures and be able to assess them in the context of one's own unique setting.
		develop an objective view of social reality
		understand the structure and functioning of the society and its consequent processes of social change

2. Semester II

Name of the Courses	Courses Code	Course Outcome
Technical Communication II	H110	be familiar with the essentials of effective communication
		know the different tools of effective technical communication
		understand the importance of staging the argument, and know various institutional / disciplinary norms
Introduction to Economics	H101	familiarity with the basic concepts of economy such as: Price determination, policies for controlling inflation, role of government, sources of revenue and expenditure of the Union, State and Local government and Balance of Payment

(A) Electives

Name of the Courses	Courses Code	Course Outcome
Introduction to Psychology	H225	better understanding of human behavior.
		differentiate between scientific and non-scientific information about human behavior and mental processes.
		understand the working of their own conscious behavior and interpersonal relationship.
		apply psychological principles everyday life situations.
Environmental Economics and Environmental Impact Assessment	H201	Students would get to know the interaction between economy and environment
		Economic tools used for controlling environmental degradation
		Understanding the need for environmental impact assessment of developmental projects and its procedure
Introduction to Innovation System	H239	Appreciate the imperative of innovation within society.
		Critically analyze different types of innovation.
		Use evidence to critically challenge innovation practices. Identify possible changes in innovation system.
Life and Community in Urban World	H238	Formulate effective argumentation on city life.
		Explain and evaluate historical and contemporary urbanization processes.
		Demonstrate understanding of the diverse nature of urban populations and social problems these populations.
		Identify ways of creating sustainable, and efficient built environments.
Organizational Behaviour	H227	demonstrate knowledge organizational behavior theories and concepts.
		explain the challenges that managers and leaders face in contemporary organizations
		critically evaluate organizational practices and the impact on work behavior and performance.
		describe how the individual, groups and organization level variables interact and influence major organizational outcomes.

Sociology of Science and Technology	H235	Familiarization with the societal perspective in study of science and technology
		provide a basic understanding of issues that fall under broader spectrum of inter-relationship between science & technology and society
Perspectives on Indian Society	H236	Understanding of the basic features of Indian Society: both past and contemporary.
		To acquaint the Students about some of the major social Institutions from Sociological Perspectives
		Understanding of various processes of Social Change and Problems of Indian Society.
Science Communication and Citizen	H237	Evaluate the role of communication in science.
		Provide constructive analysis of popular science communication in a variety of real-world settings.
		Identify target audience and define applicable message.
		Develop a sense of the social and political context for science communication.
The City in Modern Fiction	HS 210	To learn to read critically.
		To learn to contextualize concepts and themes using the framework of the 'modern.'
		To learn structural elements, such as plot, setting, characters, techniques of exposition, that underpins fiction.
Speculative Fiction	H209	the literary, social, political and genre importance of Speculative Fiction in the contemporary times as well as historically
		a detailed overview of the way Speculative Fiction has developed historically,
		some important works in Speculative Fiction , and the rich diversity in the field,
		not just the Western tradition of Speculative Fiction, but also the Indian tradition of Speculative Fiction, from ancient times to the present
		some of the oft-occurring themes such as utopias, dystopias, and issues of gender, class, environment, multiculturalism, technology, myth-making, alternate history, etc.

SCHOOL of COMPUTER SCIENCES

(A) Core Courses:

Sr. No.	Name of the Course	Course code
1	Programming and Data Structures Lab – I	CS141
2	Programming and Data Structures Lab – II	CS142
3	Theory of Computation	CS201
4	Discrete Structures and Computation	CS202
5	Design and Analysis of Algorithms	CS301

(B) Electives:

Sr. No.	Name of the Course	Course code
1	Modern Cryptology	CS451
2	Algorithmic Coding Theory	CS452
3	Complexity Theory	CS453
4	Linear Programming and Combinatorial Optimization	CS454
5	Distributed Network Algorithms	CS455

Course Outcome:

(A) Core Courses

Name of the Courses	Courses Code	Course Outcome
Programming and Data Structures Lab – I	CS141	Learn the fundamentals of programming.
		Write code for basic programming tasks.
		Create new data types suitable to the requirements
Programming and Data Structures Lab – II	CS142	Learn the fundamentals of data structures
		Write efficient codes for a wide range of programming tasks.
Theory of Computation	CS201	Learn the Mathematical Foundations of computers
		Construct abstract computational machines for basic tasks.
		Understand principles of programming languages and compilers
Discrete Structures and	CS202	Solve problems related to fundamentals of mathematical logic.

Computation		Model and solve practical problems using graph-theoretic techniques.
		Solve problems related to counting and combinatorics.
Design and Analysis of Algorithms	CS301	Learn the basics of algorithms.
		Measure the efficiency of candidate algorithms.
		Write new algorithms for basic computational tasks.

(B) Electives

Name of the Courses	Courses Code	Course Outcome
Modern Cryptology	CS451	Learn the basics of information security
		Write codes for implementing security protocols.
		Analyze candidate information security solutions.
Algorithmic Coding Theory	CS452	Learn the fundamentals of information theory.
		Write a new data compression algorithm
		Create error resilient storage solutions.
Complexity Theory	CS453	Learn the efficiency limits of computations.
		Derandomizing randomized algorithms
Linear Programming and Combinatorial Optimization	CS454	Solve linear optimization problems
		Model certain game theoretic problems as linear programming problems.
Distributed Network Algorithms	CS455	Design new algorithms for distributed networks
		Find the efficiency limit of distributed algorithms.

BACK TO MAIN

M.Sc. NURSING

(PROGRAM CODE: HLTH15)

1. Course under TMC

Program code: HLTH15	**Program Specific Outcome**	Designed to develop nurse leaders who will assume roles as Nurse Specialist, Nurse Educator, Administrator and Researcher.
		Develop ability to contribute to the knowledge of profession through research development and validation of nursing theories.

Core courses

Sr. no	Course Name	Course code
1	ADVANCED NURSING PRACTICE	09HLTH15-001-C
2	CLINICAL SPECIALITY – I MEDICAL SURGICAL NURSING	09HLTH15-002-C
3	NURSING EDUCATION	09HLTH15-003-C
4	NURSING MANAGEMENT	09-HLTH15-004-C
5	NURSING RESEARCH AND STATISTICS	09HLTH15-005-C
6	CLINICAL SPECIALITY- II MEDICAL SURGICAL NURSING – ONCOLOGY NURSING	09HLTH15-006-C

Course Outcome

Course Name	Course code	Course outcome
ADVANCED NURSING PRACTICE	09HLTH15-001-C	Designed to develop an understanding of concepts and constructs and theoreticalbasis of advanced nursing practice
		Ability to critically analyse different theories of nursing and otherdisciplines.
		Develop advance Nurse Practitioner who is assumeexpanded and extended role.
CLINICAL SPECIALITY – I MEDICAL SURGICAL NURSING	09HLTH15-002-C	Designed to assist students in developing expertise and in depth knowledge in the field of Medical Surgical Nursing.
		It will help students to appreciate the patient as a holistic individual and develop skill to function as a specialized Medical-Surgical Nurse.
		Enable the students to function as educator, manager and researcher in the field of Medical Surgical Nursing.

NURSING EDUCATION	09HLTH15-003-C	Designed to assist students to develop a broad understanding of fundamental principles, trends and issues related to education and nursing education.
		Provide opportunity to students to understand, appreciate and acquire skills in teaching and evaluation, curriculum development, implementation, maintenance of standards and accreditation of various nursing educational programs.
		Develop and/or adopt model of nursing service and nursing education collaboration
NURSING MANAGEMENT	09-HLTH15-004-C	Designed to assist students to develop a broad understanding of Principles, concepts, trends and issues related to nursing management.
		Provide opportunity to students to understand, appreciate and acquire skills in planning, supervision and management of nursing services at different levels to provide quality nursing service.
NURSING RESEARCH AND STATISTICS	09HLTH15-005-C	Designed to assist the students to acquire an understanding of the research methodology and statistical methods as a basis for identifying research problem, planning and implementing a research plan.
		Enable the students to evaluate research studies and utilize research findings to improve quality of nursing practice, education and management.
		Develop skills in preparing research proposal and implementation of scientificresearch process.
CLINICAL SPECIALITY- II MEDICAL SURGICAL NURSING – ONCOLOGY NURSING	09HLTH15-006-C	Designed to assist students in developing expertise and in-depth understandingin the field of oncology Nursing.
		Develop advanced skills for Nursingintervention in various oncological conditions.
		Enable the student to function as oncologynurse practitioner/specialist and provide quality care.

BACK TO MAIN

POST GRADUATE DIPLOMA IN FUSION IMAGING TECHNOLOGY
(PGDFIT)
UNDER TMC
(PROGRAM CODE: HLTH16)

Course Structure:

I. Courses at TMC

Program Code : HLTH16	Programme Specific Outcome	To develop highly skilled human resource with specialization in Nuclear medicine and fusion imaging science and technology to render quality patient service and related research in nuclear medicine.

(A) CORE COURSES
Paper 1: Basic Sciences in Nuclear Medicine

Sr. No.	Name of the Course	Course code
1	Basic physics in nuclear medicine	09-HLTHI6-001-C
2	Basic chemistry in nuclear medicine	09-HLTHI6-002-C
3	Basic mathematics and statistics in nuclear medicine	09-HLTHI6-003-C
4	Basic computer relevant in nuclear medicine	09-HLTHI6-004-C
5	Basic biology in nuclear medicine	09-HLTHI6-005-C

Paper 2: Radiation Safety, Radiation biology and Radiopharmacy

Sr. No.	Name of the Course	Course code
1	Radiation Biology	09-HLTHI6-006-C
2	Radiation protection	09-HLTHI6-007-C
3	Radio pharmacy and radiopharmaceuticals	09-HLTHI6-008-C

Paper 3: Instrumentation in Nuclear Medicine and Fusion Imaging

Sr. No.	Name of the Course	Course code
1	Non imaging equipment used in Nuclear medicine	09-HLTHI6-009-C
2	Imaging equipment used in Nuclear Medicine	09-HLTHI6-010-C
3	Calibration and Quality Control Of Imaging Equipments Used In Nuclear Medicine	09-HLTHI6-011-C
4	Computer and Computer system used in Nuclear Medicine	09-HLTHI6-012-C

Paper 4: Clinical Nuclear Medicine and Fusion Technology

Sr. No.	Name of the Course	Course code
1	Human anatomy and physiology relevant in nuclear medicine	09-HLTHI6-013-C
2	Scintigraphy Study and data processing	09-HLTHI6-014-C
3	Therapeutic Nuclear Medicine technique	09-HLTHI6-015-C
4	Hospital administration and patient care	09-HLTHI6-016-C

(B) PRACTICALS

Sr. No.	Name of the Course	Course code
1	Practical in radiation protection, radiopharmacy and instrumentation in Nuclear medicine	09-HLTHI6-001-P
2	Practical in clinical Nuclear Medicine and Fusion Technology	09-HLTHI6-002-P

Course Outcomes:

(A) CORE COURSES

Paper 1: Basic Sciences in Nuclear Medicine

Name of the Course	Course code	Course Outcome
Basic physics in nuclear medicine	09-HLTHI6-001-C	At the end of the program, the student will be able to apply principles of basic science concepts in understanding, analysis and prediction of physical systems.
Basic chemistry in nuclear medicine	09-HLTHI6-002-C	At the end of the program, the student will be able to apply principles of basic science concepts in understanding, analysis and prediction of Chemical systems.
Basic mathematics and statistics in nuclear medicine	09-HLTHI6-003-C	At the end of the program, the student will be able to apply principles of basic science concepts in understanding, analysis and prediction of Mathematical systems.
Basic computer relevant in nuclear medicine	09-HLTHI6-004-C	At the end of the program, the student will be able to apply principles of basic science concepts in understanding, analysis and prediction of computational systems.
Basic biology in nuclear medicine	09-HLTHI6-005-C	At the end of the program, the student will be able to apply principles of basic science concepts in understanding, analysis and prediction of Biological systems.

Paper 2: Radiation Safety, Radiation biology and Radiopharmacy

Name of the Course	Course code	Course Outcome
Radiation Biology	09-HLTHI6-006-C	To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application radiation induced effects to the biological systems.
Radiation protection	09-HLTHI6-007-C	To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application of radiation protection concepts in medicine in general and nuclear medicine in particular.
Radio pharmacy and radiopharmaceuticals	09-HLTHI6-008-C	To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application of chemical sciences with pharmaceutical science applied in radiation medicine.

Paper 3: Instrumentation in Nuclear Medicine and Fusion Imaging

Name of the Course	Course code	Course Outcome
Non imaging equipment used in Nuclear medicine	09-HLTHI6-009-C	To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application of Physics and instrumentation used in radiation counting and measurment.
Imaging equipment used in Nuclear Medicine	09-HLTHI6-010-C	To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application of physics and instrumentation used in radiation enabled medical imaging using various equipments like CT, PET. SPECT, MRI ect.
Calibration and Quality Control Of Imaging Equipments Used In Nuclear Medicine	09-HLTHI6-011-C	To introduce subjects/concepts/ideas for implementation and performance of quality control of various medical imaging devices like CT, PET. SPECT, MRI and fusion equipments ect.
Computer and Computer system used in Nuclear Medicine	09-HLTHI6-012-C	To introduce concepts and architecture of computers used in nuclear medicine for the purpose of image acquisition, image reconstruction, image processing, quantification, archival and retrieval of images.

Paper 4: Clinical Nuclear Medicine and Fusion Technology

Name of the Course	Course code	Course Outcome
Human anatomy and physiology relevant in nuclear medicine	09-HLTHI6-013-C	To understand and apply the basic concepts of human anatomy and physiology related to nuclear medicine enabled diagnosis and treatment of various clinical conditions.
Scintigraphy Study and data processing	09-HLTHI6-014-C	To thoroughly understand the entire process of nuclear medicine imaging i.e. patient preparation, radiation safety, image acquisition, image processing and pitfalls in imaging and image interpretation for various Nuclear medicine imaging procedures.
Therapeutic Nuclear Medicine technique	09-HLTHI6-015-C	To thoroughly understand the entire process of nuclear medicine therapy i.e. patient preparation, radiation safety, dose administration, post therapeutic complications etc. in various Nuclear medicine therapeutic procedures.
Hospital administration and patient care	09-HLTHI6-016-C	To develop human resource with specialization in theoretical and practical aspect of hospital administration, patient care and ethics related to patient care to enable him/her to deliver quality healthcare services to the patient

(B) PRACTICALS

Name of the Course	Course code	Course Outcome
Practical in radiation protection, radiopharmacy and instrumentation in Nuclear medicine	09-HLTHI6-001-P	To thoroughly understand and execute the entire process of quality assurance in nuclear medicine i.e. quality control of radiopharmaceuticals and various instrument used in nuclearmedicine as well as interoperation of quality control reports.
Practical in clinical Nuclear Medicine and Fusion Technology	09-HLTHI6-002-P	To thoroughly understand and execute the entire process of nuclear medicine diagnostic and therapeutic procedure.

BACK TO MAIN

M. Sc. in CLINICAL RESEARCH (Program Code: HLTH17)

I. Courses at TMC

Program Code : HLTH17	Programme Specific Outcome	Each student should complete the training programme as per the modules planned.
		All the necessary training imparted by classroom lectures and on the job training while being posted in various DMGs in TMH and ACTREC, and external postings are mandatory.
		The student is expected to participate in the regular evaluation exams after each module and university exams at end of 1 year and 2 years of the program to be followed by 1 year of compulsory Internship.
		The training would help the student to acquire an understanding of clinical research and drug development process in general and specific in oncology clinical research.
		Feedback is received from the stakeholders in the 3 years of training and internship. Students are also engaged in giving us their feedback of the program.

Course Structure:

1. **MODULE – 1**

Sr. No.	Name of the Course	Course code
1	BASICS OF PHARMACY, DRUG DISCOVERY AND DEVELOPMENT	09-HLTH17-001-C
2	ETHICS	09-HLTH17-002-C

2. **MODULE – 2**

Sr. No.	Name of the Course	Course code
1	CLINICAL TRIAL DESIGN	09-HLTH17-003-C

3. MODULE – 3

Sr. No.	Name of the Course	Course code
1	Roles and Responsibilities of various Stakeholders in Clinical Research.	09-HLTH17-004-C

4. MODULE – 4

Sr. No.	Name of the Course	Course code
1	Quality Control/Quality Assurance in Clinical Research and Pharmacovigilance.	09-HLTH17-005-C

5. MODULE – 5

Sr. No.	Name of the Course	Course code
1	Clinical Data Management	09-HLTH17-006-C

6. MODULE – 6

Sr. No.	Name of the Course	Course code
1	EPIDEMIOLOGICAL STUDIES	09-HLTH17-007-C

7. SPECIAL MODULE

Sr. No.	Name of the Course	Course code
1	Newer techniques in Clinical research	09-HLTH17-008-C
2	Communication Skills	09-HLTH17-009-C
3	Clinical Research in Vaccines, Medical Devises.	09-HLTH17-0010-C
4	Investigator-initiated studies – special issues	09-HLTH17-0011-C
5	Studies in alternative systems – Ayurveda.	09-HLTH17-0012-C

Course Outcomes.

1. **MODULE 1**

Name of the Course	**Course code**	**Course Outcome**
BASICS OF PHARMACY, DRUG DISCOVERY AND DEVELOPMENT	09-HLTH17-001-C	To gain basic knowledge about general medicine, various cancers and its management, how drugs are discovered in the laboratory and in the clinics, what is the importance of conducting research, how clinical research is conducted. Students also learn of important medical terminologies and are introduced to treatment modalities and pharmacological concepts in treatment and management of various diseases.
ETHICS	09-HLTH17-002-C	This topic introduces the events in history that led to evolution of Ethics in Clinical Research. It also trains the students on various ethical principles and guidelines which are mandatory to be followed by every clinical research profession.
		It trains the students to rules and regulations to be followed in India and also international guidelines for conducting ethical research, including the informed consent process.
		This module prepares the background knowledge base for becoming a trained clinical research person who can support all types of research activities.
		Students are also taught the Indian regulations and some international regulations in the conduct of clinical trials.

2. MODULE 2

Name of the Course	Course code	Course Outcome
CLINICAL TRIAL DESIGN	09-HLTH17-003-C	This module introduces the students to the study protocol and how to write a protocol, what are the elements of a good protocol.
		The sessions on statistics prepares the students with basic knowledge of statistical designs and tests which are applied while generating clinical trial data.
		Sessions are devoted to evaluation of safety parameters in a clinical trial.
		Students are assigned protocols for which they have to design the Informed Consent Documents, in the format which meets the guidelines and regulations.
		To understand and apply the knowledge of biostatistics to clinical work To understand and interpret available literature relevant to the clinical trials.

3. MODULE 3

Name of the Course	Course code	Course Outcome
Roles and Responsibilities of various Stakeholders in Clinical Research	09-HLTH17-004-C	To understand the roles of Ethics Committee members and their responsibilities while reviewing the protocol proposals. The need to have SOPs for their functioning and how to document minutes of the meeting and responses to Investigators.
		To understand the role and responsibilities for Good Clinical Practices while being an Investigator for a clinical trial. The role and responsibilities of the Clinical Research Coordinator.
		How to initiate a study at a site, how to monitor the clinical trials, document their findings of the activities and take corrective and preventive actions.
		To understand how to write a monitoring visit report.

4. MODULE 4

Name of the Course	Course code	Course Outcome
Quality Control/Quality Assurance in Clinical Research and Pharmacovigilance	09-HLTH17-005-C	To understand what is a study Audit. How audits are conducted and reported.
		To understand how to Audit all study related documents, including study files, essential documents, and informed consents.
		To understand and learn how to take corrective and preventive actions on findings of an Audit (CAPA process)
		To understand how to plan for an inspection and actions needed to facilitate the inspection.
		To learn and understand how to conduct Pharmacovigilance (PV) during clinical trials and in the post- marketing period of a new drug. To learn how to evaluate various adverse events which get reported in clinical trials and after marketing of a drug. Management of reporting timelines for serious adverse events, as per Indian Regulations.

5. MODULE 5

Name of the Course	Course code	Course Outcome
Clinical Data Management in Clinical Research	09-HLTH17-006-C	To understand various aspects of data management after clinical trial data is generated.
		They learn of the various standards to be applied for data management, quality controls and assurance of the data that is generated.
		How to write a study report after data is generated.
		How to prepare a report for publication in journals or poster presentations or conference presentations.

6. **MODULE 6**

Name of the Course	Course code	Course Outcome
EPIDEMIOLOGICAL STUDIES	09-HLTH17-007-C	To understand various types of Epidemiological studies.
		To learn how the data helps in disease prevention.
		To understand the importance of screening and public health studies

7. **SPECIAL MODULE**

Name of the Course	Course code	Course Outcome
Newer techniques in Clinical research	09-HLTH17-008-C	Students get to know of newer developments in clinical research tools that can be used.
Communication skills	09-HLTH17-009-C	Clinical research professionals require skills in verbal and written communications. They also need to learn how to present themselves at hospitals and with site study team members.
		To learn how to present at conferences by using various techniques for making a presentation, e.g. power-point presentations.
		Clinical Research professionals learn how to interact with peers, juniors, doctors and other site staff. Some skills are required while interacting with patients too. All this is covered in this class.
Clinical Research in Vaccines, Medical Devices	09-HLTH17-0010-C	To appraise and sensitise students of how clinical research needs to be conducted with Vaccines, Medical Devices.
		To learn what rules and regulations and guidelines govern studies with vaccines and medical devices.
Investigator-initiated studies – special issues	09-HLTH17-0011-C	To learn and understand how academic studies are conducted.
		How to conduct multi-centre academic studies.
		How to manage such investigator initiated studies, including planning for adequate funds for such studies.
Studies in alternative systems – Ayurveda.	09-HLTH17-0012-C	To appraise and sensitise students of how clinical research needs to be conducted with Herbal/Ayurvedic medicines.
		To learn what rules and regulations and guidelines govern studies with herbal and Ayurvedic drugs.

BACK TO MAIN

INTEGRATED Ph.D. ENGINEERING SCIENCES

(SINGLE DEGREE)

(Program Code: ENGG18)

Course Structure:

I. Courses at BARC

Program Code : ENGG18	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Accelerator Physics and Technology	EN501
2	Engineering Mathematics	EN502-505
3	Health Physics and Rad & Indl Safety	EN506
4	Nuclear Fuel Cycle Technology	EN508
5	NPP & Advanced Reactor Concepts	EN509
6	Reactor Physics and Engineering	EN510

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Accelerator Physics and Technology	EN501	The course introduces basic concepts of accelerator physics, Vacuum and cryogenic systems
		The course discusses concepts of storage ring physics, RF linear accelerators, and principles and instrumentation related to beam diagnostics.
		The course also introduces different types of accelerators and basic concepts of synchrotron radiation sources
Engineering Mathematics	EN502-505	Advanced knowledge in computational data analysis, data fitting and error analysis

		Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
Health Physics and Rad & Indl Safety	EN506	Learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Nuclear Fuel Cycle Technology	EN508	Familiarisation with font and back end of nuclear fuel cycle technology
		Knowledge of radioactive waste generation on nuclear fuel burning and its processing
NPP & Advanced Reactor Concepts	EN509	Good understanding of Thermal, Fast Breeder and advanced reactor physics concepts
		Familiarization with reactor physics design challenges
Reactor Physics and Engineering	EN510	Learn neutron physics, reactor physics; reactor kinetics and reactor control, all needed for working with nuclear reactors.

(A) MECHANICAL COURSES

(A1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Code design for PVP	EN610
2	Computational fluid Dynamics and Heat Transfer	EN611
3	Finite Element Method	EN621
4	Fracture Mechanics	EN622
5	Mechanics of Solids	EN624

(A2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Machine Design	EN711
4	Material Science in Nuclear Engineering	EN712
5	Multi-scale material modelling	EN715
6	Nuclear Emergencies	EN716
7	Reliability Engineering	EN718
8	Vibration	EN721

(A3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(A1) Core Engineering

Name of the Course	Course code	Course Outcome
Code design for PVP	EN610	Basis of ASME Sec.VIII and Sec.III eqns. for Pressure Vessel and Piping Design
		Nozzle openings, Vessel design under ext. pressure
		ANSI / ASME B31.1 and B31.3 piping code
		NDE Examination of welds, Acceptance standard
Computational fluid Dynamics and Heat Transfer	EN611	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer

Finite Element Method	EN621	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Fracture Mechanics	EN622	LEFM and EPFM, Material fracture props. determination
		PTS event of RPV and Master Curve Concept
		Computational Fracture Mechanics
		Fracture Mechanisms
Mechanics of Solids	EN624	Principles and Fundamental Equations of Elasticity
		Analysis of Stress and Strain, Thermal Stresses
		Introduction to Plasticity
		Theory of Plates and Shells

(A2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Programming Language C++
		Parallel Programming
		Scientific Visualization
		Artificial Neural Network
Fluid Power Technology	EN709	Basic principles of hydraulics and pneumatics, pressure control
		Fluid power pumps and compressors, Fluid experiments
		Directional and flow control valves, Fluid Logic & Control
		Advanced Hydraulic Control Circuits, Electronics and Instrumentation for Hydraulics
Machine Design	EN711	Basic Principles of Machine Design, Design and Drawing Practices
		Sealing Methods
		Special Dimensional Inspection Techniques
		Advanced Manufacturing Techniques
Material Science in Nuclear Engineering		Metallurgy of steels
		Nuclear Materials

	EN712	Advanced Polymeric materials and Composites
		Corrosion
Multi-scale material modelling	EN715	Atomistic models: Molecular dynamics, Monte Carlo methods
		Inter-atomic potentials, Mesoscopic methods
		Modeling at microscale
		Bridging the scale gaps between different simulation levels
Nuclear Emergencies	EN716	Radiation Shielding, Nuclear Waste Management
		Nuclear Accidents/emergencies, Effects of Hiroshima & Nagasaki bombing
		Medical decontamination with demonstration
		Monitoring of High radiation field area
Reliability Engineering	EN718	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Vibration	EN721	Single and Multi-degree-of-freedom Systems, Free vibration
		Response of Systems To Ground Motion: Earthquake motion
		Flow Induced Vibration
		Vibration Measurement and Signal Analysis

(A3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
MiniProject		To provide a hands-on experience of working in an

MiniProject	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee

(B) CHEMICAL ENGINEERING COURSES

(B1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Chemical Reaction Engineering	EN601
2	Advanced Mass Transfer	EN604
3	Code design for PVP	EN610
4	Computational Fluid Dynamics and Heat Transfer	EN611
5	Nuclear Chemical Engineering	EN628
6	Process Dynamics and Control	EN634
7	Process Modeling, Simulation and Optimization	EN635

(B2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Fluid Power Technology	EN709
3	Material Science in Nuclear Engineering	EN712
4	Membrane Technology	EN714

(B3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591

2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(B1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Chemical Reaction Engineering	EN601	Fundamentals of Non-ideal reactors & RTD studies
		Understanding Non-isothermal effects & dynamical behaviour
		Overview of Heterogeneous reactions
		Approaches in Advanced reaction engineering & reactor design
Advanced Mass Transfer	EN604	Understanding Mass transfer with and without chemical reactions
		Rate based approaches for design
		Selection and design of various contacting equipment
		Process intensification approaches
Code design for PVP	EN610	Overview of Theories for pressure vessel design
		ASME Sec. VIII Div. 1 and Div - II equations
		Pressure vessel design as per ASME
		Design of piping as per B31.1 piping code.
Computational Fluid Dynamics and Heat Transfer	EN611	Understanding Kinematics of fluid flow and governing equations
		Classification of Partial Differential Equations & their discretization
		Convective heat transfer for internal and external flows
		Numerical Solution of fluid flow and heat transfer equations
Nuclear Chemical Engineering	EN628	Overview of Recovery and processing of nuclear materials
		Uranium conversion and reconversion

		Isotope Separation
		Nuclear Waste Management
Process Dynamics and Control	EN634	Introduction to process control & control loop dynamics
		Fundamentals of state-space controls, state, measurement equations
		General solution of the state equation
		Multi-variable controls, de-coupling, relative gain array
Process Modeling, Simulation and Optimization	EN635	Formulation of Dynamic and steady state models
		Flow sheet Analysis & Plant Simulation
		General Approaches for Non-Linear Systems
		Plant optimisation by Genetic Algorithms and Neural Nets

(B2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Understanding Programming Language C++
		Finite difference, finite volume, finite element discretization, grid generation, artificial neural network
		Parallel Programming, Message Passing Interface and MPI communications
		Scientific Visualization methods
Fluid Power Technology	EN709	Basic principles of Hydraulics and pneumatics
		Properties of hydraulic fluids and pneumatic air
		Roto-dynamic pumps, pressure and flow control
		Approaches in Hydraulic Circuit Design
Material Science in Nuclear Engineering	EN712	Overview of Nuclear Materials & their classifications
		Structure and properties of nuclear materials
		Processing of Nuclear Materials

		Material characterization techniques
Membrane Technology	EN714	Overview of Novel Membranes
		Preparation and Characterization
		Membrane Technologies
		Applications of Membrane Technology

(B3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Science and Engineering

(C) METALLURGY

(C1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Corrosion	EN615

2	Extractive Metallurgy	EN620
3	Mechanical Metallurgy	EN623
4	Nuclear Materials	EN628
5	Nuclear Metallurgy	EN629
6	Physical Metallurgy	EN630
7	Process Control & Instrumentation	EN631

(C2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Computational Techniques	EN701
2	Digital Signal Processing & Image Processing	EN706
3	Image processing and Machine Vision	EN710
4	Materials Characterization	EN713
5	Multi scale Material Modeling	EN715
6	Nuclear Chemical Engineering	EN628
7	Nuclear Emergencies	EN716
8	Welding Science & Technology	EN723

(C3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(C1) Core Engineering

Name of the Course	Course code	Course Outcome
Corrosion	EN615	Understanding electrochemical theory of corrosion & corrosion basics
		General principles of corrosion control
		Forms of corrosion and its mitigation
		Corrosion problems in nuclear industry and its mitigation
Extractive Metallurgy	EN620	Thermodynamics and kinetics of metal extraction
		Advanced material processing techniques
		Process metallurgy of rare metals, special materials and alloys
		Process metallurgy of U, Th, Pu, Be, Zr, Hf, Nb, Ta & rare earths
Mechanical Metallurgy	EN623	Exposure to stress tensor, state of stress, principal stress, hydrostatic, deviatoric stress
		Dislocations and deformation behaviour
		Creep & creep law, deformation mechanism map
		Fracture mechanics and fatigue of metals
Nuclear Materials	EN628	Vacuum melting & solidification, controlling casting defects of U, Zr and Ti alloys
		Cold & hot working, dynamic recovery, recrystallization of fuel tube, texture microstructure control
		Powder metallurgy of oxide, mixed oxide, carbide, intermetallic nuclear fuel material
		Applications of powder metallurgy in applications relevant to DAE
Nuclear Metallurgy	EN629	Fabrication of different types of fuel for research and power reactors

		Health physics, radioactivity and safety aspects of Pu handling
		Effects of irradiation on nuclear fuel and structural materials, hydriding related problems in Zr alloys
		Post irradiation examination (PIE) of nuclear fuel and structural material
Physical Metallurgy	EN630	Understanding basics of crystallography, crystal defects during irradiation
		Thermodynamics, phase equilibria & phase transformation
		Diffusion mechanism, equations & solutions
		Recovery, Recrystalization and Grain Growth
Process Control & Instrumentation	EN631	Understanding basic principles of measurement
		Sensors, transducers & transmission methods for pressure, vacuum, flow, level
		Principles of Automatic Control Systems
		Fail safe principles, simple logic circuits, ladder circuits for control action

(C2) Electives

Name of the Course	Course code	Course Outcome
Advanced Computational Techniques	EN701	Exposure to programming languages: C and C++
		Application of finite difference, finite volume, finite element techniques, ANN etc. in DAE
		Introduction to parallel programming concepts
		Data storage & visualisation techniques and case studies
Digital Signal Processing & Image Processing	EN706	Introduction to digital signal processing system & applications
		Discrete Fourier transform, fast Fourier transform

		Image processing, image enhancement, image segmentation & analysis, morphological operations
Image processing and Machine Vision	EN710	Introduction to digital image model representation, image sensor, digitizer, computer, standard file format
		Image enhancement segmentation and analysis, restoration
		Morphological operations and image compression
		Machine vision & introduction to image understanding
Materials Characterization	EN713	Introduction to microscopy techniques: optical, SEM, TEM, AFM, STEM, EBSD, FIM
		XRD and applications, basics of SIMS, RBS
		Analytical TEM, chemical analysis in materials science
		Thermal expansion and conductivity, TGA/DTA/DSC, mechanical properties
Multi scale Material Modeling	EN715	Introduction to types of models and multiscale approaches
		Atomistic models – molecular dynamics
		Basics of Monte Carlo methods
		Analysis of simulation results, bridging scale gap between different simulation levels
Nuclear Chemical Engineering	EN628	Recovery & processing of U, Th, Zr, rare earths from from ores / intermediates
		Uranium Conversion/reconversion
		Isotope Separation
		Nuclear Waste Management
Nuclear Emergencies	EN716	Introduction to nuclear fuel cycle, transportation of radioactive material
		Radiological accidents / emergencies
		Effects of nuclear detonation, testing nuclear weapons
		Emergency Response methodology/ Philosophy

Welding Science & Technology	EN723	Overview of various welding processes - arc welding, beam welding, hybrid welding
		Cold Bonding/Solid State Bonding
		Welding metallurgy under high cooling rates
		Types of welding defects and its prevention

(C3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I & VivaVoce-II	EN591	Assessment of grasp of the basic concepts in the courses covered
		Examine the aptitude of the student to apply the knowledge gained in individual subjects to establish linkages and solve problems across domains
Practicals	EN592	Enhancing acquired skills and making reports
Mini Project	EN593	To provide a hands-on experience of working in an ongoing project of the Department.
		Gaining experience in in formulating and executing a scientific/technical problem
		Compiling a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee

(D) CIVIL ENGINEERING

(D1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Civil Engg Design of Concrete & Steel Strct I	EN608.1

2	Civil Engg Design of Concrete & Steel Strct II	EN608.2
3	Design Basis Hazards & Geotechnical Engg	EN621
4	Earthquake Engineeing & Structural Dyanmics	EN609
5	Finite Element Method	EN626
6	Mechanics of Solids	EN624

(D2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Struct Dynamics & Earthquake Engg	EN724
2	Construction Materials, Management & Quality	EN614
3	Safety & Reliability of Civil Engineering	EN722
4	Project Management	EN717

(D3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(D1) Core Engineering

Name of the Course	Course code	Course Outcome
Civil Engg Design of Concrete & Steel Strct I	EN608.1	Various structures of nuclear facilities; safety, seismic, design and quality classifications of structures
		Design loads on structures and load combinations as per BIS, ACI and AERB standards
		Design of RC structures; fracture mechanics concept in RC design

		Shallow and deep foundation design; machine foundation design
Civil Engg Design of Concrete & Steel Strct II	EN608.2	Design of prestressed concrete structures
		Design of lined and unlined reactor containment structures using RCC-G/BPEL/BAEL and ASME codes
		Design of steel structures using BIS, AERB and AISC standards
		Design of underground and overhead water retaining structures; design of natural draft cooling tower
Design Basis Hazards & Geotechnical Engg	EN621	Siting of nuclear facilities; hazards due to internal and external events; design basis natural hazards, such as, seismic, flood, wind, snow and solar radiations
		Human-induced design basis hazards, such as, aircraft/missile impact, explosions/blast, and toxic gas release
		Soils and its classifications; laboratory and field tests on soils and rock; compaction of soils; bearing capacity of soils and rocks
		Stages of geotechnical investigations; soil and rock sampling; geophysical investigations; seismic refraction survey, cross-hole seismic test; ERT; liquefaction potential of sites
Earthquake Engineeing & Structural Dyanmics	EN609	Seismic waves and wave propagation; time history; response spectra; seismic instrumentation
		Dynamic loadings; dynamic response of SDOF and MDOF systems; dynamics of continuum system
		Response spectra and time history approaches for determining seismic structural

		response; SSI and FSI; structural response in frequency domain
		Seismic requalification of existing installations; retrofitting techniques
Finite Element Method	EN626	Basis of FEM; energy principles; shape function requirements; C0 and C1 continuity
		Derivation of stiffness matrix and load vector for bar, beam, 2D plane and 2D iso-parametric elements; evaluation of strain and stress
		Incompatible quadrilateral elements; Tetrahedron, and hexahedron elements; plate bending elements; shell elements; patch test; adoptive meshing; error analysis
		Non-linear problems; material and geometric non-linearity
Mechanics of Solids	EN624	Concepts of elasticity; Equilibrium equations; Solution of 1-D boundary value problem; tensors algebra
		Analysis of stress and strain; transformation using direction cosines; principal planes; octahedral plane; state of pure shear; strain deviator tensor
		Strain displacement relationship; Isotropy and Anisotropy; Strain energy; Plane stress and plane strain problems; solution for beam bending problem; solution in polar co-ordinates; thermal stresses
		Analysis of thin and thick plates; shear deformation theories; membrane theory of shells of revolution and translation; bending analysis of shells; application to cylindrical, spherical and conical shells; introduction to plasticity

(D2) Electives

Name of the Course	Course code	Course Outcome
Advanced Struct Dynamics & Earthquake Engg	EN724	Concept of performance based seismic design; seismic demand; capacity of structures; performance levels
		Concept of seismic and vibration control; passive control; semi-active control; active control; base isolation techniques
		Methods of testing; qualification of system by testing; seismic instrumentation; measurement of displacement, velocity, acceleration
		Fluid-structure interaction techniques; multibody dynamics
Construction Materials, Management & Quality	EN614	Construction materials, such as, concrete, reinforcement, structural steel, paints, water-proofing materials
		Design of formworks; slip forms; prestressing systems
		QA in civil design, materials, construction, O&M, and regulatory inspection
		Dewatering; rock excavation, construction safety and JHA; mode of tendering; contract clauses; dispute adjudication
Safety & Reliability of Civil Engineering	EN722	Statistics and probability; discrete and continuous random variables; probability distributions
		Concept of structural safety; limit states; MVFOSM; Hasofer Lind reliability index; Cornell reliability index; Monte Carlo simulation
		Probabilistic safety assessment; seismic fragility analysis; seismic risk; health assessment of existing concrete and steel structures; rehabilitation and retrofitting

		techniques; service life prediction
		Concept of industrial safety; fire hazard analysis; safety in handling machinery, equipment and tools; fitness and protection of personnel
Project Management	EN717	Type, cost and schedule of nuclear power projects; resources of project; project organization chart; delegation of power
		Scheduling in a project by PERT, CPM, precedence diagram method; project management software for planning, scheduling and monitoring
		Preparation of target plan, updating of progress, monitoring variance and reporting; physical and financial monitoring; capital budgeting and expenditure control
		Contingency plan; construction management; project management; SWOT analysis; problem solving techniques

(D3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
Mini Project	EN5A93	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg.

(E) ELECTRICAL ENGINEERING

(E1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design I	EN602
2	Computer Based System Design I	EN612
3	Electrical Systems for Nuclear Power Plants	EN618
4	Modern Control Systems Design and Simulation	EN625
5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(E2) Electives

Sr. No.	Name of the Course	Course code
1	Advanced Electrical Engg. Design II	EN702
2	Artificial Intelligence and its Applications	EN703
3	Computer Based System Design II	EN704
4	Digital Signal Processing & Image Processing	EN706
5	Image Processing & Machine Vision	EN710
6	Signal Conditioning, Recovery and EMI Aspects	EN719
7	Software Engineering	EN720

(E3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(E1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design I	EN602	Materials and Electrical Properties, NDT, MFL
		Superconducting Properties
		Understanding Control Techniques of Electrical Motors and Electronics
		FEM and Applications
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Electrical Systems for Nuclear Power Plants	EN618	Recapitulation of Power System Design Analysis
		Basics of Switchyard Design Principles
		Understanding Protection Systems
		Exposure to Electrical Systems in NPP
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity

		Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters
		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(E2) Electives

Name of the Course	Course code	Course Outcome
Advanced Electrical Engg. Design II	EN702	Understanding Vector Control of PM Synchronous Motors
		Exposure to Design and Applications of Variable Reluctance Stepper Motors and Switched Reluctance
		Understanding Pulse Power Techniques
		High Voltage Systems
Artificial Intelligence and its Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies

		Understanding Reinforcement Learning and Dynamic Programming
Computer Based System Design II	EN704	Exposure to Data Communication Interfaces for Control Applications, Fieldbuses
		Understanding Real Time System Design Principles
		Understanding IPC mechanisms in RTOS
		Exposure to Safety System Design Regulations
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics

		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems

(E3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(F) ELECTRONICS ENGINEERING

(F1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Electronic Circuit Design Techniques	EN603
2	Advanced Nuclear Instrumentation	EN605
3	Embedded & Computer Based Sys. Design	EN619
4	Modern Control Systems Design and Simulation	EN625

5	Process Control & Instrumentation	EN633
6	Reactor Control Engineering and Instrumentation	EN637-8
7	Reliability Engineering	EN639

(F2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Digital Signal Processing & Image Processing	EN706
3	Embedded Electronics Software	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720
7	Artificial Intelligence & Applications	EN703

(F3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(F1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Electronic Circuit Design Techniques	EN603	Introduction to VLSI Design Flow, HDL, Design and Simulation of HPD
		Understanding Semiconductor Detectors , MEMS Desin
		Introduction to RF Electronics

		Understanding Transmission Lines, Waveguides, RF Amplifiers,
Advanced Nuclear Instrumentation	EN605	Understanding Electronics in Spectroscope Design
		Nuclear Instruments, Alpha, Beta and Gamma Detectors, Scintillation Counters
		Introduction to Accelerator Instrumentation
		Understanding Reactor Neutronic Instruments and Signal Processing
Embedded & Computer Based Sys. Design	EN619	Overview of Microprocessors and Interfacing
		Understanding Techniques for Embedded Systems Design, EMI/EMC Requirements
		Exposure to Computer Communication, Encoding and Technologies
		Understanding Software Developments for NPP/Accelerator C&I
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Process Control & Instrumentation	EN633	Overview of Measurement Principles, Accuracy, Hysteresis
		Understanding Flow, Pressure, Level,Temperature, pH, Conductivity Measurementsand Advanced Instruments
		Understanding, Control Valves, design and PLC, Smart Transmitters

		Industrial Instrumentation, P&I Diagrams, Instrumentation in NPP
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(F2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models

		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications
Signal Conditioning, Recovery and EMI Aspects	EN719	Review of Analog Signal Conditioning & Recovery Techniques
		Understanding Quantization Techniques, Aliasing Filters
		Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation
		Exposure to EMI, Modeling Techniques and Shielding
Software Engineering	EN720	Understanding Software Design Fundamentals and Life Cycle
		Exposure to Modelling Techniques for Software Design and UML basics
		Software Quality Assurance, Verification and Planning
		International and Nuclear Standards for Safety Critical Systems
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

(F3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(G)INSTRUMENTATION ENGINEERING

(G1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Applied Process Instrumentation	EN607
2	Computer Based System Design I	EN612
3	Modern Control Systems Design and Simulation	EN625
4	Reactor C&I and Human Machine Interface	EN636
5	Reactor Control Engineering and Instrumentation	EN637-8
6	Reliability Engineering	EN639

(G2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Computer Based System Design II	EN706
3	Digital Signal Processing & Image Processing	EN707
4	Image Processing & Machine Vision	EN710
5	Signal Conditioning, Recovery and EMI Aspects	EN719
6	Software Engineering	EN720

(G3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(G1) Core Engineering

Name of the Course	Course code	Course Outcome
Applied Process Instrumentation	EN607	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation
		Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Computer Based System Design I	EN612	Microprocessors & Interfacing Techniques
		Interconnect Buses and Industrial Systems
		Introduction to HDL and FPGA based System Design
		Understanding Fault Tolerant Architectures and TMR
Modern Control Systems Design and Simulation	EN625	Understanding State Space Techniques
		Understanding Controllability and

		Observability, Kalman Criterion
		Stability Analysis, Lyapunov Criterion
		Principles of State Observer, LQR, Ricati Equation
Reactor C&I and Human Machine Interface	EN636	Overview of Reactor C&I & Power Supply Requirements for Instrumentation
		Understanding Control Room Design and Exposure to Codes & Guides
		Exposure to Relay & Control Logic Design, Critera for Relay, PLC & DCS Technologies
		C&I Cable Requirements
Reactor Control Engineering and Instrumentation	EN637-8	Fundamental Principles of Nuclear Instrumentation, In-Core, Ex-Core Detectors
		Modes of Signal Processing, Pulse and Campbell techniques
		Reactor Core Instrumentation and Familiarisation
		Health Physics Instrumentation
Reliability Engineering	EN639	Understanding Reliability Principles and Applications to Nuclear Reactor Systems
		Overview of Statistical Methods
		Exposure to Fault Tolerance, Fault Avoidance Techniques
		Understanding Industrial Quality Assurance Techniques and Processes

(G2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming

<table>
<tr><td rowspan="4">Computer Based System Design II</td><td rowspan="4">EN706</td><td>Understanding Digital Signal Processing Techniques</td></tr>
<tr><td>Understanding Fourier Transforms, FFT, Digital Filters and Applications</td></tr>
<tr><td>Understanding Image Processing Techniques</td></tr>
<tr><td>Understanding Image Compression Techniques</td></tr>
<tr><td rowspan="4">Digital Signal Processing & Image Processing</td><td rowspan="4">EN707</td><td>Understanding Digital System Design Flows and EDA/SE Tools</td></tr>
<tr><td>Understanding Real time System Task Models</td></tr>
<tr><td>Scheduling Paradigms for Hard Real Time Systems</td></tr>
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<tr><td>Understanding Image Models for Machine Vision</td></tr>
<tr><td>Scene Interpretation and recognition</td></tr>
<tr><td>Understanding Robotic Applications</td></tr>
<tr><td rowspan="4">Signal Conditioning, Recovery and EMI Aspects</td><td rowspan="4">EN719</td><td>Review of Analog Signal Conditioning & Recovery Techniques</td></tr>
<tr><td>Understanding Quantization Techniques, Aliasing Filters</td></tr>
<tr><td>Theory of Signal Analysis, Function bases, orthogonal basis, Wavelet, Multiscale Characterisation</td></tr>
<tr><td>Exposure to EMI, Modeling Techniques and Shielding</td></tr>
<tr><td rowspan="4">Software Engineering</td><td rowspan="4">EN720</td><td>Understanding Software Design Fundamentals and Life Cycle</td></tr>
<tr><td>Exposure to Modelling Techniques for Software Design and UML basics</td></tr>
<tr><td>Software Quality Assurance, Verification and Planning</td></tr>
<tr><td>International and Nuclear Standards for Safety Critical Systems</td></tr>
</table>

(G3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life
Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills
		Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg

(H)COMPUTER SCIENCE AND ENGINEERING

(H1) Core Engineering

Sr. No.	Name of the Course	Course code
1	Advanced Operating Systems	EN606
2	Computer Graphics & Visualisation	EN613
3	Distributed Computing	EN616
4	Networking & Information Security	EN627
5	Reactor Control Engineering	EN637
6	Software Engineering and Formal Methods	EN640

(H2) Electives

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence & Applications	EN703
2	Data Base Management System & Web Technology	EN705
3	Digital Signal Processing & Image Processing	EN706
4	Embedded Electronics Software	EN707
5	Feedback Control System	EN708
6	Image Processing & Machine Vision	EN710

(H3) Non-Subject Assignments

Sr. No.	Name of the Course	Course code
1	VivaVoce–I& VivaVoce-II	EN591
2	Practicals	EN592
3	MiniProject	EN593

Course Outcomes:

(H1) Core Engineering

Name of the Course	Course code	Course Outcome
Advanced Operating Systems	EN606	Understanding IPC Calls
		Shell Programming
		Understanding Distributed File Systems
		Applications of System Calls
Computer Graphics & Visualisation	EN613	Understanding Geometric Transformations
		Applications of Geometric Projections
		Techniques for Hidden Surface Removals
		Applications of Scientific Visualisation
Distributed Computing	EN616	Understanding modern CPU Architectures
		Understanding Interconnect Techniques
		Understanding and Applications of HPC

		Understanding Grid Computing and Workflows
Networking & Information Security	EN627	Understanding Issues in the transport of data and Techniques
		Satellite Communications
		Understanding Network Security Concepts
		Advances in Cryptography and Cryptanalysis
Reactor Control Engineering	EN637	Understanding Physics behind Rector Control
		Understanding Point Kinetics Model and Reactor Periods
		Understanding Issues with Large Reactor Control and Modelling
		Understanding Control Requirements for PWR, PHWR, BWR and FBR
Software Engineering and Formal Methods	EN640	Understanding Techniques for modelling software
		Application of Model Checking and Theorem Proving
		Understanding Agile Programming
		Understanding Software Testing

(H2) Electives

Name of the Course	Course code	Course Outcome
Artificial Intelligence & Applications	EN703	Understanding Search Problems and A* Algoritm
		Soft Computing Techniques like ANN & SVM
		Data Mining Technologies
		Understanding Reinforcement Learning and Dynamic Programming
Data Base Management System & Web Technology	EN705	Understanding SQL and Complex queries
		Understanding Clusters and Distributed Databases
		Understanding and Working with Web Technologies
		Modelling data and design of real data bases

Digital Signal Processing & Image Processing	EN706	Understanding Digital Signal Processing Techniques
		Understanding Fourier Transforms, FFT, Digital Filters and Applications
		Understanding Image Processing Techniques
		Understanding Image Compression Techniques
Embedded Electronics Software	EN707	Understanding Digital System Design Flows and EDA/SE Tools
		Understanding Real time System Task Models
		Scheduling Paradigms for Hard Real Time Systems
		Getting an overview of Practical RTOS
Feedback Control System	EN708	State Space Representation and Applications
		Time Domain Analysis
		Appreciating need for Stability Analysis & Techniques
Image Processing & Machine Vision	EN710	Understanding techniques for Image Processing and Morphological Operations
		Understanding Image Models for Machine Vision
		Scene Interpretation and recognition
		Understanding Robotic Applications

(H3) Non-Subject Assignments

Name of the Course	Course code	Course Outcome
VivaVoce–I& VivaVoce-II	EN591	Assessment of Fundamental Concepts in Nuclear Engineering
		Assessment of Understanding of Domain Subjects and their Applications in Nuclear Sc. & Engg
		Assessment of capabilities to apply to solve real life

Practicals	EN592	Enhancing skills and reporting
MiniProject	EN593	Enhancing Skill Set for handling real life problems
		Understanding and Documentation skills

BACK TO MAIN

Course Structure:

II. Courses at IGCAR

Program Code: ENGG18	Programme Specific Outcome	To develop manpower for carrying out research and development work in the area of nuclear and engineering sciences
		Provide effective training to the students to work with various equipment including sophisticated facilities

FOUNDATION COURSES

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors	NR
2	Engineering Mathematics	EM
3	Materials and Metallurgy	MM
4	Fast Reactor Physics and Shielding	RP
5	Reactor Engineering	RE
6	Health Physics and Radiological Safety	HP
7	Project Management	PM

Course Outcomes:

FOUNDATION COURSES

Name of the Course	Course code	Course Outcome
Nuclear Reactors	NR	Exposure to mechanical aspects of power plant engineering Details understanding of thermal and fast power reactors Introduction to sodium technology
Engineering Mathematics	EM	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering Introduction to numerical methods for solving ordinay and partial differential equations Probability and statistics Different types of transformations
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Reactor Engineering	RE	Basic understanding of core design of LMFBR Coolant circuits of LMFBR and special characteristics of sodium technology
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation Principles of radiation detection and Radiation Protection procedures Familiarization with principles of radiation detection and radiation Protection procedures
Project Management	PM	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(A) MECHANICAL ENGINEERING

(A1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Code Design for Pressure Vessels and Piping	ME1
2	High Temperature Design and Inelastic Analysis	ME4
3	Computational Fluid Dynamics	ME6
4	Finite Element Method	ME8
5	Advanced Heat and Mass Transfer	ME10
6	Reliability Engineering	ME13
7	Manufacturing Technology	ME14

(A2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Machine Design	ME3
2	Structural Integrity Assessment Methods and NDE	
3	Vibration Engineering and condition Monitoring	
4	Seismic Design of Nuclear Reactors and Facilities	ME5
5	Plant Dynamics	

6	Experimental Mechanics	
7	Process Control and Instrumentation	ME15

(A3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-001-P
2	Seminar -1,2,3	02ENGG04-001-S

Course Outcomes:

(A1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for Pressure Vessels and Piping	ME1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping. In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered. It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
High Temperature Design and Inelastic Analysis	ME4	This course has direct relevance with the design of fast breeder reactor components & piping system. It covers mainly about the role of high-Temperature design concerning FBR programme, significant failure modes and associated design guidelines and advanced inelastic analysis methods. The high temperature design aspect is followed based on the RCC MRx RB procedure. Reliable design of components and piping system operating under high temperature operating conditions should address the additional damage associated with creep, fatigue and creep-fatigue interactions predominantly under thermo-mechanical loadings. There are many unresolved problems in the area of high-temperature

		design such as visco-plasticity behaviour, ratcheting behaviour, high temperature crack initiation behaviour etc. These aspects are addressed in this course with the support of tutorials.
Computational Fluid Dynamics	ME6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis Numerical Solution of Complete Fluid Flow and Energy Equation
Finite Element Method	ME8	Element shape functions, Bar elements, Beam elements, 2D and 3D elements, Shell element
		2D isoparametric formulation
		Introduction to Nonlinear problems
		Finite element applications for design
Advanced Heat and Mass Transfer	ME10	Advanced knowledge in heat and mass transfer Laminar boundary layer and forced convective heat, turbulent flow and heat transfer Heat transfer in porous media and heat transfer with phase change Radiation heat transfer
Reliability Engineering	ME13	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Manufacturing Technology	ME14	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles plastic deformation, processes like rolling, forging, extrusion etc in the case of metal forming module. Arc welding process,welding metallurgy, defects, inspection, quality control aspects are covered inwelding module. Extraction of Uranium and Zirconium from ore to final product form is coveed in the material processingmodule.

(A2) ELECTIVES

Name of the Course	Course code	Course Outcome
Machine Design	ME3	Basic concepts in vibrations analysis
Structural Integrity Assessment Methods and NDE		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
Vibration Engineering and condition Monitoring		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	ME5	Introduction to earthquakes, design basis ground motion and IS 1893 spectra Introduction of earthquake engineering and analysis for multi degree freedom systems
Plant Dynamics		Analysis and design of structures, equipments and piping
Experimental Mechanics		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Process Control and Instrumentation	ME15	Understanding the concepts of instrumentation and control for nuclear power plants
		Able to identify and define instrumentation and control needs of a process or machine
		Able to provide indicative choice of instruments in the design

(A3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-001-P	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Seminar -1,2,3	02ENGG04-001-S	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(B) ELECTRONIC AND INSTRUMENTAL ENGINEERING

(B1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	EL2
2	Nuclear Instrumentation	EL3
3	Reliability Engineering	EL4
4	Software Engineering	EL5
5	Human Machine Interface for Reactor Control Instrumentation	EL8
6	Modern Control of Dynamic Systems	EL10

(B2) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Artificial Intelligence and Digital Signal Processing	EL6
2	Process Instrumentation	EL7
3	Embedded and Computer based systems Design	EL9
4	Analytical Instrumentation	EL11

(B3) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-002-P
2	Seminar -1,2,3	02ENGG04-002-S

Course Outcomes:

(B1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	EL2	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	EL3	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Reliability Engineering	EL4	Introduction to reliability engineering applied to C&I systems
		Basic concepts of reliability, statistics and fault tolerence
		Probabilistic Safety (Risk) Assessment methods in the NPPs
Software Engineering	EL5	Introduction to software engineering and standards
		Software quality assurance, verification and validation
		Software analysis, design and configuration management
Human Machine Interface for Reactor Control Instrumentation	EL8	The subject is aimed on advanced design in new trends and development philosophy in the area of human machine interface. The student should obtain an overview of technologies implemented for reactor programmes and acquire an insight of the technical background to apply the same in context of reactor applications.
		The course work is framed in order to give an Introduction to various PFBR systems and HMI models in Distributed Digital Control System and their application to process systems such as special supervision systems, component handling systems, Reactor Protection Systems & Reactor Regulating Systems and Incident monitoring & mitigation systems. Learn about PC based process control system, Supervisory Control and Data Acquisition Systems.
		This course includes Familiarisation of plant automation overview, Soft Console versus conventional control panels, Guidelines for design of HMI displays, Building HMI systems, designing plant databases, alarm management techniques,

		Security features, creating process mimics, Trending historical data, Methods of passing data to HMI package etc. The capabilities of commercially available Professional HMI packages will also be explored.
Modern Control of Dynamic Systems	EL10	Introduction to state variable description with examples
		Controllability, observability and control system design

(B2) ELECTIVES

Name of the Course	Course code	Course Outcome
Artificial Intelligence and Digital Signal Processing	EL6	Exposure to fundamentals of digital signal processing algorithms
		Exposure to practical DSP algorithms and its implementation on different platforms
		Exposure to system design using pre conditioning circuits, anti-aliasing filters and digital signal controllers
		Exposure to system design case studies like Condition Monitoring System for rotating equipments And radar signal processing
		After course completion the student will be able to handle practical engineering problems solvable by digital signal processing techniques
		It is a specialised course which will give an introduction to AI techniques.
		It will give a flavour to fuzzy logic, robotics, neural networks, genetic algorithm.
Process Instrumentation	EL7	Detailed exposure to Flow, Pressure, Level, Temperature
		Understanding Analytical Instrumentation Exposure to Control Valves, Sizing calculation, P/I & I/P Converters, Impulse Tubing
		Exposure to P&I Diagrams and Design Guides
Embedded and Computer based systems Design	EL9	Understanding of VME bus and cPCI bus architecture.
		'C' programming with MISRA C compliant.
		Electronics design in analog and digital domain
		Learning of VLSI based design using EDA tools.
		Learning of VHDL based digital design.
		Electronics system design using TMR architecture, fault tolerant design
		Introduction of reliability analysis for electronics system.
Analytical Instrumentation	EL11	Introduction to the principles and applications of modern analytical instruments Sensitivity, precision, and limitations of analytical instruments

(B3) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-002-P	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Seminar -1,2,3	02ENGG04-002-S	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(C) CHEMICAL ENGINEERING

(C1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Nuclear Chemical Engineering	CE1
2	Chemical Engineering Thermodynamics	CE2
3	Transport Phenomena	CE3
4	Multi-Phase Flow Systems	CE4
5	Code Design for Pressure Vessels and Piping	CE5
6	Computational Fluid Dynamics and Heat Transfer	CE6
7	Advanced Chemical Reaction Engineering	CE7

(C2) SPECIALIZED COURSES

Sr. No.	Name of the Course	Course code
1	Process Analysis and Control	CE8
2	Advanced Mass Transfer	CE9

(C3) ELECTIVES

Sr. No.	Name of the Course	Course code
1	Preparedness &Response to Nuclear Emergencies Artificial Intelligence Methods &Applications Membrane/ Separation Process and Technology	CEEL

(C4) PROJECT/SEMINAR

Sr. No.	Name of the Course	Course code
1	Project	02ENGG04-003-P
2	Seminar -1,2,3	02ENGG04-003-S

Course Outcomes:

(C1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Nuclear Chemical Engineering	CE1	Introduction to nuclear chemical engineering for production, processing and management of nuclear materials
		Modelling and Simulation in Nuclear Chemical Engineering
Chemical Engineering Thermodynamics	CE2	Understanding the concepts of Thermodynamics , scope of Classical Thermodynamics, Phase Equilibrium, Chemical Reaction Equilibria.
Transport Phenomena	CE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyze transport problems
		Analyze transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyze transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Multi-Phase Flow Systems	CE4	Introduction to multiphase flow and its classification
		Modeling and Simulation in Nuclear Chemical Engineering
		Applications of two-phase flow in the design of steam generators
		The phenomena of fluidization and its industrial application
Code Design for Pressure Vessels and Piping	CE5	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits.
		The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tubesheet design

		for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.
Computational Fluid Dynamics and Heat Transfer	CE6	Basics of Fluid Flow, Heat Transfer and Numerical Analysis
		Turbulent Flow and Heat Transfer
		Numerical Solution of Complete Fluid Flow and Energy Equation
		Reactor Heat Transfer
Advanced Chemical Reaction Engineering	CE7	Understanding of thermodynamics and kinetics of chemical reactions
		Design and analysis of chemical reactors
		Modelling of multiphase reactors

(C2) SPECIALIZATION

Name of the Course	Course code	Course Outcome
Process Analysis and Control	CE8	Understanding of dynamics of chemical process systems and nonlinear process dynamics
		Design of multivariable controllers
Advanced Mass Transfer	CE9	Introduction to theories of mass transfer and advanced mass transfer processes
		Selection and design of contacting equipment in nuclear chemical industries

(C3) ELECTIVES

Name of the Course	Course code	Course Outcome
Preparedness & Response to Nuclear Emergencies	CEEL	Introduction to robotics, genetic algorithm and fuzzy logic and their applications
Artificial Intelligence Methods & Applications		
Membrane/ Separation Process and Technology		

(C4) PROJECT/SEMINAR

Name of the Course	Course code	Course Outcome
Project	02ENGG04-003-P	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)
Seminar -1,2,3	02ENGG04-003-S	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(D) MATERIALS SCIENCE

(D1) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Engineering Mathematics	MS1
2	Computational Methods	MS2
3	Materials and Metallurgy	MS3
4	Reactor Physics and Fuel Design	MS4
5	Health Physics	MS5
6	Metallurgical Thermodynamics	MS6
7	Experimental Methods for Materials Research	MS7
8	Structural Materials for Nuclear Reactors	MS8
9	NDE Science and Technology	MS9
10	Physical Metallurgy	MS10
11	Fuel Cycle Physics and Introduction to Fuel Cycle	MS11
12	Introduction to Materials Science and Engineering	MS12
13	Corrosion Science and Engineering	MS13
14	Mechanical Behavior of Engineering Materials	MS14
15	Manufacturing Technology	MS15

Course Outcomes:

(D1) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Engineering Mathematics	MS1	Advanced knowledge in Mathematics to understand the mathematical formulation of concepts in science and engineering
		Introduction to numerical methods for solving ordinary and partial differential equations
		Probability and statistics
		Different types of transformations
Computational Methods	MS2	Introduction to programming languages such as C# and Matlab
		Exposure to numerical techniques for solving partial differential equations
		Neural network for predictive applications
		Basics of atomis modelling, molecular dynamics and introduction to Monte-carlo simulation
		Introduction to FEM and current trends in modelling and imulation

Materials and Metallurgy	MS3	To develop a basic understanding on the classification of materials
		Mechanical property based selection of materials for nuclear application and standards
		Various fabrication related issues in material including welding and corrosion
		Non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Reactor Physics and Fuel Design	MS4	Introduction to basic nuclear and neutron physics concepts
		Nuclear reactors and fuel design concepts
		Reactor kinetics
Health Physics	MS5	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures
Metallurgical Thermodynamics	MS6	Introduction to Classical thermodynamics: 1st and 2nd laws and their applications
		Thermodynamic properties of pure substances and mixtures Solution thermodynamics
		Phased equilibria in multicomponent systems and stability
		Chemical reactor equilibria Exposure to experimental methods for determining thermodynamic properties
Experimental Methods for Materials Research	MS7	Exposure to various experimental techniques for materials characterization, including X-ray techniques, electron microscopies, ion-beam techniques, electron spectroscopies nuclear spectroscopies, vibrational spectroscopy and resonance absorption spectroscopies
		Basic understanding of underlying physics
Structural Materials for Nuclear Reactors	MS8	Exposure to the three stage nuclear power programme
		Concept of selection of structural materials for different applications
		Materials for thermal reactors, fast breeder reactors and reprocessing applications
		Materials processing and fabrication of components
NDE Science and Technology	MS9	Introduction to various non-destructive evaluation techniques for safe and reliable operation of structures and components
		Surface, volumetric and Dynamic NDE
Physical Metallurgy	MS10	Basic understanding of crystal structure and microstructure
		Knowledge of origin, construction and classifications of metallurgical phase diagrams

		Understanding of different types of metallurgical phase transformations and underlying principles
		Introduction to microstructural characterization techniques and tools
Fuel Cycle Physics and Introduction to Fuel Cycle	MS11	Introduction of nuclear fuel cycles
		Introduction to exploration, recovery and enrichment and uranium and other nuclear fuel materials
		Different types of nuclear fuels and fuel fabrication
		Recycling the spent fuel, fission products and actinides
Introduction to Materials Science and Engineering	MS12	Introduction to basic structures, bonding and defects in solids and techniques for their characterization
		Physcial properties of materials
		Basics of phase diagram and phase transformations
		Techniques for synthesis of materials
Corrosion Science and Engineering	MS13	Basic understanding of corrosion process, monitoring and preventation
		Introduction to thermodynamics and kinetics of corrosion
		Forms of corrosion and corrosion in nuclear reactor and reprocessing plants
Mechanical Behavior of Engineering Materials	MS14	Introduction to engineering materials
		Elastic and plastic deformation in polycrystalline materials
		Strengthening mechanisms in polycrystalline structural materials
		Exposure to damage mechanisms such as creep, fatigue and also exposure to fracture mechanics
Manufacturing Technology	MS15	The course cover Metal forming, Welding & fabrication technologies and extraction of nuclear materials from Ore and processing.
		Participants are introduced to principles of plastic deformation, processes like rolling, forging, extrusion etc. in the case of metal forming module.
		Arc welding process, welding metallurgy, defects, inspection, quality control aspects are covered in welding module. Extraction of Uranium and Zirconium from ore to final product form is covered in the material processing module.

(E) FAST REACTOR ENGINEERING – I

(E1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(E2) CORE ENGINEERING

Sr. No.	**Name of the Course**	**Course code**
1	Code Design for pressure vessel and piping	FRE1
2	Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2
3	Transport Phenomena	FRE3
4	Reliability Engineering	FRE4
5	Process Design and Control	FRE5
6	Vibration Engineering and Condition Monitoring	FRE6
7	Seismic Design of Nuclear Reactors and Facilities	FRE7
8	Emergency Preparedness and Disaster Management	FRE8

(E3) OPERATIONS

Sr. No.	**Name of the Course**	**Course code**
1	Plant Dynamics and Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva Voce

Course Outcomes:

(E1) FUNDAMENTALS

Name of the Course	**Course code**	**Course Outcome**
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(E2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Code Design for pressure vessel and piping	FRE1	Design of pressure vessels and piping are standardised. Various codes present the design in detail. In general ASME Sec VIII Div 1 and B31.1 Power Piping code are most popular for industrial vessels and piping circuits. The course contains the design of cylindrical vessels for internal and external pressure, different types of closures, nozzle reinforcement, piping flexibility analysis and WRC bulletin 107 & 298 for qualification of nozzles. The course also include introduction to tube sheet design for heat exchangers as per TEMA code, flange design and support design for vessels and piping.
		In the present subject, basic design philosophy and design procedure for thickness calculation are covered. The literature and experimental background to the design procedures and thickness calculation are also covered.
		It is a thirty hours course, which is sufficient to cover basic theoretical introduction to above subject. This subject gives the insight into the design procedure which is helpful to understand and use the code for designing.

Advanced Heat and Mass Transfer and Computational Fluid Dynamics	FRE2	Advanced knowledge in heat and mass transfer
		Laminar boundary layer and forced convective heat, turbulent flow and heat transfer
		Heat transfer in porous media and heat transfer with phase change
		Radiation heat transfer
Transport Phenomena	FRE3	The subject of transport phenomena includes three closely related topics: fluid dynamics, heat transfer, and mass transfer. Fluid dynamics involves the transport of momentum, heat transfer deals with the transport of energy, and mass transfer is concerned with the transport of mass of various chemical species. In this course we study these three transport phenomena together. After passing the course the student will be able to:
		Apply the shell balance approach to derive differential mass and heat balance equations in Cartesian, cylindrical, and spherical coordinate.
		Apply the generalized differential mass and heat balance equations and the Navier-Stokes equations to analyse transport problems
		Analyse transport problems in simple geometries and derive analytically the concentration, temperature or velocity distribution
		Analyse transport problems in complex geometries and calculate numerically the concentration, temperature, or velocity distribution using a simulation software
		Apply the concept of transfer coefficients to describe mass and heat transfer across interfaces
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Vibration Engineering and Condition Monitoring	FRE6	Basic concepts in vibrations analysis
		Basics of rotor dynamics and rotor balancing
		Flow induced vibrations
		Response of systems to earthquake
		Vibration measurements, instruments used and analysis of vibration signals
Seismic Design of Nuclear Reactors and Facilities	FRE7	Introduction to earthquakes, design basis ground motion and IS 1893 spectra
		Introduction of earthquake engineering and analysis for multi degree freedom systems
		Analysis and design of structures, equipment and piping
		Indian Standard Criteria for earthquake resistant design

		Siesmin design snd requalifications of NPPs
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(E3) OPERATIONS

Name of the Course	Course code	Course Outcome
Plant Dynamics and Control	FRE09	Introduction to plant dynamics and overall control
		Reactor control concepts: start up and shut down
		Reactivity control devices
Turbine Generator Fundamentals	FRE10	Introduction to principles of steam turbine cycles and turbine parts
		General turbine design aspects and governor theory
		Commissioning and operation of turbine
		Turbine troubles
Mechanical and Electrical Equipment	FRE11	Introduction to various mechanical and electrical equipment and their operating cares such as bearings, seals, power transmission equipment, pumps, valves and actuators, compressors, chillers, motors, transformers etc.
Maintenance Engineering	FRE12	Overview of maintenance in NPPs, maintenance policies and planning
		Spare parts maintenance and inventory control, condition based maintenance
		Vibration monitoring
Regulatory Framework for NPPs	FRE13	Introduction to Atomic Energy Act 1962 and the Factories Act 1948
		AERB and its functioning
		Electricity Act 2003 and the Boiler Act
		Environmental protection acts
Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)

(F) FAST REACTOR ENGINEERING – II

(F1) FUNDAMENTALS

Sr. No.	Name of the Course	Course code
1	Nuclear Reactors & Sodium Technology	NR
2	Reactor Engineering	RE
3	Fast Reactor Physics and Shielding	RP

4	Materials and Metallurgy	MM
5	Health Physics and Radiological Safety	HP

(F2) CORE ENGINEERING

Sr. No.	Name of the Course	Course code
1	Reactor Control Engineering	FRE15
2	Nuclear Instrumentation	FRE16
3	Reliability Engineering	FRE4
4	Process Design and Control	FRE5
5	Embedded System Design & Human Machine Interface	FRE17
6	Process Instrumentation	FRE18
7	Emergency Preparedness and Disaster Management	FRE8

(F3) OPERATIONS

Sr. No.	Name of the Course	Course code
1	Plant Control	FRE9
2	Turbine Generator Fundamentals	FRE10
3	Mechanical and Electrical Equipments	FRE11
4	Maintenance Engineering	FRE12
5	Regulatory Framework for NPPs	FRE13
6	Practical's	FRE14
7		Viva-Voce

Course Outcomes:

(F1) FUNDAMENTALS

Name of the Course	Course code	Course Outcome
Nuclear Reactors & Sodium Technology	NR	Exposure to mechanical aspects of power plant engineering
		Details understanding of thermal and fast power reactors
		Introduction to sodium technology
Reactor Engineering	RE	Basic understanding of core design of LMFBR
		Coolant circuits of LMFBR and special characteristics of sodium technology

Fast Reactor Physics and Shielding	RP	In this course students learn about Properties of Nuclei; Binding Energy Curve; Stability Curve, liquid drop models of nuclei and importance of nuclear data, which are needed to understand nuclear fissions and fission energy. Further, reactor physics including fast reactors, Indian research reactors; reactor kinetics and reactor control, and concepts of radiation shielding all are needed to the students working with the area of interdisciplinary science as nuclear reactor technologies.
Materials and Metallurgy	MM	Development of a basic understanding on the classification of materials, mechanical property based selection of materials for nuclear application and standards
		Understanding of various fabrication related issues in material including welding and corrosion and non-destructive evaluation/assessment techniques to monitor and evaluate material damage
Health Physics and Radiological Safety	HP	Introduction to radiation sources and learning the interaction of ionizing radiation with matter
		Knowledge of Biological effects of ionising radiation, Radiation Protection and Regulation
		Principles of radiation detection and Radiation Protection procedures
		Familiarization with principles of radiation detection and radiation Protection procedures

(F2) CORE ENGINEERING

Name of the Course	Course code	Course Outcome
Reactor Control Engineering	FRE15	Introduction to the physics of reactor control and kinetics
		Basics of typical reactor control systems of different types of reactors
		Reactor operation and power plant control
Nuclear Instrumentation	FRE16	Students learn about basics of interaction of radiation with matter.
		Principle & Techniques to detect and measure ionizing radiation.
		Basics of radiation counting statistics
		Introduction to Neutron Flux Measurement in FBTR and PFBR.
Reliability Engineering	FRE4	Regression analysis, Functions of Random Variables
		Probabilistic Fracture Mechanics
		System Reliability Analysis
		Reliability in Engineering Design
Process Design and Control	FRE5	Introduction to state variable description
		Controllability and Observability
		Control System Design
Embedded System Design & Human Machine Interface	FRE17	Introduction to Microprocessor Based Hardware Design
		Computer Communication and Networks
		Fault Tolerant and Distributed Architectures
		Programmable Logic Controller Design
		Overview of plant automation and Human Machine Interface (HMI)

Process Instrumentation	FRE18	Design, selection, typical specifications, calibration standards, installation, testability and diagnostics of measuring instruments of various process variables
		Reliability principles, Fail safe design principles
Emergency Preparedness and Disaster Management	FRE8	Introduction to Nuclear and Radiological Emergency / disaster scenario and their Management Mitigation and management of Nuclear/Radiological Emergencies

(F3) OPERATIONS

Name of the Course	Course code	Course Outcome
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Practical's	FRE14	Class room training followed by field training on PFBR simulator for reactor operation and maintenance
	Viva Voce	To meet the research requirement of the individual student. (Course content varies according to instructor's choice.)